Testing, Evaluation, and Specification for Polymeric Materials Used for Transportation Infrastructures

Final Report

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"The opinions, findings and conclusions expressed in the publication are those of the authors and not necessary those of the State of Florida Department of Transportation."

Approximate Conversions to SI Units				
Symbol	Known	Conversion Factor	Find	Symbol
Length				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
Area				
in^2	square inches	645.2	Square millimeters	mm^2
ft^2	square feet	0.093	Square meters	m^2
yd^2	square yard	0.836	Square meters	m^2
Volume				
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
Temperature (exact Degrees)				
^oF	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	^oC
Force and Pressure or Stress				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
Approximate Conversions from SI Units				
Symbol	Known	Conversion Factor	Find	Symbol
Length				
mm	millimeters	0.039	inch	in
m	meters	3.28	feet	ft
Area				
mm^2	Square millimeters	0.0016	square inches	in^2
m^2	Square meters	10.764	square feet	ft^2
m^2	Square meters	1.195	square yard	yd^2
Volume				
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Temperature (exact Degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
Force and Pressure or Stress				
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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16. Abstract

Test protocols for material quality assurance are recommended for assessing sunlight degradation of polymeric products used in transportation-related products. One structural plastic product and five detectable warning surface (DWS) products were evaluated using a laboratory xenon weatherometer and exposed to outdoor condition at Gainesville, Florida. For the structural plastic product, which is made from recycled high density polyethylene (HDPE) blended with 2.7% carbon black, the OIT test (ASTM D 3895) is the best indicator for the sunlight degradation. The DWS products were made from polyester, polyurethane, polyolefin, or epoxy and reinforced with glass fibers, inorganic fillers, or aluminum particles. The color change (ΔE) through color measurement using a spectrocolorimeter is a good parameter to monitor sunlight effect on the DWS products. Based on sunlight irradiance, the laboratory test data can be correlated directly with those obtained from the outdoor exposure. It was found that using ASTM D2565 with borosilicate inner and outer filter and setting irradiance intensity at 60 ± 2.5 W/m^2 can generate similar degradation as outdoor environment for most of the tested products.

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The experimental testing, data analysis, and maintenance of the xenon weatherometer were carried out by Dr. Sukjoon Na (Post-doc), Mr. Siavash Vahidi (graduate student), Mr. Hieu Nguyen, and Mr. Nay Ye Oo (undergraduate students) at Drexel University.

EXECUTIVE SUMMARY

The objective of this project is to evaluate sunlight degradation of polymeric products used in transportation-related applications, and to recommend test protocols for quality assurance measurement. One structural plastic product and five detectable warning surface (DWS) products were investigated for their sunlight degradation behavior. An ATLAS Ci-4000 weatherometer equipped with a xenon lamp and inner and outer borosilicate filters was used to simulate outdoor sunlight in the laboratory. The xenon test condition was set according to ASTM D2565, but three irradiances (41.5, 60, and 80 ± 2.5 W/m^2) were applied for at least 3,000 hours each. The outdoor exposure test was carried out at Gainesville, Florida. The test setup was according to ASTM D1435 without backing material, and the exposure duration was 24 months.

For the structural plastic product, which is made from recycled HDPE blended with 2.7% carbon black, four material properties were used to evaluate the effect of sunlight on the product throughout the exposure period. The surface morphology was examined using a digital light microscope. The stabilizer depletion was monitored using the oxidative induction time (OIT) test (ASTM D 3895), the molecular weight change of the polymer was assessed using the melt index (MI) test (ASTM D 1238), and the mechanical properties was assessed by tensile test (ASTM D638, Type IV). Among these four properties, OIT test data provided the most meaningful information regarding the sunlight degradation. Changes in OIT profiles across the thickness of the test coupons throughout the exposure duration indicated that sunlight degradation mainly took place at the surface layer (0.015 ± 0.005 inch) under both xenon light and outdoor sunlight. As stabilizers were depleted by sunlight via photo-degradation, surface cracking was observed subsequently leading to the decrease of tensile break strain. On the other hand, the surface degradation did not impact the overall molecular weight as indicated by the results of MI tests. Based on the OIT test data, the xenon irradiance at 60 ± 2.5 W/m^2 generated a similar degradation as the outdoor exposure. Because the depletion of stabilizer is the precursor of the polymer degradation, the OIT test was recommended to be the test method to evaluate the sunlight resistance of HDPE structural plastics. A test protocol was recommended for assessing the depletion of stabilizer using laboratory xenon weatherometer through the OIT test.

For the five DWS products, three colors (black, red, and yellow) were included, making total of 15 test samples. The DWS products are all reinforced polymer composites. The polymer matrix is made from polyester, polyurethane, polyolefin, or epoxy and reinforced with glass fibers, inorganic fillers, or aluminum particles. Three material properties were used to assess effect of sunlight on these products throughout the exposure time. The surface morphology was examined using a digital light microscope. The color was measured using a spectrocolorimeter (X-rite RM200QC), and the color change (the ΔE value) was calculated for each exposure time. A newly designed abrasion test was used to assess the surface degradation caused by sunlight. Based on the ΔE value and verified by the surface appearance, the xenon irradiance at 60 ± 2.5 W/m^2 generated similar degradation as the outdoor exposure, except for the red and yellow SafeRoute product samples. Also, the ΔE value is commonly specified for DWS products by the manufacturers. The change of ΔE can be explained by the fading of color and surface texture and appearance of reinforcement (fibers or fillers). However, no correlation was found between ΔE and mass loss obtained from the abrasion test. Furthermore, the change of ΔE varies with the polymer type and color. A test protocol was recommended for assessing the color change under sunlight degradation using laboratory xenon weatherometer.

The test methodologies presented in this project can be used to evaluate the sunlight degradation of any polymeric products used in the transportation-related applications. The irradiance-based correlation method enables direct comparison of test data between weatherometer and outdoor tests, ensuring the same sunlight degradation mechanism taking place in both test conditions.

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CHAPTER 1 – INTRODUCTION

In the past few decades, Florida Department of Transportation (FDOT) has been using products made from polymeric materials in new construction and/or retrofitting deteriorated structures. It is expected that their usage will continuously increase. However, unlike conventional construction materials, such as concrete, metal, and asphalt, which have abundant case history to demonstrate their service performance, products made from polymer are new to transportation applications; and thus, their product specifications may not capture the in-service requirements, particularly the life-cycle performance. Currently, FDOT requires that construction materials should possess the same service life as the associated structures, which ranges from 25 years for noncritical system to 100 years for critical systems. Construction products made from polymer must also comply with this requirement.

To ensure that polymeric materials possess the expected longevity, FDOT retained Dr. ElSafty from University of North Florida and Dr. Hsuan from Drexel University to develop test protocols and specifications that can predict the long-term performance of these materials. FDOT has identified four priorities based on the degradation mechanisms.

1. Sunlight degradation
2. Oxidative degradation
3. Hydrolytic degradation
4. Ozone degradation

Sunlight degradation is the greatest concern because all polymeric materials used in outdoor condition are susceptible to such degradation. In addition, Florida's climate (high ambient temperature and greater number of sunny days) further aggravates the degradation process. Therefore, the focus of this project is on the sunlight degradation.

1.1 Objectives and Tasks

The objective of this project is to evaluate sunlight degradation of polymeric materials used in transportation related products, and to recommend test protocols for quality assurance measurement. Systematical study will be performed to investigate different exposure conditions for the laboratory weatherometer, and to identify the appropriate test method to assess changes of material properties after the exposure. Test results will be analyzed to determine the appropriate exposure condition for laboratory weatherometer to simulate the in-service condition and, testing protocols will be recommended for quality assurance measurement. Following steps were taken to accomplish the project objectives:

1. Compiling recent technical papers, and standard test methods and specifications published by Florida Department of Transportation (FDOT) and manufacturers will be carried out.
2. Identifying the test products that are representing the need of FDOT.
3. Performing exposure in laboratory weatherometer and outdoor environment.
4. Conducting laboratory testing to evaluate changes in material properties of both laboratory tested samples and outdoor-exposed samples
5. Investigating the effect of irradiance on the degradation of different polymeric materials using physical, mechanical and analytical tests.
6. Identifying the appropriate test condition for the laboratory weatherometer to simulate the outdoor exposure.
7. Recommending the testing protocols for quality assurance of the polymeric products.

CHAPTER 2 – TEST MATERIALS

A list of polymeric products used as structural plastics in bridge fender systems and as Disability Warning Surface (DWS) were provided by Dr. Chase Knight at the Materials Research Laboratory in Gainesville, Florida. There are total of 20 companies (2 structural plastics companies and 18 DWS companies); the list of them had been included in Appendix-A. For the structural plastics, high density polyethylene (HDPE) is the polymer used to manufacture the products. In contrast, there is a variety of polymers being used in the making of DWS products, and they included polyester, epoxy, polyurethane, polypropylene, etc. The types of polymer used in the 20 polymeric products are included in Appendix-A. (It should note that few of the companies do not specify the polymer used in their product.) From the list of products, one structural plastic and five DWS products were selected for this study. These six products represent the spectrum of the polymers, and they are listed in Table 2-1. In addition, three colors were selected for the five DWS products.

Table 2-1 –Information about Test Products and Dimension of Test Coupons

Product Type	Product/Manufacturer	Product Name	Color	Polymer
Structural Plastic	Bedford Technology LL.	Sea Timber	Black	High Density Polyethylene
DWS	ADA Solution, Inc.	ADA Solutions	Black, Yellow Red	Polyester with Fiberglass
	Cape Fear Systems	AlertCast	Black, Yellow Red	Polyester (NPG*) with Fiberglass
	Detectable Warning Systems	Redimat	Black, Yellow Red	Polyurethane with Fiberglass
	SafeRoute Products	SafeRoute	Black, Yellow Red	Polyolefin with filler
	Engineered Plastics Inc.	Armor-Tile	Black, Yellow Red	Epoxy with Alumina particles

* NPG = Neopentylglycol

Samples of these products were obtained from the manufacturers (either donated by the manufacturers or purchased from the manufacturers). Details of the six product samples regarding the dimensions and surface texture are included in the report as Appendix-B.

2.1 Structural Plastic Product

The structural plastic product supplied by Bedford Technology, LLC was made from recycled polyethylene blended with carbon black. (The type of recycle polyethylene was not revealed by the manufacturer.) The product is used for protecting bridge piers against marine vessel collisions.

The amount of carbon black was measured using a thermogravimetry analysis (TGA). The test was performed by heating the specimen from 20°C to 800°C under nitrogen atmosphere at a rate of 10°C/min. The thermal curve is shown in Figure 2-1. The polymer decomposition temperature was detected at 417°C, and the residual weight is 2.7% which corresponds to the percentage of carbon black content in the material. It has been found that carbon black content ranging from 2.5 to 3% is the optimum level without causing an antagonistic effect on the stabilizer (Hawkins, 1984; Wong and Hsuan, 2014).

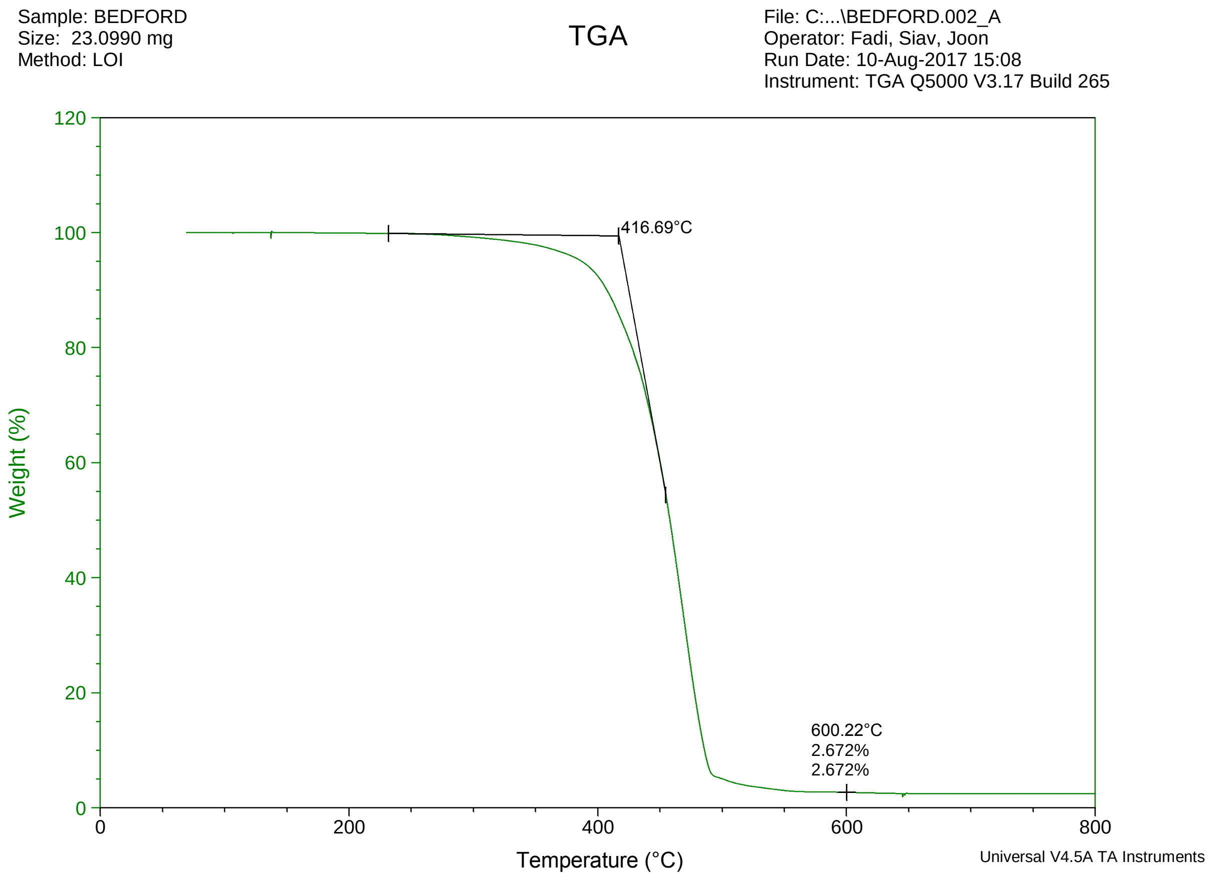


Figure 2-1 – TGA thermal curve of Bedford HDPE structural plastic sample

2.2 Detectable Warning Surface (DWS) Products

The five DWS products studied in the project were manufactured from five types of polymers. The polymer matrix of four DWS products was evaluated for their glass transition temperature (T_g) and melt point using a differential scanning calorimeter (DSC). The summary of thermal transition temperatures of four DWS products is shown in Table 2-2.

Table 2-2 – Thermal Transition Temperatures of Four DWS Products

Manufacturer	Product	Polymer	Melting Temperature (°C)	Glass Transition Temperature (°C)
ADA Solutions Inc.	ADA Solutions	Polyester	Y – 310.6 R – 314.2 B – 305.0	Y – 61.7 R – 60.6 B – 62.4
Cape Fear Systems	AlertCast	Polyester (NPG)	Y – 310.4 R – 306.6 B – 307.9	Y – 45.6 R – 46.3 B – 46.3
Detectable Warning Systems	Redimat	Polyurethane	Y – 375 R – 334 B – 324	Y – 125.5 R – 125.8 B – 130.3
Engineering Plastics Inc.	Armor-Tile	Epoxy	Y – 279 R – 283 B – 287	Y – ND R – 55.5 B – 58.0

Note: NT – Not Detectable; Y = Yellow; R = Red, B = Black

The SafeRoute DWS samples were indicated to be made from polyolefin. However, the company did not specify the type of polyolefin which can be polyethylene, polypropylene, polybutylene or their copolymers. To identify the type of polyolefin and other blended additives, thermal analyses were performed on the three samples. Table 2-3 shows the summary of thermal properties of three samples. Based on the melting temperature, the Yellow and Red samples are likely made from an isotactic polypropylene (PP) based polymer which has a melting temperature of 165°C. The Black sample could be a type of polyethylene (PE)/polypropylene (PP) copolymer because the melting temperatures fall between these two polymers. However, the type of copolymer is not known (i.e., blending two polymers or copolymerization). A significant amount of residual weight, up to 40 wt-% was measured in all three samples. The purpose of adding filler to the polyolefin is to increase the hardness and lower cost of the product sample. The filler can be color pigment and other inorganic materials; the most common type of inorganic filler material is calcium carbonate. Because SafeRoute samples were made from polyolefin which is sensitive to processing degradation and oxidation during the service, stabilizer is likely added to the material formulation. OIT tests were performed based on ASTM D3895, and their values are lower than that in the Bedford HDPE structural plastic product.

Table 2-3 – Thermal Transition Temperatures and OIT of SafeRoute Samples

Sample Color	Melting Peak (^oC)	Decomposition Temperature (^oC)	Residual Weight (%)	OIT at 200^oC (min)
Black	153	446	39.6	6.8
Red	165	443	40.1	6.0
Yellow	165	431	40.1	5.2

Chapter 3 – LITERATURE REVIEW

Based on the objectives of this project, the literature review is focusing on the following three topics:

a) Test methods used for sunlight exposure of polymeric materials included in this project.
b) Test methods used to evaluate changing material properties after sunlight exposure.
c) Methods to predict UV degradation of polymeric materials in the service environment

3.1 Sunlight Degradation

Sunlight is well recognized as being a dominant degradation factor in many polymers. The wavelength of the sun's radiation extends from the infrared (> 700 nm), through the visible spectrum (approximately 400- to 700-nm) and into the ultraviolet (< 400 nm), with a cut-off at around 300 nm depending on atmospheric conditions. When solar radiation strikes the polymer surface, photons with energy similar, or higher, than the chemical bond strength of the polymer cause a series of reactions that can lead to polymer chain scission or crosslinking, and eventual degradation of polymer properties. Table 3-1 shows the wavelengths or wavelength ranges that cause photo-degradation of few commodity polymers. All these wavelength values fall within the UV region (< 400 nm). Thus, the sunlight degradation also refers as ultraviolet (UV) degradation or photo-degradation.

Table 3-1 – Wavelengths for Various Polymers

Polymer	Wavelength (nm)
Polyethylene (PE)	330-360[1]
Polypropylene (PP)	335-360[2]
Polyvinyl chloride (PVC)	320[3]
Polyamide (PA)	< 300, 340-400[4]
Polyester (PET)	325[3]

[1]Hu (1997); [2]Zhang et al., (1996); [3]Hirt and Searle (1964); [4]Hu (1998)

3.2 Test Methods for Sunlight Degradation

There has been a long and active debate in the development and acceptance of an accelerated and economic standardized method to evaluate the photo degradation of polymer. The key challenge is to develop a method that can closely correlate to the effects of actual field weathering. Several factors have strong influence on such correlation; they are outlined as follows (Koerner et al., 1998; Suits and Hsuan, 2003):

- Polymers respond differently when exposed to different regions of the light spectrum, as shown in Table 3-1.
- Different stabilizers in the polymer formulation affect the test results.
- Colors affect the polymer response to sunlight, particularly the visible light region.
- Variability of the local climate is difficult to predict.
- Variability in the design of various accelerated weathering apparatuses to accomplish the above is difficult and expensive.

The test methods can be divided into two groups: outdoor exposure methods and in-door weatherometer methods.

3.2.1 Outdoor exposure methods

Under ideal circumstances, the candidate polymer should be exposed at the testing site with similar climate condition as the in-service location. For an outdoor exposure procedure of this type, ASTM D1435 "Standard Practice for Outdoor Weathering of Plastics" provides a guide to evaluate products made from polymeric materials. In ASTM D1435, samples are mounted on a rack resides at a 45^{o} angle facing south for maximum effects of sunlight exposure. However, this test is rarely performed due to the required long exposure time. The degradation rate depends on the polymer type, stabilization formulation, configuration and geometry of the product. The intent of the standard guide is to provide the user with a standard by which to evaluate solar degradation at a specific site in terms of the expected life of the polymeric product, not in terms of incident radiation from the exposure. Thus, due to the variability of the climate from site-to-site, direct comparison between test data obtained from different sites is difficult. In order to perform any type of comparison, the total solar radiant energy and solar UV radiant energy should be measured during the exposure duration together with ambient temperature and moisture.

3.2.2 Laboratory weatherometer methods

Laboratory weatherometer simulates sunlight degradation in a controlled environment so that more consistent results can be generated in comparison to outdoor exposure methods. These devices are useful in assessing suitable stabilizers for polymeric products as well as to confirm the formulation for quality control or quality assurance purposes. Two types of weatherometers are currently used to evaluate the sunlight degradation of polymer and they are described in the following:

(a) <u>Xenon weatherometer</u>

The xenon weatherometer uses a long arc, water cooled xenon lamp equipped with inner and outer filters as the light source. When borosilicate inner and outer filters are used, the irradiance spectrum closely resembles natural daylight, as shown in Figure 3-1. Gugumus (1987) compared lifetimes of polypropylene (PP) tapes with hindered amine light stabilizers (HALS) in a xenon arc weatherometer to field exposure and found that the xenon arc with a filter (>295 nm) correlated well with outdoor weathering. Furthermore, the device is widely used by many Department of Transportation agencies to evaluate polymeric coating materials, asphaltic materials, and thus is included in many specifications. A limitation of this

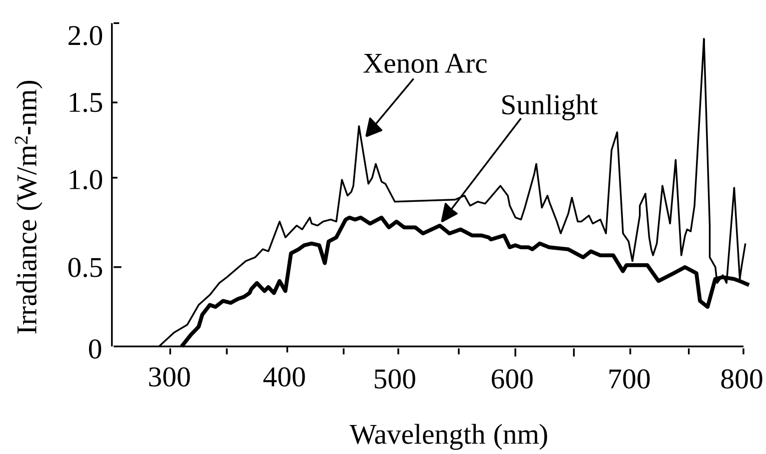


Figure 3-1 – Spectra of xenon Arc with borosilicate filters and sunlight device, however, is its acceleration factor which is very minimal as shown in Figure 3-1. In addition, the high initial cost and maintenance may be challenge for small companies to perform the test.

(b) Ultraviolet (UV)-fluorescent weatherometer

The UV-fluorescent weatherometer consists of eight fluorescent ultraviolet lamps. The spectral output of this light source only emits light spectrum in the UV region (<400 nm), where the energy is high enough to cause polymer degradation. There are different types of fluorescent lamps for different UV light range. The UVA-340 lamp represents light from 300 to 400 nm, as shown in Figure 3-2. The light spectrum can be controlled by varying the irradiance from 0.64- to 0.70 W/m^2-m at 340 nm. UV fluorescent weatherometers are low in initial cost and very economical in maintenance. However, the spectrum does not fully simulate the sunlight spectrum, even in the UV region. Bias may be generated for certain types of polymer, particular with different color pigments.

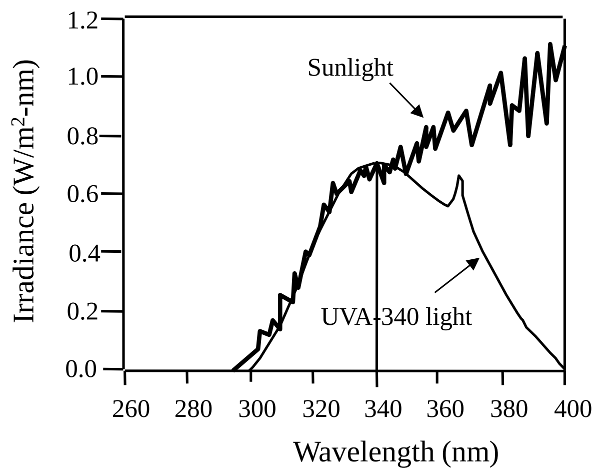


Figure 3-2 : Sunlight and UVA-340 lamp spectra

The two types of commercially available weatherometers described above have different design objectives. The xenon arc with appropriate filters can simulate the entire sunlight spectrum while the UV-fluorescent lamp concentrates at the UV region. Since there will be a variety of unknown polymers with different color pigments involved in this project, the xenon arc weatherometer is a more reliable device to evaluate sunlight degradation of the polymeric products in this study. The ASTM D2565 “Standard Practice for xenon-Arc Exposure of Plastics Intended for Outdoor Applications” to assess products consisted of homopolymer (such as polyethylene, polypropylene, polyvinyl-chloride, polyamide, etc.) will be implemented. The test parameters including temperature, light (dry)/dark (wet) cycle duration, and total irradiance (exposure time) will be studied so that the deterioration induced by the acceleration test is closely simulate to that under the outdoor environment for each polymer type.

3.2.3 Current status of the sunlight test methods

This section focuses on the sunlight test methods specified by the Florida Department of Transportation (FDOT), and used by the manufacturers to assess their products.

For the structural plastics, products should comply with FDOT specification, Section 973 (attached as Appendix-C), even though the material specification is not available for products supplied by the Bedford Technology LLC. Section 973 requires structural plastics products to be tested according to ASTM D4329 using UVA light bulbs for 500 hours with less than 10% change in Shore D durometer hardness. While the test cycle is not specified, of the three test cycles stated in ASTM D4329, Cycle A is likely to be the procedure for testing structural plastics products, since Cycle B is for automobile and Cycle C is for plastic building products.

On the other hand, there is no test protocol being implemented by FDOT for the DWS products. For the five products selected for this project, information on the sunlight exposure test can be found on their websites; however, the information is not completed. The summary of the test conditions is included in the report as Appendix-D. Overall, weatherometer equipped with either xenon arc or UV fluorescent light which complies with ASTM G151 has been specified. The exposure procedure is performed according to ASTM G155 and ASTM G154 for xenon arc and fluorescent lamps device, respectively. The condition (including parameters such as irradiance at a specific wavelength, light/dark cycle duration, temperature, and relative humidity) used for the test is not well documented. For exposure tests using the xenon weatherometer, the type of outer and inner filter around the xenon lamp should be clearly defined as well as test cycle; whereas the type of lamps (UVA-340 or UVB-313) and irradiance are essential in the weatherometer with fluorescent lamps.

3.3 Test Methods to Evaluate Sunlight Degradation of Polymeric Materials

A list of test methods obtained from product specifications listed on the manufacturers' websites and on FDOT's website is summarized in Appendix-E. There is an extensive list of tests, and some of the tests are not applicable for this project (for example a large specimen is required for the test). Nevertheless, the mechanical tests will be considered for assessing the weathered samples.

For the non-destructive tests, two tests are being specified to assess changes of material properties after samples exposed to simulated UV light or sunlight. For the structural plastics products (mainly HDPE), the hardness tested is specified, whereas the color change measurement is used for some of the DWS products. However, these two tests can only evaluate the physical change, and cannot provide insights to the sunlight degradation mechanism of the polymers. Also, color changes may not represent deterioration in mechanical properties of polymer. For example, polyurethanes exhibit color yellowing during sunlight exposure while the mechanical properties retained the same (Wypych, 2013). Additional tests therefore are needed to correlate between changes of physical properties and the mechanical and/or chemical properties.

Types of tests not being included in the product specifications are the analytical tests, (such as Fourier Transform Infrared (FTIR), thermal analytical tests, etc.), and surface morphology (such as cracking and pitting) examination. These two groups of tests are essential for detecting early changes in the polymer structure prior to the deterioration of mechanical properties. Choosing the appropriate analytical tests depends on the sunlight degradation mechanism of the polymer. The six polymeric products included in this project are made from high density polyethylene (HDPE), polyester and NGP based polyester, epoxy, polyurethane, and polyolefin. For HDPE and polyolefin, the depletion of stabilizers and antioxidants (AOs) is first stage of the oxidation degradation (either photo-oxidation or thermal oxidation) (Hsuan and Koerner, 1998; Hsuan and Wong, 2010). Once stabilizers and AOs have been completely consumed, the polymer will then undergo cross-linking and/or chain scission which impacts the rheological behavior and mechanical properties. For the other three types of polymers (polyester, epoxy and polyurethane), AO is not commonly incorporated into the products. Therefore, cross-linking or chain scission will take place in these polymers, generating new chemical compounds. Table 3-2 summaries the primary degradation of the polymers and their chemical products. In summary, monitoring changes in the amount of stabilizers and AOs in HDPE and polyolefin, and to detect new chemical components from polyester, polyurethane and epoxy are considered in this project. Table 3-3 shows some of the basic methods that are considered in this project. Additional tests will be considered when they are found to be appropriate.

Table 3-2 – Sunlight Degradation of Primary Functional Group in Different Polymers

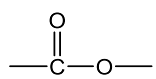
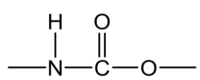
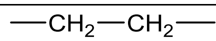
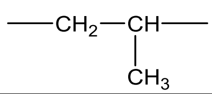
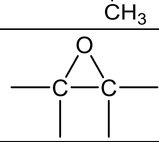
Polymer	Primary Functional Group	Primary Products after Sunlight Exposure	References
Polyester		• hydroxyl • carboxyl • anhydrides • aldehyde	Rivaton, 1993a Rivaton, 1993b Malanowski et al., 2012
Polyurethane		• carbonyl • ketone • aldehyde • amine	Rek, 1986 Yang et al., 2001 Yang et al., 2003
Polyethylene Polypropylene	 	• hydroxides • ketones • carboxyl • vinyl groups	Yashchuk et al., 2012 Geuskens et al., 1984 Torikai et al., 1986
Epoxy		• carbonyl • hydroxyl • amide	Bellenger et al., 1981 Kumar et al., 2002

Table 3-3 – Some Test Methods for Tracking Changes in Properties of UV-Exposed Samples

Property	Test Method	ASTM Standard	Purpose of Test
Physical	Physical dimensions	D5947	Dimension changes
	Carbon black content	D4218	Carbon black amount
	Carbon black dispersion	D5596	Carbon black uniformity
	Light and Scanning electron microscopy (SEM)	None	Surface morphology (cracking and pitting)
Chemical	Oxidative induction time (OIT)	D3895	Amount of antioxidant in the polyolefins
	Fourier Transform Infrared Spectroscopy (FTIR)	D2124	Identify plasticizers
	Fourier Transform Infrared Spectroscopy (FTIR)	None	Photo-oxidation chemical products
	Melt index (MI)	D1238	Molecular weight changes of polyolefins
	Solution viscosity	D1243	Molecular weight changes of polyester
Mechanical	Tensile Test	D638	Break strength and elongation

3.4 Methods to Predict Sunlight Degradation in the Service Environment

Predicting the sunlight degradation at specific site location based on data obtained from the weatherometer has long been a controversial topic. The challenge is on the inherent variability of the outdoor weather which varies from site to site (change in longitudinal and latitudinal positions). The research group at the National Institute Standard and Technology (NIST) has been doing extensive studies to correlate the laboratory data to outdoor performance (Martin et al., 2002). One of the principles is that the degradation mechanisms for the tested polymers must be the same in both environments (the weatherometer and the field site). The degradation mechanisms are governed by three environmental parameters which are *irradiance*, *temperature*, and *moisture*. Each polymer only absorbs a specific portion of the total sunlight spectrum, as shown in Table 3-1 (Hirt and Searle, 1964; Hu, 1997; Zhang et al., 1996; Gu et al., 2006). Therefore, to ensure artificial light spectrum possessing the similar required energy as outdoor for a specific polymer is crucial in the accelerated weathering test. Since xenon arc with appropriate filters can generate a light spectrum to simulate the full sunlight at noon time of Florida, it eliminates the potential mismatch in the energy (Searle et al., 1964). Devices equipped with UV fluorescent lamps can be adopted as long as the light spectrum generates the require energy for the test materials (Brennan, 1996).

The NIST group has correlated the outdoor performance with a highly sophisticated laboratory weathering test for a model epoxy coating system (Gu et al., 2006). The basic principle of their study is to generate a spectrum of data under well controlled environment using the NIST SPHERE. The variables included four temperatures, four relative humidity levels, four ultraviolet spectral wavelengths and four UV spectral intensities. For the outdoor test, the temperature and humidity were continuously monitored together with solar spectrum. The chemical changes in the exposed samples (SPHERE and outdoor) were monitored by both FTIR and UV-visible spectroscopies. The linkage between the lab and field radiation is based on the total effective dosage model (Eq. 1).

$$\boldsymbol{D_{total}(t) = \int_0^t \int_{\lambda_{min}}^{\lambda_{max}} E_0(\lambda, t)\left(1 - e^{-A(\lambda,t)}\right) \phi(\lambda) d\lambda dt} \tag{3-1}$$

Where:

$D_{total}(t)$ and the total effective dosage at time t.

λ_{max} and λ_{min} are the maximum and minimum photolytically effective wavelengths

$E_0(\lambda,t)$ is the spectral UV irradiance of the light source at time t.

$A(\lambda,t)$ is the spectral absorption of specimen at wavelength λ and time t.

$\phi(\lambda)$ is the spectral quantum efficiency.

They found that the degradation mechanism of the epoxy coating is the same between SPHERE and outdoor. Based on the cumulated FTIR measurement at 1250 cm^{-1} (C–O stretching of aryl ether) from an epoxy sample exposed in the SPHERE, Vaca-Trigo (2009) developed a series of statistical models to predict the outdoor degradation.

Although such thorough and long-term research approach is not practical to be applied to this project, the pivotal linkage is the degradation mechanism that must be the same between the weatherometer and the outdoor. Thus, this project consists of laboratory tests and field tests to ensure the linkage is valid. For accelerated weathering tests, the goal is to generate degradation quickly and then using the results to predict the field failure time. The rate of degradation can be enhanced by increasing the temperature and irradiance of the test. The temperature effect on the degradation rate is well known to be based on the Arrhenius Equation (Eq. 2) (Hsuan and Koerner, 1998; Gu, et al., 2006).

$$k_T = A * e^{\frac{-E}{RT}} \quad (3\text{-}2)$$

Where:
k_T = degradation rate in terms of temperature (%/day),
E = thermal activation energy (kJ/mol);
R = gas constant (8.314 J/mol-K),
T = incubation temperature (K), and A is a constant.

The effect of irradiance on the polymer degradation rate follows the law of reciprocity, which is that the product of the intensity of light (I) and exposure time (t) is a constant (Eq. 3) (Chin et al., 2005).

$$I * t = constant \quad (3\text{-}3)$$

Where: the rate of degradation corresponds to the ($1/t$); thus, the slope of the straight line is the reaction rate under sunlight at a constant temperature.

However, not all polymers obey to the law of reciprocity. A non-linear response to the irradiance was expressed by Schwarzschild's law (Eq. 4) (White, et al. 2006).

$$I * t^p = constant \quad (3\text{-}4)$$

Where: p is constant which is less than 1, and the value depends on the material, wavelength and intensity.

White, et al. (2006) pointed out that certain polymeric material can be degraded faster than the reciprocity law, exhibiting a non-linear relationship according to Eq. 5.

$$I^q * t = constant \quad (3\text{-}5)$$

Where: q is constant which ranges between 1 and 0.5, and the value depends on the material.

It is difficult to evaluate the effects of moisture on the sunlight degradation, since the moisture level inside the commercially available weatherometer is not controlled. In the xenon arc weatherometer, moisture is introduced by spray water onto the surface of the test specimens. The humidity level however cannot be altered. Under this circumstance, the assumption is that the water (or moisture) effect on the sunlight degradation is the same in both the laboratory test and outdoor exposure. This assumption may be reasonable for Florida's climate, since rainfall is frequently occurring.

CHAPTER 4 – SUNLIGHT EXPOSURE CONDITIONS

4.1 Xenon Weatherometer Test Conditions

An ATLAS Ci-4000 weatherometer equipped with a xenon lamp and inner and outer borosilicate filters was used to simulate the sunlight in the laboratory. The exposure condition was set according to ASTM D2565 "Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications". Three test conditions with different irradiances were used to assess the effect of light irradiance (k_J) on the test samples. The three xenon test conditions are designated to be Condition [A], [B], and [C], and the test parameters of each condition are described below:

Condition [A] – the test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C and an irradiance of *41.5 ± 2.5* W/m^2 *from 300- to 400-nm*.
Condition [B] – the test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C and an irradiance of *60 ± 2.5* W/m^2 *from 300- to 400-nm*.
Condition [C] – the test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C and an irradiance of *80 ± 2.5* W/m^2 *from 300- to 400-nm*.

4.2 Outdoor Exposure Test Condition

A steel frame was constructed according to ASTM 1435 "Standard Practice for Outdoor Weathering of Plastics" at the FDOT research facility in Gainesville, FL. Test coupons were mounted onto the steel frame facing south with an angle of 45^0 from horizontal on January 5th, 2016, as can be seen in Figure 4-1.

Figure 4-1 – Outdoor exposure setup with test coupons.

Chapter 5 – STRUCTURAL PLASTIC PRODUCT

This chapter describes the effect of sunlight on a HDPE structural plastic product by exposing samples in the xenon weatherometer and outdoor condition. In addition, the thermal effect on the HDPE structural plastic product was assess by incubating samples in forced air ovens at 65^{o}C which the temperature of the weatherometer test.

5.1 Test Coupons

Samples with different sizes were obtained from the company. The surface section was cut from the large blocks for the study. The test coupons for the exposure tests involved an extensive of preparation. Coupons with dimensions 3.25-in x 6.5-in were first cut from large samples. The cut coupons were then machine milled to a thickness of 0.1 ± 0.05-in.

5.2 Test Results from Xenon Weatherometer

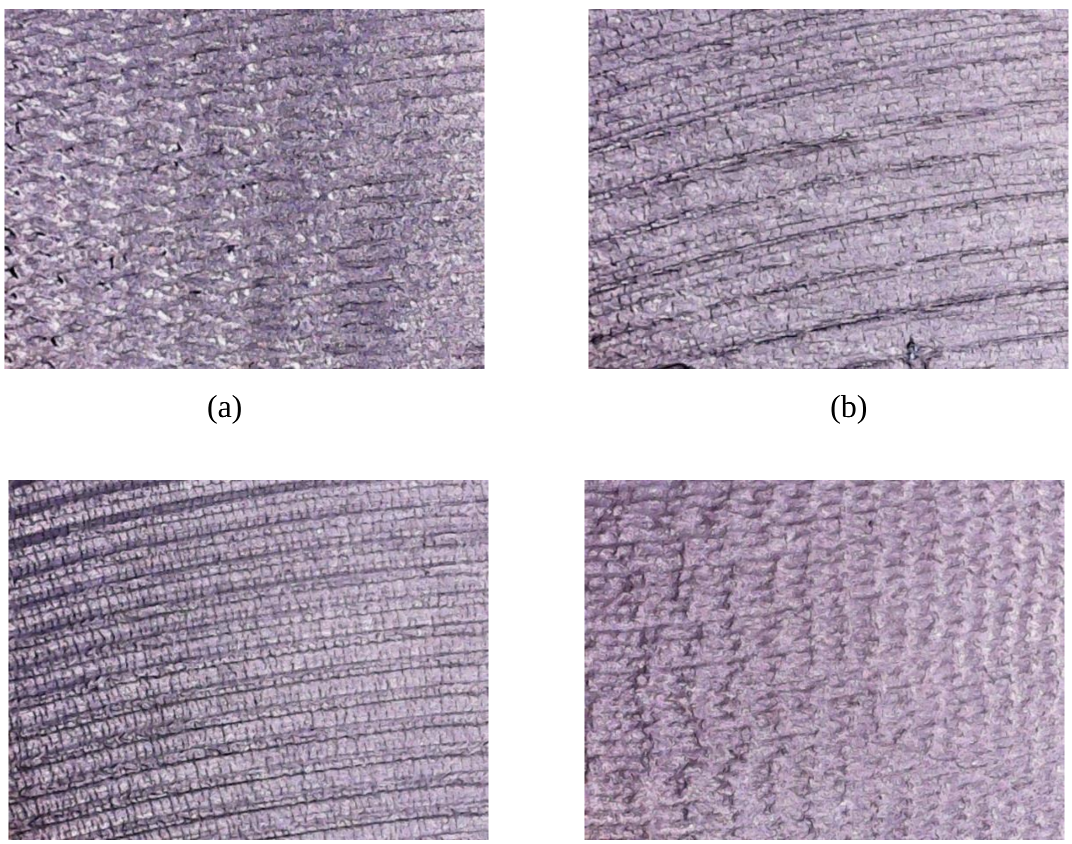
Table 5-1 shows the test methods used to evaluate the exposed HDPE structural plastic coupons. The schedule for the tests performed on the exposed coupons in xenon weatherometer included performing OIT test at every 500 hours, and MI, tensile test at every 1,000 hours with surface appearance examination. (Note: the exposure time for Condition [A], [B] and [C] were 5,000, 4,000 and 3,000 hours, respectively)

Table 5-1 – Test Methods Used to Evaluate the Xenon-Exposed HDPE Coupons

Property	Test Method	ASTM Standard	Purpose of Test
Physical	Light microscopy	None	Surface morphology (cracking)
	Melt index (MI), 190^{o}C/2.16 kg	D1238	Molecular weight changes
Chemical	Oxidative induction time (OIT)	D 3895	Amount of antioxidant remaining in the coupons
Mechanical	Tensile Test	D638-IV	Break strength and elongation

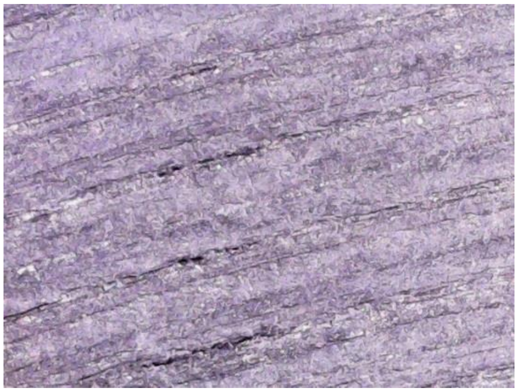
5.2.1 Surface morphology

The surfaces of HDPE exposed coupons were examined for cracking using a digital light microscope. Figure 5-1 shows photos of original (unexposed) coupon and coupons exposed to 5,000 hours, 4,000 hours, and 3,000 hours in Condition [A], [B] and [C], respectively. Photos of other exposure durations are included in Appendix-F. The curve lines on the surface of original coupon are caused by machine milling of the coupon. Those patterns were fading gradually with increasing in exposure time. Numerous microcracks can be observed on the surface facing the sunlight after 4,000 hours in Conditions [A] and [B], as shown in Fig. 5-2(a) and (b). In Condition [C], microcracks were observed on the surface after 3,000 hours (Fig. 5-1(c).

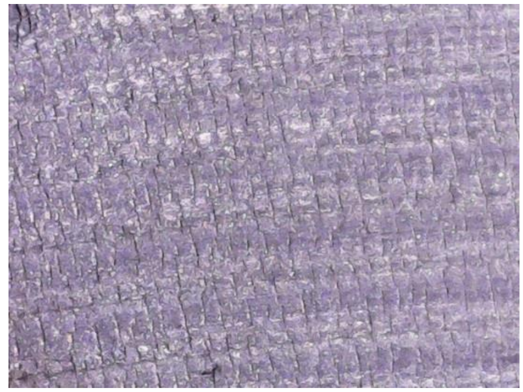


(a) (b) (c) (d)

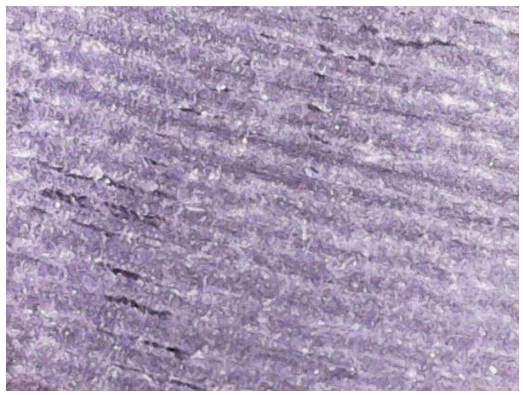
Figure 5-1 – Surface morphology observed at 30x magnification: (a) Original coupon, (b) 5,000 hours in Condition [A], (c) 4,000 hours in Condition [B], and (d) 3,000 hours in Condition [C]



(a)



(b)



(c)

Figure 5-2 – 3,000-hr-exposed surface observed at 160x magnification:
(a) Cracking in Condition [A] after 4,000 hr. (b) Cracking in Condition [A] after 4,000 hr.
(c) Cracking in Condition [C] after 3,000 hr.

5.2.2 Oxidative induction time (OIT) test

The OIT test specimens were cut across the thickness from the exposed surface to the back of the coupon; thus, the OIT value represented the overall relative antioxidant remaining in the test specimen. The OIT thermal curves of specimens taken from the original unexposed coupon and 500-hr exposed coupon under the exposure Condition [A] are shown in Figure 5-3, and a double exothermal peak was noted in the 500-hr exposed coupon. The double exothermal peak suggests non-uniform distribution of antioxidant (AO) in the test specimen. In order to assess the variation of AO concentration across the thickness of the exposed coupon, thin slices were cut along the thickness as illustrated in Figure 5-4 and the OIT tests were performed on them. OIT value of different layers at various exposure times are presented in Figure 5-5. The OIT profile will enable us to determine the penetration depth of the photon into the black HDPE structural product.

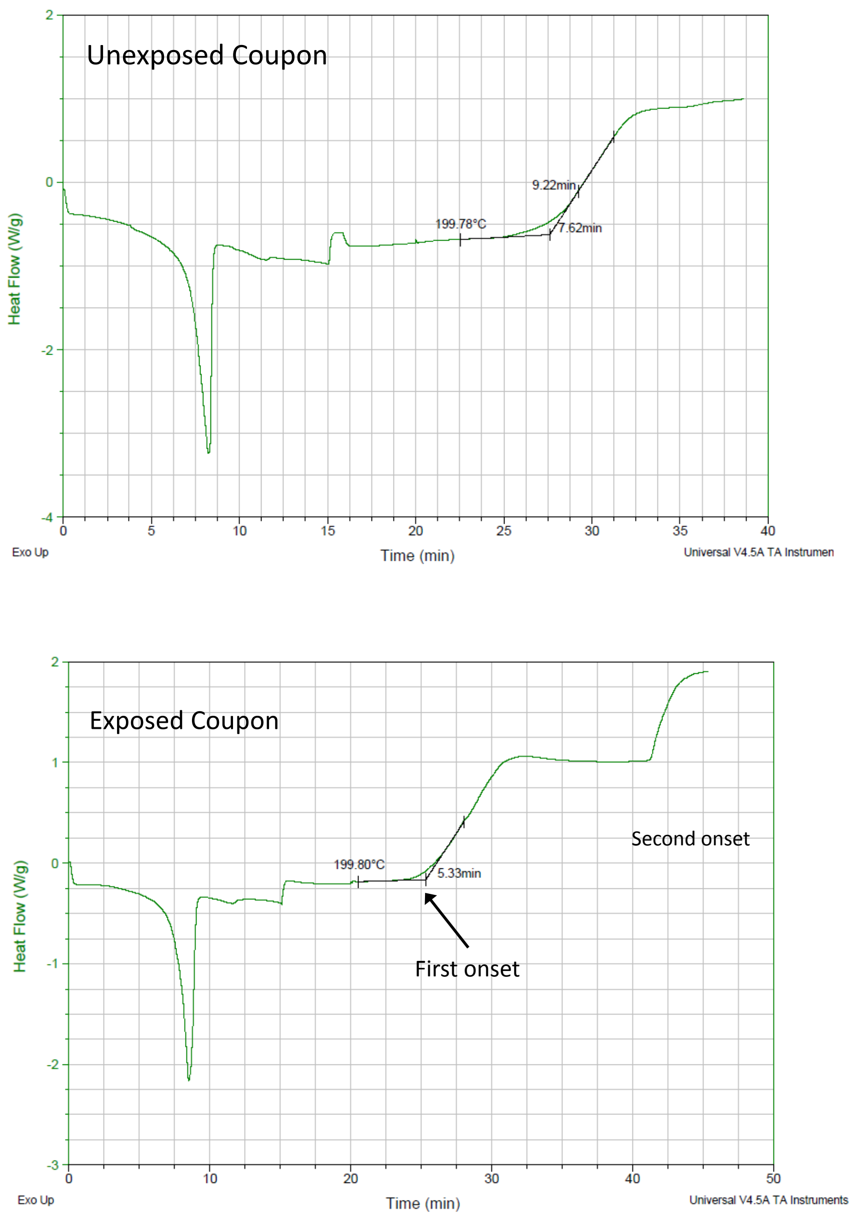


Figure 5-3 – The OIT thermal curve of unexposed coupon and 500-hr coupon exposed in Condition [A]

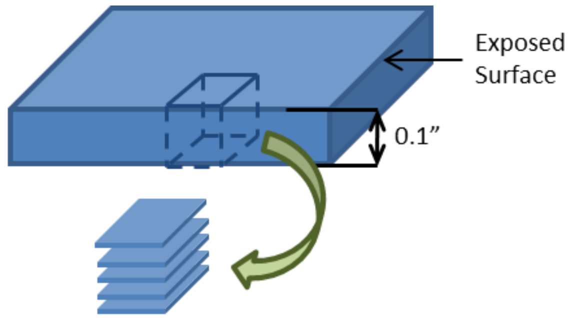
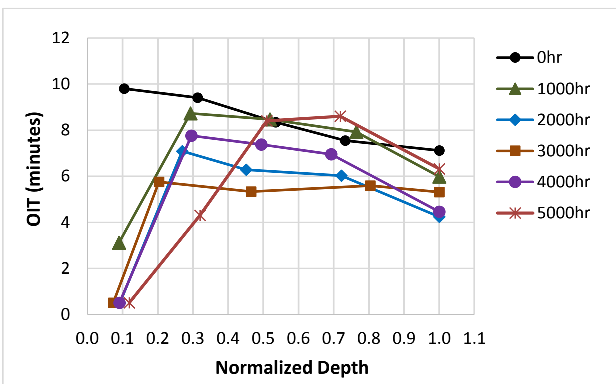
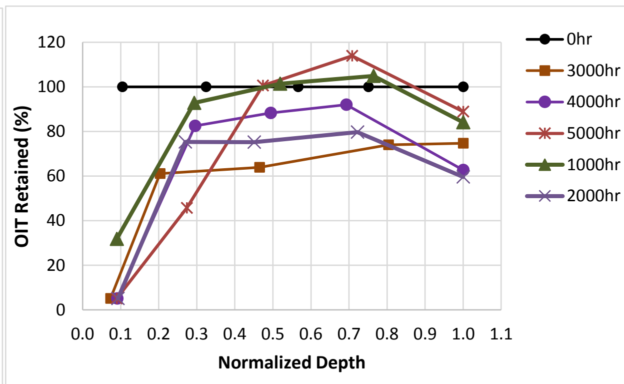


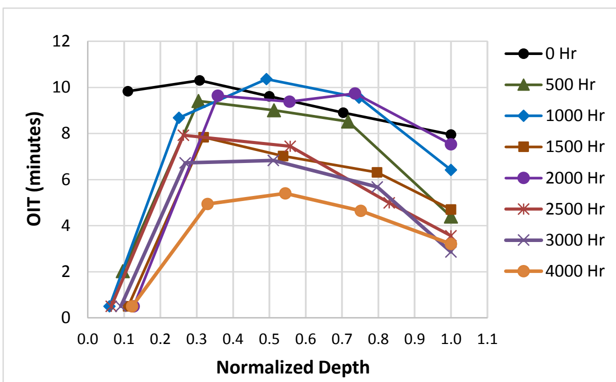
Figure 5-4 – The slides taken from the HDPE coupon for OIT testing



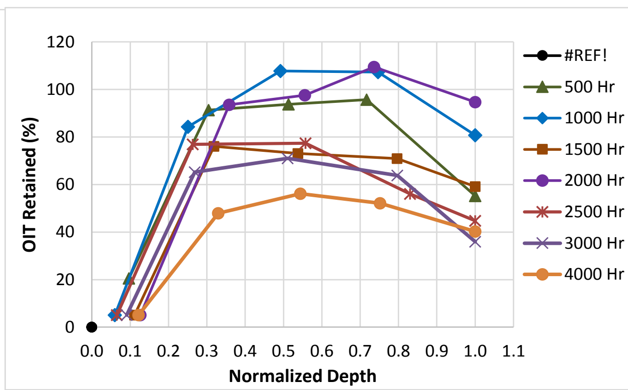
(a)



(b)

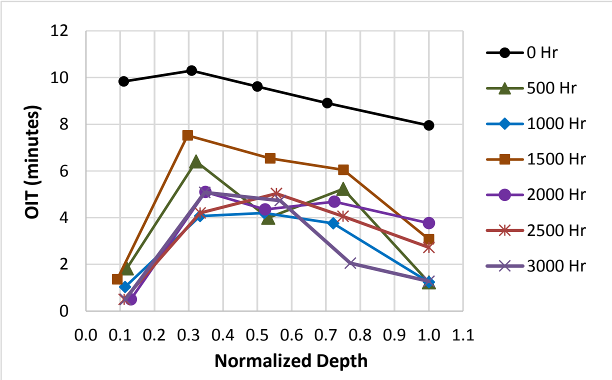


(c)

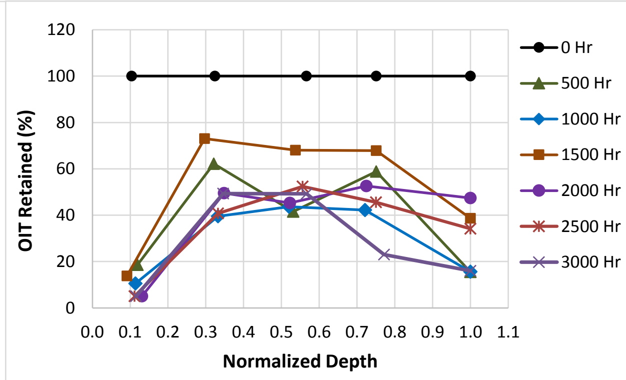


(d)

Figure 5-5 – OIT value across the thickness of the exposed coupons:
(a) OIT value in Condition [A], (b) OIT retained percentage in Condition [A],
(c) OIT value in Condition [B], (d) OIT retained percentage in Condition [B].
(e) OIT value in Condition [C], and (f) OIT retained percentage in Condition [C].



(e)



(f)

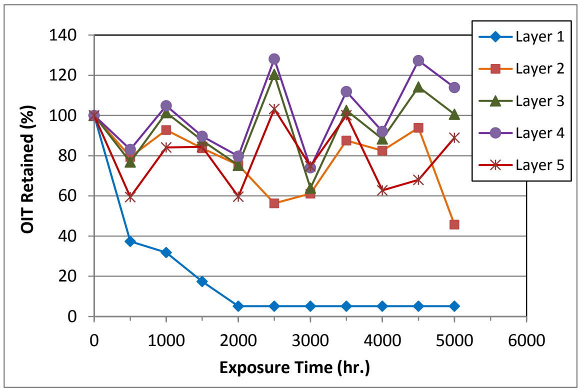
Figure 5-5 – Continued

The OIT test result is presented as OIT percentage retained, as calculated using Equation (5-1). Therefore, the antioxidant depletion rate can be compared among different coupons with different initial OIT values. Figure 5-5 presents OIT values and OIT percentage retained values against nominal thickness at different exposure times under conditions A, B, and C (The OIT test data are included as Appendix-G of this report.).

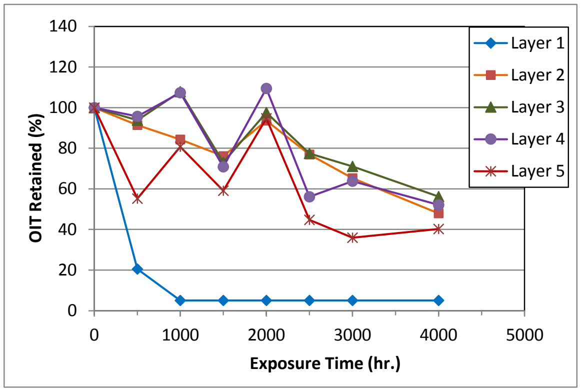
$$\boldsymbol{OIT_{\%-retained}} = \frac{\boldsymbol{OIT_{(t)\ at\ each\ exposed\ time}}}{\boldsymbol{OIT_{(0)\ initial}}} \tag{5-1}$$

It should note that a small gradient was detected in the OIT value across the thickness of the unexposed (0-hr) coupon as shown in Figure 5-5. The inner surface exhibited a lower OIT value than the surface. This may be caused by the thermal gradient building up within the sample during the product manufacturing. HDPE is a good thermal insulator; thus, the high processing temperature would retain longer in the interior of the product in comparison to the surface, especially for this product with a large cross-sectional area. A greater amount of antioxidant would be consumed inside the product than near the surface.

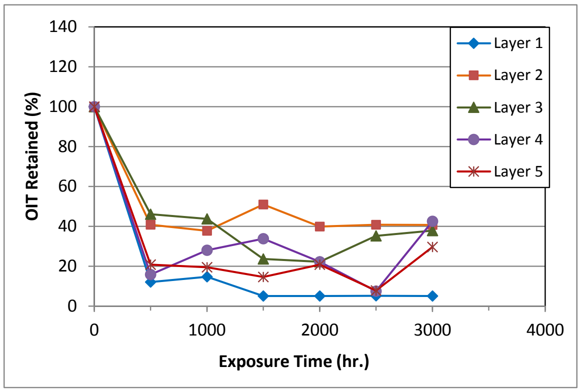
The OIT depletion at different layers throughout the exposure time in three exposure conditions is presented in Figure 5-6. Also, the OIT retained percentage at each layer under three xenon exposure conditions is shown in Figure 5-7. The first layer (Layer 1 with thickness of 0.015 ± 0.005 inch) facing the xenon light exhibited the fastest decrease in OIT, whereas the interior of the coupon (Layer 2 to 5) has much slower decrease. Condition [C] has a faster decreasing rate than Conditions [A] and [B] for all layers. This suggests that the irradiance used in Condition [C] penetrated deeper into the test coupon than Conditions [A] and [B].



(a)

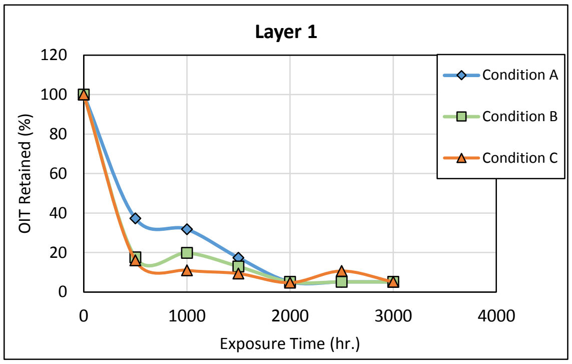


(b)

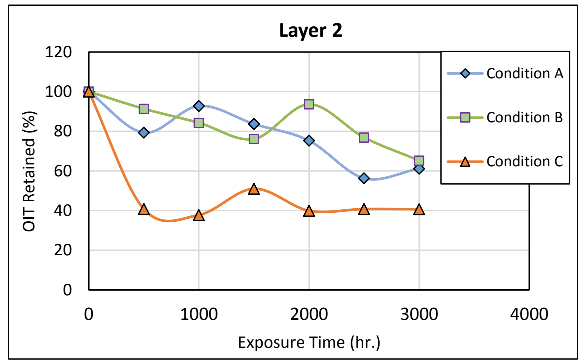


(c)

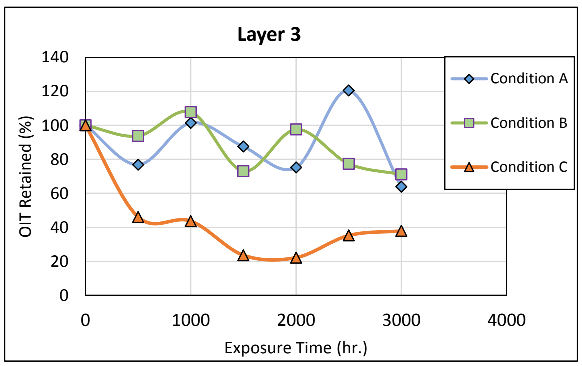
Figure 5-6 – The OIT retained percentage at each of the five layers across the thickness: (a) Condition [A], (b) Condition [B], and (c) Condition [C]



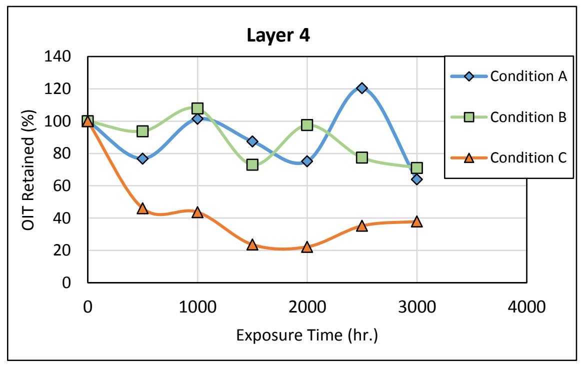
(a)



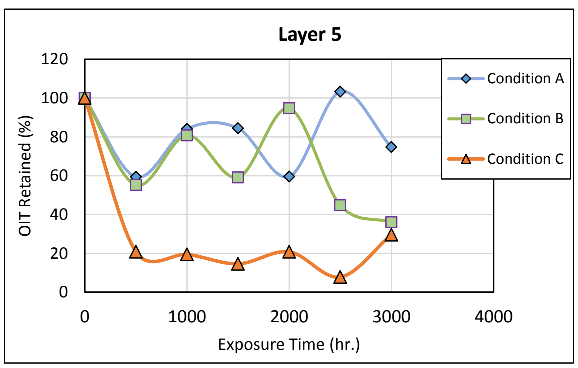
(b)



(c)



(d)



(e)

Figure 5-7 – The OIT retained percentage at each of the five layers versus exposure time in xenon weatherometer under three conditions (a) to (e).

5.2.3 Melt index test

The MI test is used to assess changes in molecular weight of the HDPE structural product after exposure. The test was performed at every 1,000 hours. A single test was performed for each exposed coupon. (The MI test data are included as Appendix-G of this report.)

The MI value throughout the exposure remained almost constant regardless of the testing conditions, as can be seen in Figure 5-8. This suggests that the molecular weight of the exposed coupons did not change. The amount of surface degradation is insignificant with respect to the entire test coupon.

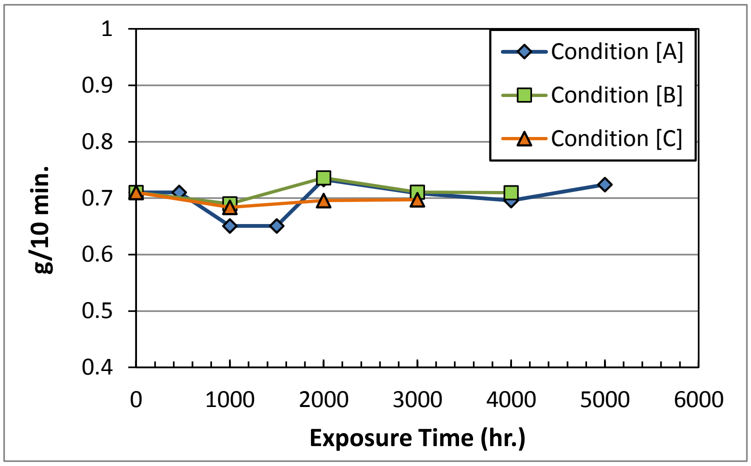


Figure 5-8 – Comparison of MI values of test coupons exposed to xenon test under Conditions [A], [B], and [C]

5.2.4 Tensile test

The tensile properties were used to assess the mechanical properties of the HDPE coupons. Two replicates were tested every 1,000 hours and the average values of tensile properties (yield stress, yield strain, ultimate stress, ultimate strain and break strain) are summarized in Table 5-2. (The tensile test data are included as Appendix-G of this report.) The results indicate that sunlight degradation has a significant impact on the bulk tensile behavior of a HDPE product. Figure 5-9 illustrates the three types of stress/strain curves obtained from the tensile testing of exposed coupons.

Table 5-2 – Average Value of Tensile Properties

Exposure Time (hr)	yield stress (psi)	yield strain (%)	ultimate stress (psi)	ultimate strain (%)	break strain (%)
Condition [A]					
0	3293	18	1971	305	319
500	3253	16	1824	232	330
1000	3426	15	1891	150	171
1500	3095	18	1925	435	445
2000	3228	17	1808	309	335
3000	3483	15	1759	96	114
4000	3458	16	1716	64	129
5000	3617	15	1470	22	27
Condition [B]					
0	3293	18	1971	305	319
500	3629	15	1943	38	50
1000	3880	15	2098	69	59
2000	3585	13	1639	24	30
3000	3781	13	2108	32	40
4000	3728	14	2176	80	97
Condition [C]					
0	3293	18	1971	305	319
500	3793	14	2050	32	39
1000	3644	14	N/A	N/A	116
2000	3551	15	1975	139	176
3000	3663	14	1843	21	27

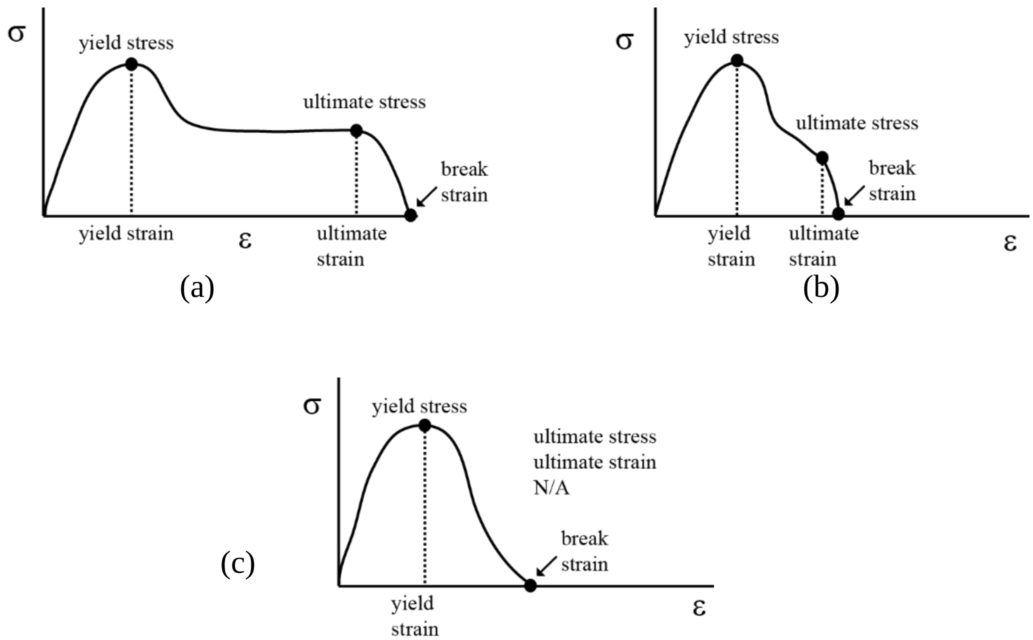


Figure 5-9 – Tensile behavior of HDPE: (a) type 1, (b) type 2 and (c) type 3

Test results from conditions A, B and C are presented in Figure 5-10. For all conditions, no significant changes were measured in yield stress, ultimate stress and yield strain during the exposure time (Figure 5-10(a)-(c)). The break strain decreased with exposure time for all conditions. A drop from 300% to about 40% was measured after 500 hours under Conditions [B] and [C]. Similar reduction under Condition [A] was observed after 3,000 hours.

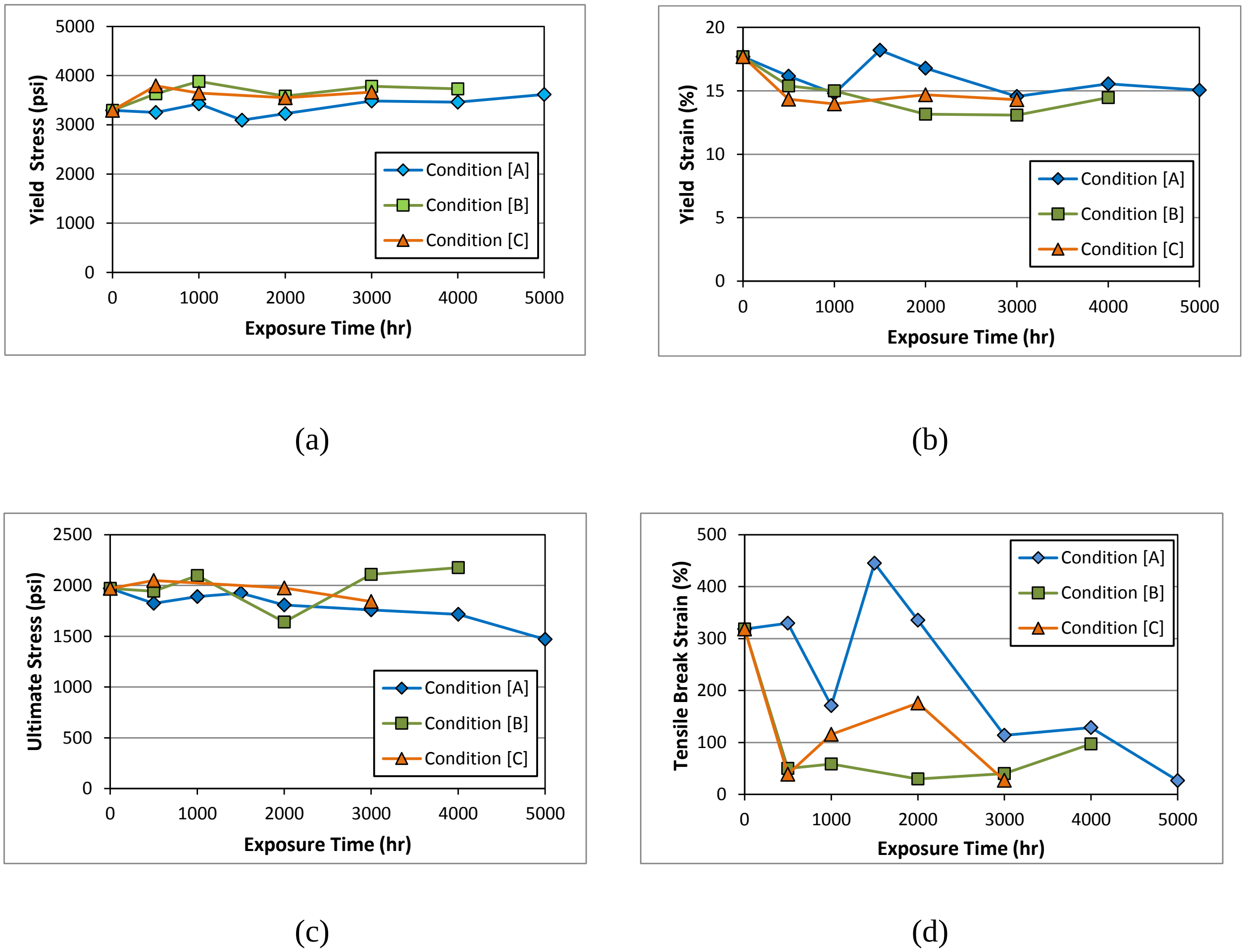
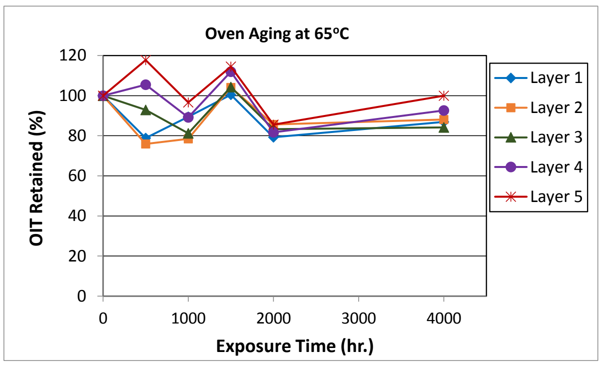


Figure 5-10 – Comparison of tensile properties between Conditions [A], [B], and [C]: (a) yield stress, (b) yield strain, (c) ultimate stress, and (d) break strain

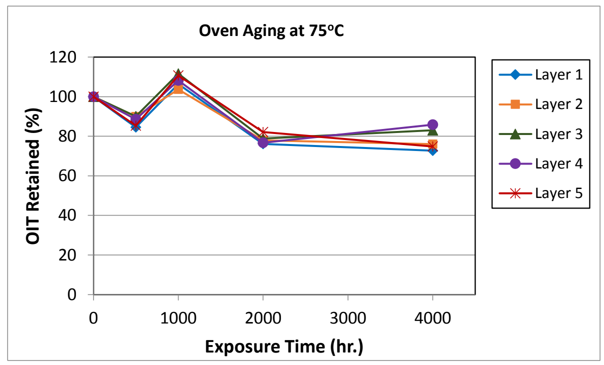
5.3 Test Results from Oven Aging

The OIT retained value of HDPE coupons aged in forced air ovens exhibited very small variation across the thickness in comparison to those exposed in the weatherometer. The OIT test results for the first 4,000 hours at 65 ^oC, 75 ^oC and 85^oC are shown in Figure 5-11. (The OIT test data are included as Appendix-G of this report.). This clearly indicates that xenon light impacts the exposed surface layer of the HDPE coupon; whereas the temperature effect is throughout the entire coupon.

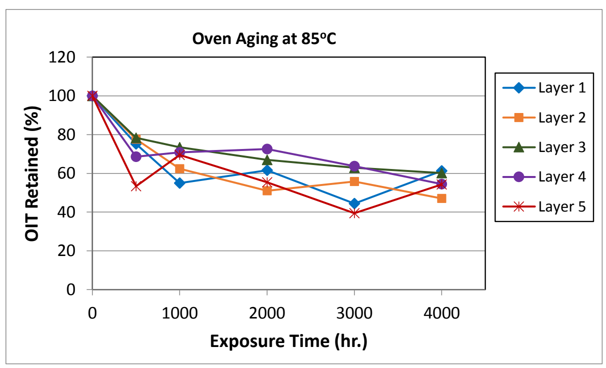
Figure 5-12 indicates that the OIT values are significantly affected by the temperature condition and exposure time. After 10,000 hours of exposure, the OIT value in 85°C dropped to 33% while the value in 65°C and 75°C decreased to 70% and 53%, respectively. Further increase of exposure time to 18,000 hours led to a decrease of the OIT value to 29%, 24% and 11% in the temperature of 65°C, 75°C and 85°C, respectively.



(a)



(b)



(c)

Figure 5-11 – OIT test results of coupons aged in oven at three temperatures: (a) 65°C, (b) 75°C and (c) 85°C

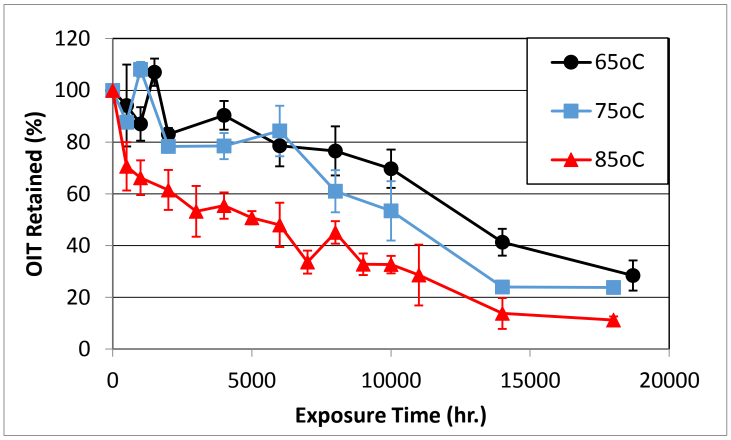


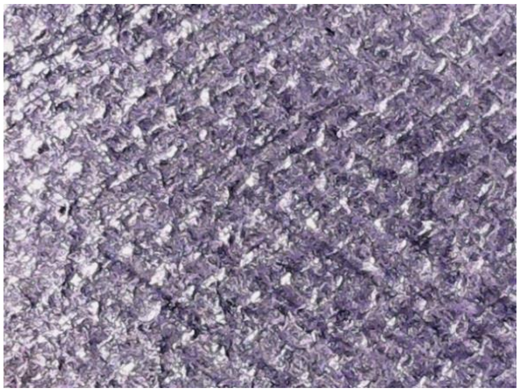
Figure 5-12 – The average OIT value of coupons aged in forced air ovens at three temperatures

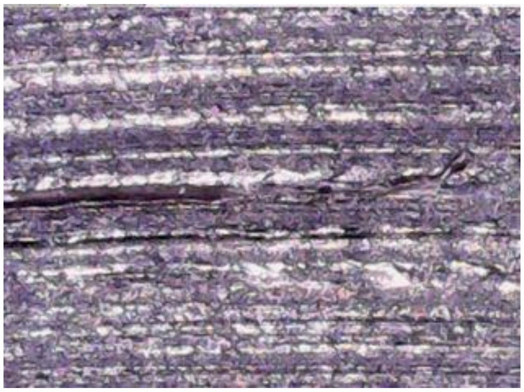
5.4 Test Results from Outdoor Exposure

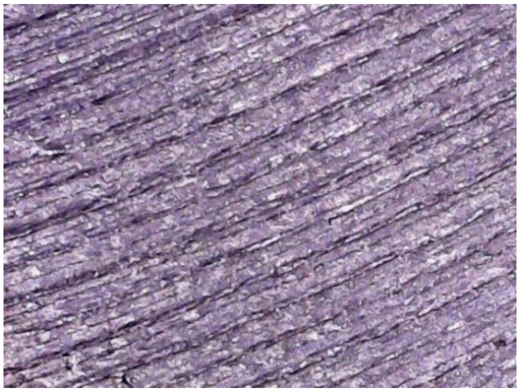
Test coupons were prepared from the HDPE structural plastic product in the dimensions of 2 in. wide and 6.5 in. long and 0.1 ± 0.005 in. thick. Twelve coupons were prepared, and two coupons were retrieved every four months for testing.

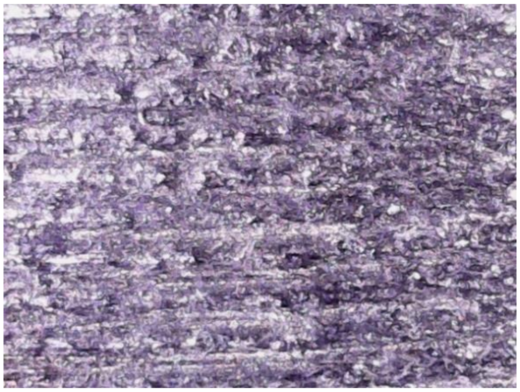
5.4.1 Surface morphology

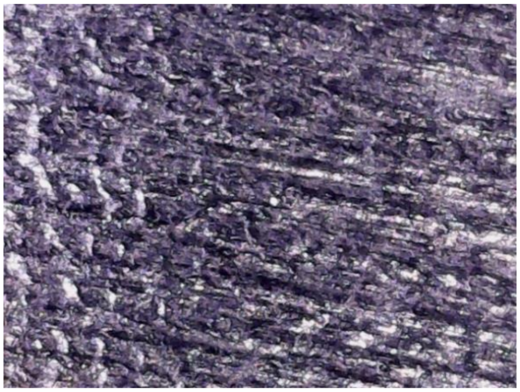
The surface appearance of the outdoor-exposed coupons was examined under a light microscopic. Photographs were taken to represent the surface texture of each coupon. Figure 5-13 shows the surface appearance at different periods of exposure time. Cracking was observed under a magnificent of 160x in 8-, 16- and 24-month coupons, and the cracking took place in a localized area.


Original


8-month Outdoor


12-month Outdoor


16-month Outdoor


20-month Outdoor

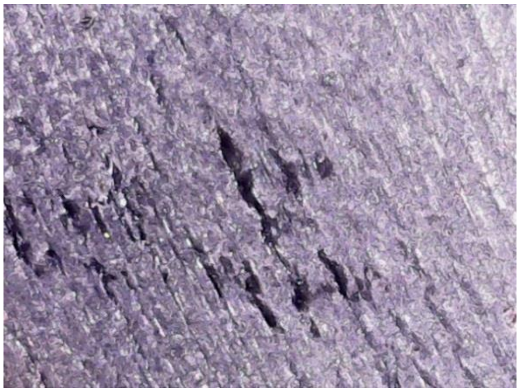
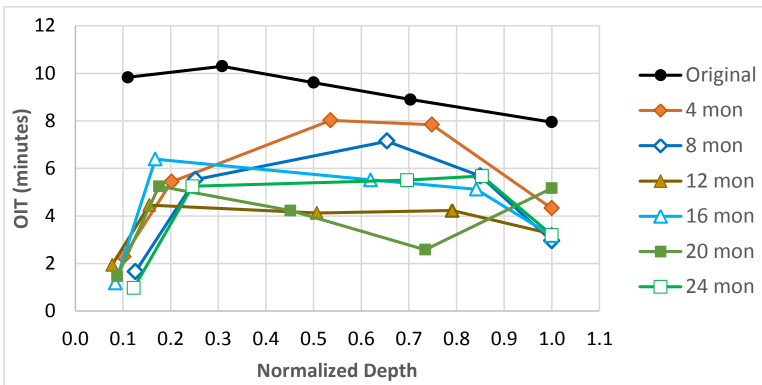

24-month Outdoor

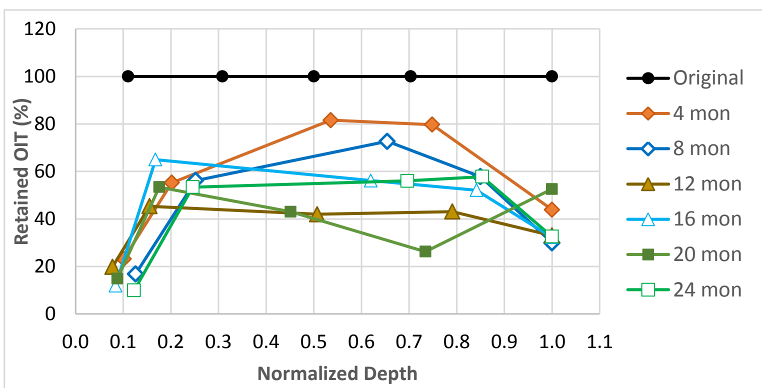
Figure 5-13 – Surface appearance of outdoor-exposed coupons of HDPE structural product

5.4.2 Oxidative induction time (OIT) test

The amount of stabilizer remaining in the exposed samples was assessed using the OIT test. Two replicate tests were performed from each retrieved coupon. Figure 5-14(a) and (b) shows the OIT value and retained OIT percentage against the normalized depth at different exposure times. (The OIT test data are included in Appendix-G of this report.)



(a)



(b)

Figure 5-14 – OIT value across the thickness of the exposed coupon.
(a) OIT value and (b) OIT retained percentage

Figure 5-15 shows the change in OIT retained percentage for all layers of HDPE coupons throughout the 24 months of exposure. The surface layer with an average thickness of approximately 0.012-inch is directly exposed to the sunlight, and has the greatest decrease in OIT, particularly in the first four months. The core layers (layers 2, 3, and 4) exhibit a more gradual decrease and the decrease is much less than the surface layer. The decrease of OIT retained percentage for the backside layer falls between the surface layer and core layers.

Figure 5-16 shows the decrease of OIT in the surface layer, core section (average of layers 2, 3 and 4) and the backside layer. The core section exhibits a large variation in the average OIT retained percentage, in a range of 20%. This is likely due to the non-uniform distribution of the stabilizer in the test coupons.

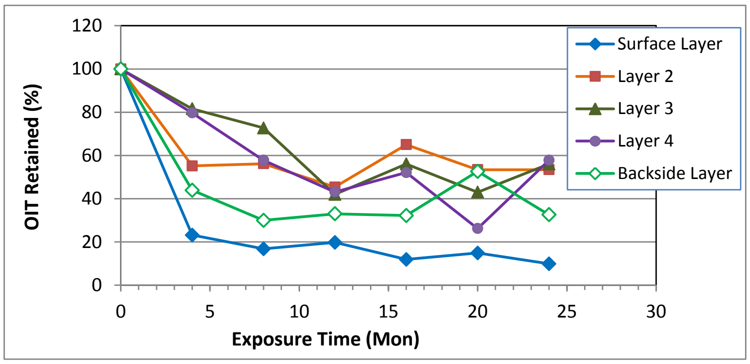


Figure 5-15 – The OIT retained percentage at each of the five layers across the thickness

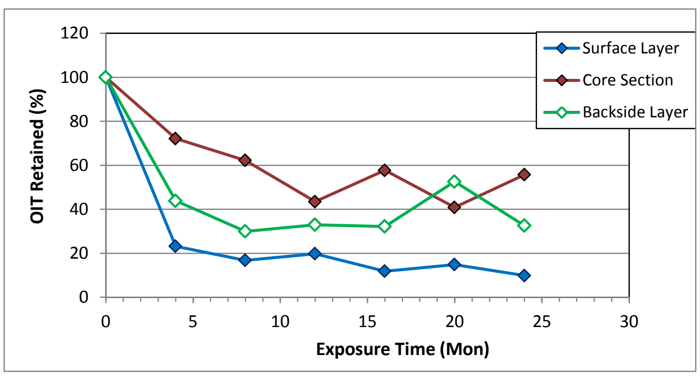


Figure 5-16 – The average OIT retained percentage of surface, core, and backside layers.

Overall, the OIT test data clearly demonstrate the effect of sunlight on the depletion of stabilizer in the HDPE structural product. After 24 months of outdoor exposure, the OIT retained percentage dropped to approximately 10% (an OIT value of 1 minute). In contrast, the core section still retained approximately 50% of the stabilizer. Because of the mounting configuration, the backside of the coupons were also exposed to indirect sunlight irradiance; its OIT retained percentage dropped to 30% after 24 months.

5.4.3 Melt index (MI) test

The MI value throughout the 24 months of outdoor exposure remained almost constant, as can be seen in Figure 5-17. This indicates that the overall molecular weight of the polymer did not change.

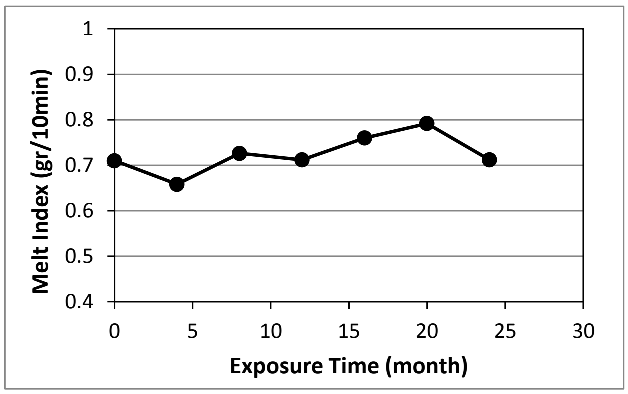
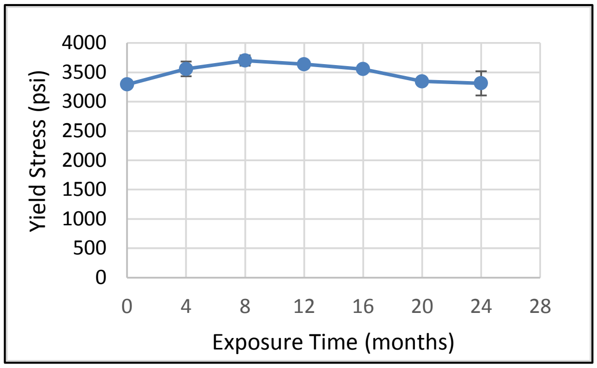


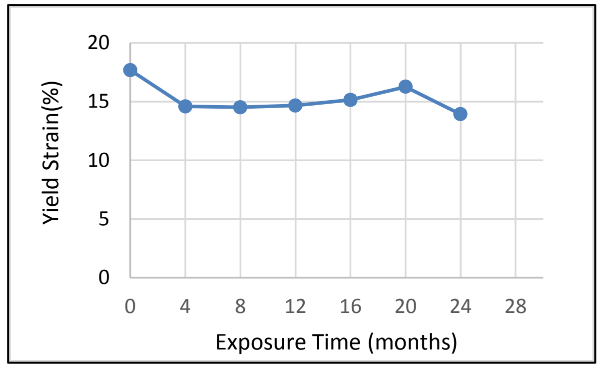
Figure 5-17 – MI values of outdoor test coupons

5.4.4 Tensile test

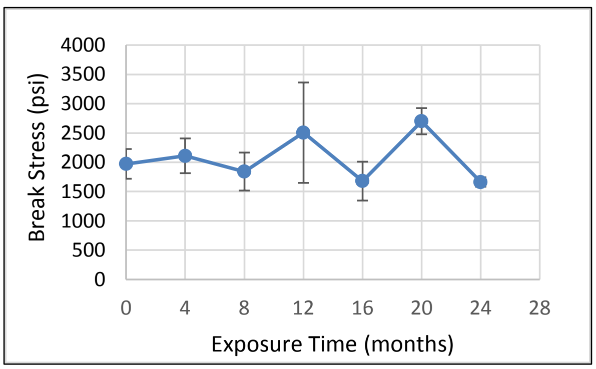
The tensile properties were used to assess the mechanical properties of the HDPE coupons exposed to the outdoor environment. Four replicates were tested on the retrieved samples in every 4 months. (Tensile test data are included in Appendix-H.) The graphic form of the average values of four tensile properties with error bar representing the standard deviation is shown in Figure 5-18(a) to (d). Except for the break strain, the other three properties (yield stress and strain, and break stress) are relatively constant. There is a large variation in the break strain values even for the original unexposed material, therefore it is difficult to draw a definitive conclusion on the change of behavior. On the other hand, the 24-month's sample exhibits a low break strain with much smaller error bar among the four tests, which may indicate the beginning of surface degradation.



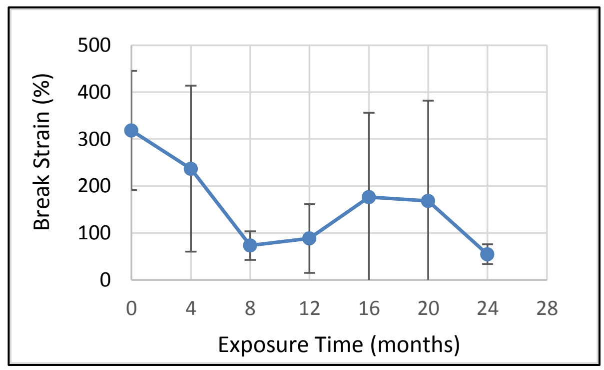
(a)



(b)



(c)



(d)

Figure 5-18 – Tensile properties of outdoor samples:
(a) yield stress, (b) yield strain, (c) break stress, (d) break strain

5.5 Comparing Test Results of Xenon Weatherometer and Outdoor Exposure

To compare test data between weatherometer and outdoor environment, the test time in weatherometer exposure conditions must be converted to the equivalent outdoor condition at Gainesville, FL. The closest location at which the reliable radiation energy data are available is Miami, FL. Atlas Weathering Services Group provides annual reports for total and UV solar radiation at an angle of 45^{o} with horizontal. The results for the past 10 years are summarized in Table 5-3. Also included in the table is the average solar radiation values from Tampa Bay and Port St. Joe obtained from the Department of Transportation weather stations. The average radiation value at Tampa Bay is similar to that of Miami, while the value at Port St. Joe is lower than that of Miami. However, there are missing data from these two locations.

Table 5-3 – Annual Solar Radiation Energy Summary in Miami, Tampa Bay, and Port St. Joe, Florida

Year	Total Solar Radiation, MJ/m^2 (295- to 2500-nm)		
	Miami	Tampa Bay	Port St. Joe
2007	6345.3	The average radiation was calculated based on measured data from November 2014 to September 2016 (However data from certain months are missing from the data sheet.)*	
2008	6259.0		
2009	6446.4		
2010	6181.9		
2011	6568.1		
2012	6316.3		
2013	6017.5		
2014	6452.7		
2015	6306.1		
2016	6309.2		
Average	**6320.3**	**6262.6**	**5628.4**
*The missing data for Tampa Bay includes: 11/2014-3/2015, 6/2015-8/2015, 9/2015 to11/2015, 12/2015-4/2016. The missing data for Port St. Joe includes: 12/2014-1/2015, 4/2015-5/2015, 9/2015-3/2016, 4/2016-5/2016.			

Using the average value for the past 10 years, the equivalent outdoor exposure time was calculated using Equation 5-2:

$$t_{Outdoor} = \frac{E_{total,Weatherometer}}{E_{total,Outdoor}} \times 12 \quad (5\text{-}2)$$

Where:

$t_{Outdoor}$ = equivalent outdoor exposure time based on Miami Florida in Months,
$E_{total,\ weatherometer}$ = total absorbed energy in the weatherometer (MJ/m^2), and
$E_{total.outdoor}$ = total absorbed energy in the outdoor environment (MJ/m^2), from Table 5-3.

The total absorbed energy in the weatherometer can be obtained using Equation 5-3:

$$E_{total,weatherometer} = I_{300-400} * \alpha * t * 0.0036 * \beta \quad (5\text{-}3)$$

Where:

$E_{total,weatherometer}$ = total absorbed radiation energy in the weatherometer (MJ/m^2),
$I_{300-400}$ = irradiance level (W/m^2),
α = $I_{300-800}$ / $I_{300-400}$,
t = exposure time (hour), and
β = $I_{300-2500}$ / $I_{300-800}$

The conversion factor α was provided by the manufacturer of the weatherometer, and was used to convert the irradiance in the 300- to 400-nm bandpass to irradiance in the 300- to 800-nm bandpass. The conversion factor β was obtained by calculating the total irradiation from the reference solar spectrum provided by ASTM G173 and dividing it by the irradiation in the 300- to 800-nm bandpass in the same spectrum.

Figure 5-19 shows the correlation between xenon exposure time and Florida exposure time for three xenon test conditions using Equation (1) and (2).

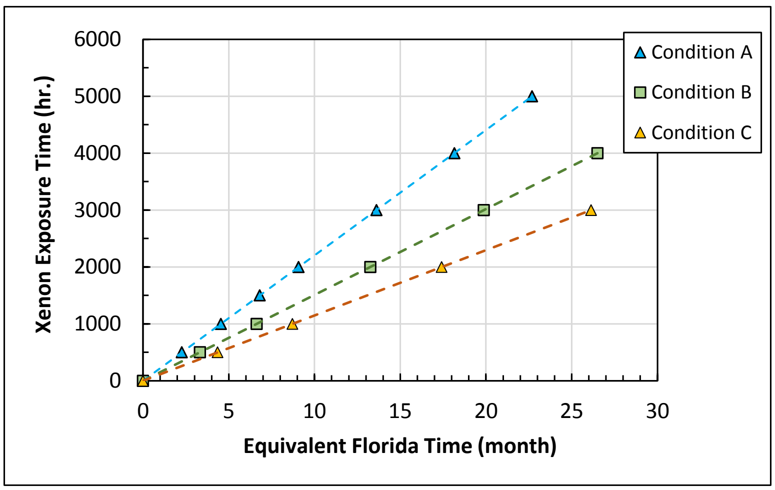
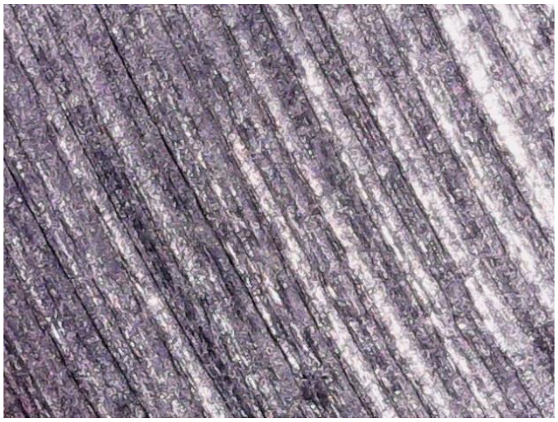


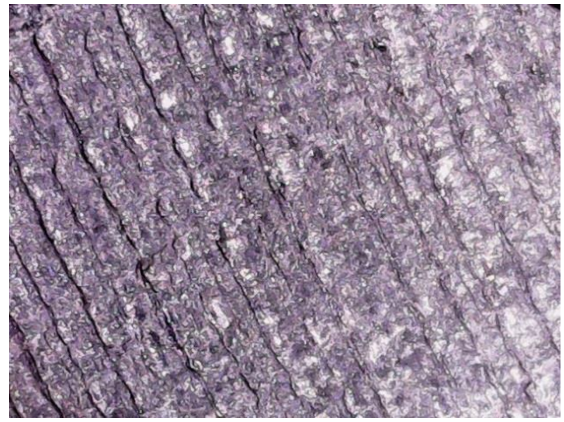
Figure 5-19 – Correlation between xenon testing time and equivalent Florida exposure time for three test conditions

5.5.1 Surface morphology

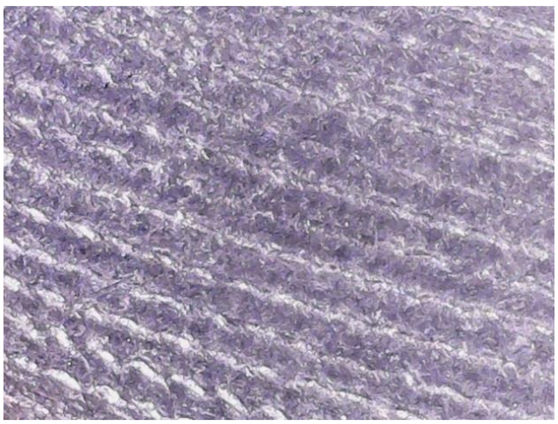
The surface appearance of exposed coupons was examined under a light microscopic. Photos were taken to represent the surface texture of each coupon. Figure 5-20 shows the surface photos after 3,000 hours of exposure in xenon weatherometer under Conditions [A], [B], and [C], and after 24 months of outdoor exposure at Gainesville, Florida. Cracks were observed on the coupon's surface in Condition [C], while no cracking was observed under Conditions [A] and [B] for the same period of exposure. For coupons exposed to the outdoor environment, cracks were observed in 8, 16 and 24 months of exposure under a magnification of 160, see Figure 5-20(f) for the 24-month surface. The cracking took place in a localized area in one or both exposed coupons.



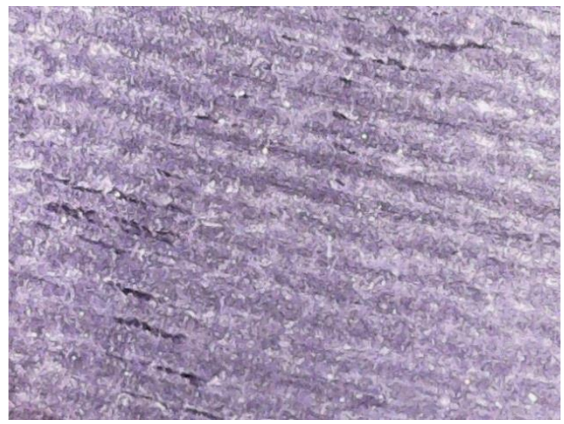
(a) Original 160x



(b) Xenon Condition [A] 3,000hr, 160x

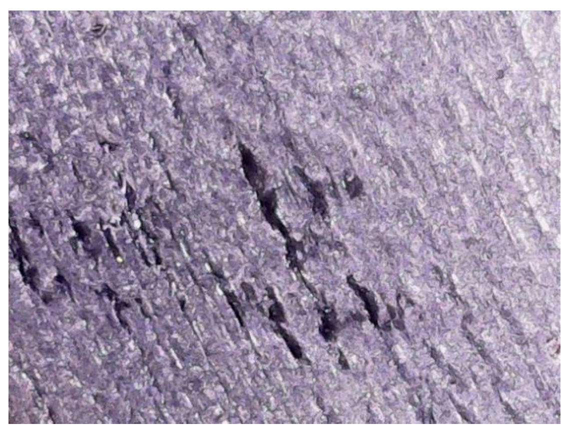


(c) Xenon Condition [B] 3,000 hr, 160x



(d) Xenon Condition [C] 3,000 hr, 160x

(e) Outdoor 24 Months, 100x



(f) Outdoor 24 Months, 160x

Figure 5-20 – Surface appearance of exposed coupons of HDPE structural product

5.5.2 Melt index (MI) test

Figure 5-21 shows a graph by plotting MI value versus equivalent Florida time in months using Equation (5-2). The MI values essentially did not change with time under all four exposure conditions. This indicates that the molecular weight of the bulk polymer in the exposed coupons did not change, even though the surface has shown degradation cracking.

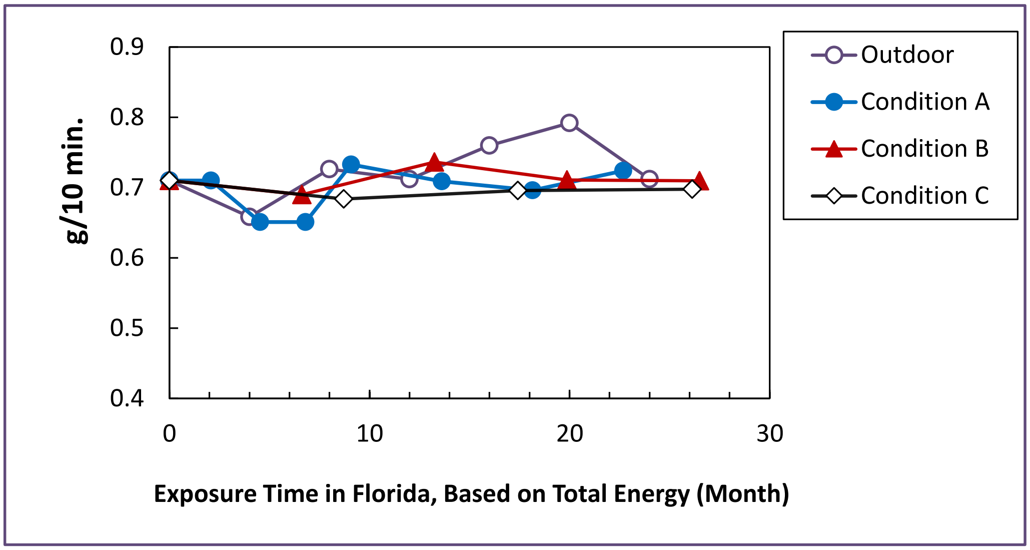


Figure 5-21 – Comparing MI values under four exposure conditions based on Florida exposure time

5.5.3 Oxidative induction time (OIT) test

The focus of the comparison between xenon and outdoor exposure is on the surface layer of the exposed coupon because it exhibited the greatest decrease in the OIT retained percentage under all of the exposure conditions, Figure 5-22 shows a comparison of the changes of OIT retained percentage with equivalent Florida time in four exposure conditions. The decreasing rates of OIT retained percentages in four conditions are relatively similar. The OIT dropped to the range of 5 to 15% after 12 months Florida time. For xenon exposed coupons, the OIT percentage decreased to less than 5%, while the outdoor coupon reached to 10%.

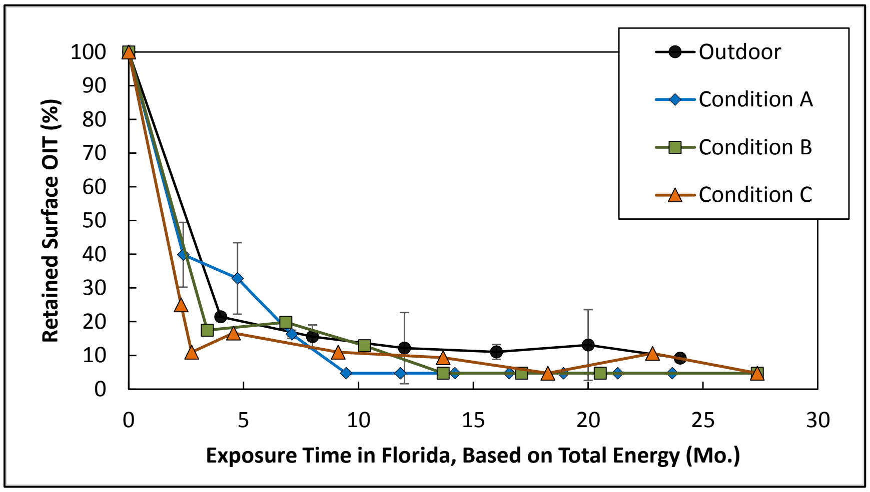


Figure 5-22 – Comparing the average OIT retained percentage of the surface layers under four exposure conditions based on Florida time.

5.5.4 Tensile test

The comparison of tensile property focuses on the break strain which has the greatest impact from the sunlight. Figure 5-23 shows a graph plotting the average values of tensile break strain versus equivalent Florida time. There is a large variation in the break strain values for most of the exposure conditions, except Condition [B] in which consistently low break strain values were obtained throughout the test duration even after 500 hours machine time (or about 3.5 Florida time). The break strain is extremely sensitive to the surface cracking which observed in coupons exposed to 3,000 hours in Condition [C] and 24-months of outdoor condition. However, cracking was not observed on coupons exposed to Condition [B] throughout the 3,000 hours experimental time. Therefore, the low break strain values measured from coupons in Condition [B] are likely caused by the defects in the material not the sunlight degradation.

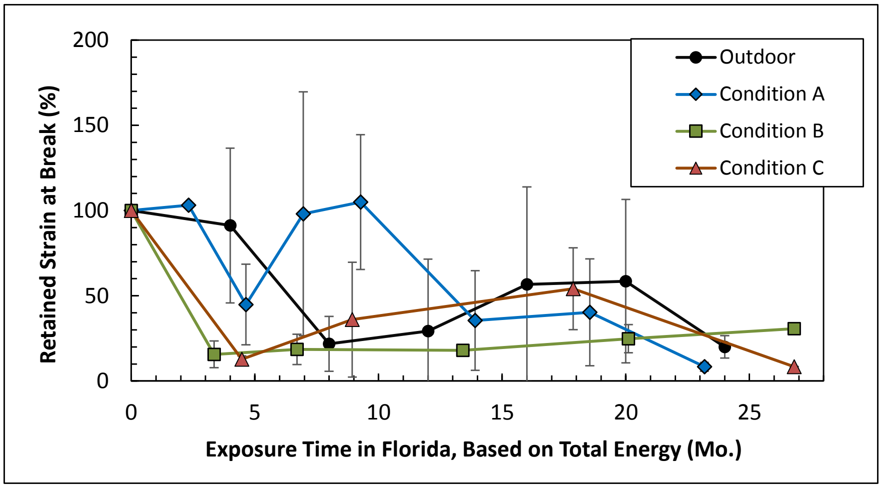


Figure 5-23 – Comparing tensile break strain of four different exposure conditions based on Florida exposure time

5.5.5 Summary

Table 5-4 lists the time to reach the critical value for OIT and tensile break strain, and the appearance of surface cracking. The critical value of 20% OIT retrained is selected because this corresponds to 2 minutes OIT value which was minimum value set for HDPE corrugated pipe in Florida material specification. The critical value for tensile break strain is 50% which is commonly referred as the half-life of the material. Based on the data shown in Table 5-4, the OIT retained values exhibited consistent changes in the three xenon test conditions; the time to reach critical value is invert proportional to the intensity of the irradiance. In contrast, the tensile break strain varies greatly under different exposure conditions.

Table 5-4 – Time to Reach Critical Value for OIT, Tensile Break Strain, and Surface Cracking

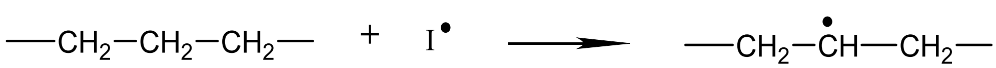
Exposure Conditions	Time to reach < 20% OIT retained on the surface layer	Time to reach < 50% tensile break strain	Surface Cracking
Condition [A]	1,500 hr. (6.8 months, FL)	3,000 hr. (14 months, FL)	4,000 hr.
Condition [B]	1,000 hr. (6.6 months, FL)	500 hr. (3.4 months, FL)	4,000 hr.
Condition [C]	500 hr. (4.4 months, FL)	500 hr. (4.4 months, FL)	3,000 hr.
Outdoor, FL	8 months	8 months	8 months

5.6 Degradation Mechanism for HDPE Structural Plastics

Degradation of polyethylene (PE) due to photo-oxidation proceeds by a series of free radical chain reactions (Grassie and Scott, 1985; Hamid, 2000). This process may be initiated by one the following:

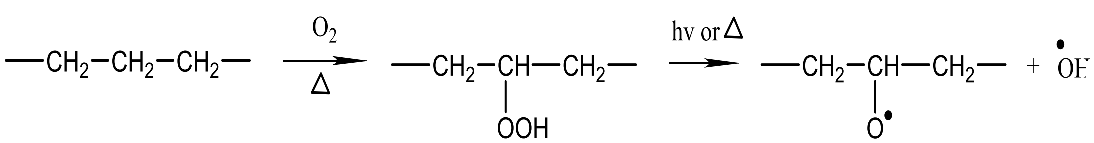
i) Presence of initiator:

Solar radiation cannot be absorbed by polyethylene structure. Also, it does not have enough energy to disrupt C-C or C-H bonds of polyethylene. The presence of an initiator (oxygen), can lead to formation of free radicals under exposure to solar radiation (Geuskens.1984; Torikai, 1986).



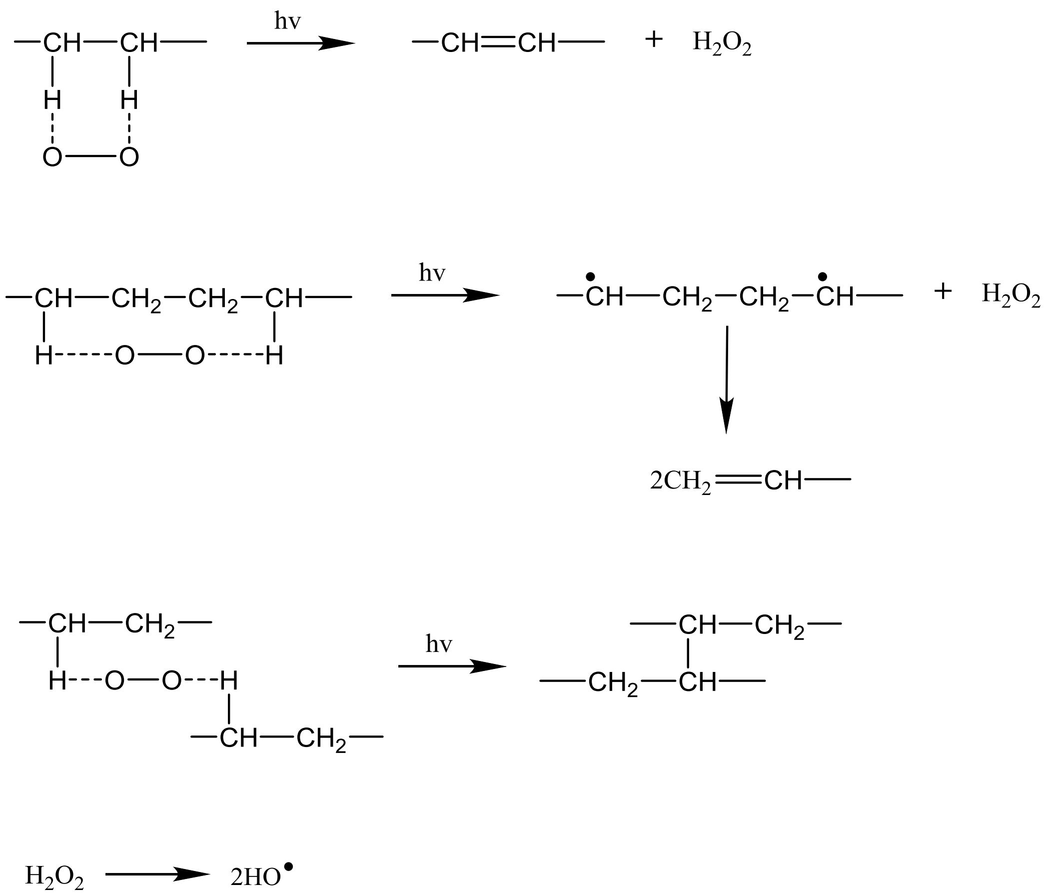
ii) Presence of hydroperoxides:

Thermal degradation can form hydroperoxides, which can lead to production of radicals. These radicals can cause cross-linking or chain scission.



iii) Formation of charge-transfer complexes with oxygen:

Oxygen charge-transfer processes have not been identified yet. Therefore, they could be regarded as hypothetical processes that can explain the changes in polymers. The following reactions show the formation of charge-transfer complexes:



One of the above-mentioned initiation steps may produce two free radicals. The succeeding processes produce other compounds containing hydroxyl, carbonyl, and vinyl groups. These compounds will also absorb photo-radiation and undergo changes that will lead to further degradation.

In commercially available polyethylene products, such as the Bedford product tested in this project, stabilizer and carbon black have been incorporated into the polymer. The purpose of stabilizers is to protect PE from thermal degradation during the extrusion processing as well as from oxidation degradation during the service life. Carbon black is mainly to protect the product from sunlight degradation by converting the photon energy to heat through absorption and scattering mechanisms (Hawkins, et al. 1959; Kovacs and Wolkober 1976; Margolin, et al. 1985; Mwila, et al. 1994; Wong, et al. 2012).

Figure 5-24 shows the schematic diagram that illustrated the effect of stabilizer the oxidation degradation of PE (Hsuan and Koerner, 1998). A similar effect also applies to the photo-degradation, because both degradations are based on the same free radical oxidation mechanism. The stabilizer (typically comprising antioxidants) sacrificially reacts with oxygen to prolong the service life of PE. Once the stabilizer is completely (or mostly) consumed by the oxidation reactions, the polymer starts to degrade. Therefore, determining the depletion rate of stabilizer in PE can predict the onset of the polymer degradation (Hsuan and Wong, 2010).

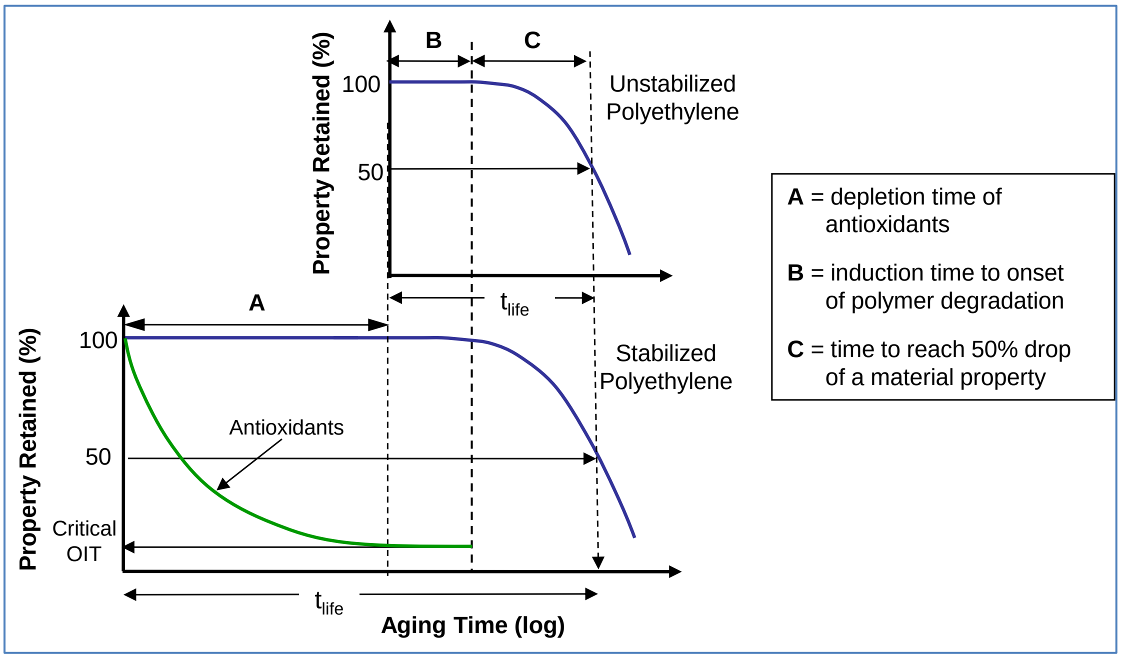


Figure 5-24 – Three stages of degradation of a stabilized PE

In this study, OIT was used to determine the depletion rate of stabilizer in the sunlight exposed PE samples. At the same time, the degradation of PE was assessed by the melt index test and tensile test. The test results of Bedford product confirmed that PE started to degrade as the OIT value reached a minimum time value at approximately 2.0 minute, at which the tensile break strain began to decrease rapidly. Although FTIR spectrophotometer can be used to measure the formation of carbonyl groups generated from the oxidation degradation of polyethylene, the high IR absorption of carbon black makes it difficult to detect carbonyl peaks.

5.7 Test Protocol for HDPE Structural Plastics

The test protocol for HDPE structural product is based on the test results of the Bedford product. The test protocol includes exposure condition in a xenon weatherometer and test methods for the exposed coupons.

For Structural Plastics, FDOT Section 973 specifies the product acceptance and materials. The plastic materials properties requirement is listed in the table 1 of the document. The ultraviolet property is specified using ASTM D4329 with UVA lamp. The exposure time is 500 hours and the reduction in Shore D durometer hardness must be less than 10%. Although Section 973-3 states that "*Mix the plastic with appropriate colorants, UV inhibitors, hindered amine light stabilizers and antioxidants so that the resulting product meets the material property requirements specified in Tables 1 and 2.*", there is no test specified to assess the stabilizers before and after the UV exposure of the plastic.

Four test methods, digital light microscope, OIT, MI, and tensile test were used to evaluate the original and exposed HDPE samples. The OIT test was found to provide the most meaningful result, showing a consistent change with exposure time for all test conditions. The tensile break strain can be a good indicator for the deterioration in mechanical property of the product samples, but it is extremely sensitive to the cracking that was resulted from the sunlight degradation. Furthermore, the surface degradation cracking took place locally, a large variation in tensile break strain was obtained. Therefore, it is difficult to draw a conclusive decision. The surface morphology examination is good method to verify the cause for the decrease of tensile break strain. However, it is a time-consuming process to exam the entire surface at different magnifications.

5.7.1 Recommended test protocol for xenon weatherometer test

(a) Test sample

Test sample should be prepared from the exterior skin of the product. The dimensions of the sample should be chosen so that it could firmly fix in the sample holder or onto the sample rack using clamps. The thickness of the test samples may vary with the product, but it must be consistent with an accuracy of ± 5% of the nominal thickness

.

(b) Xenon test condition

The recommended weatherometer is ATLAS Ci-4000 equipped with a xenon lamp and inner and outer borosilicate filters. The exposure condition should be set according to ASTM D 2565 “Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications”. The test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C. The irradiance for the test standard is recommendation to be 41.5 ± 2.5 W/m^2 from 300- to 400-nm. Two higher irradiance levels at 60 ± 2.5 W/m^2 and 80 ± 2.5 W/m^2 from 300- to 400-nm were also tested in this project so that the sunlight degradation can be further accelerated, shortening the exposure time.

Based on OIT test data, the Condition [C] exhibited a greater rate of decrease than Condition [A] and [B] for all layers. This suggests that the irradiance used in Condition [C] is much severe than [A] and [B], and penetrated deeper into the exposed test coupons. This deep penetration was not detected in the outdoor-exposed coupons (see Figure 5-15). Therefor Condition [C] is not appropriate to be used to simulate the outdoor sunlight in Florida State. Between Conditions [A] and [B], the latter one will induce faster reaction rate and shorter the testing time; thus, it is more desired to be used for quality control test.

(c) <u>Material properties</u>

As indicated in Table 5-4, the OIT test provides consistent changes in all exposure conditions. Therefore, OIT test should be included in the material specification to ensure appropriate and sufficient stabilizers included in the HDPE product.

The initial OIT value is a critical material property to assure the sunlight performance of the HDPE product. However it is also essential to assess the depletion rate by testing the OIT retained percentage after a given exposure time to ensure the performance of the stabilizer.

(d) <u>Recommended test protocol</u>

The HDPE structural plastic products shall be tested for sunlight degradation resistance according to the following procedure:

- The initial OIT value of the HDPE structural product shall be defined for an anticipated service life.
- The HDPE structural product shall be tested for sunlight degradation resistance according to the following procedure:

- Test the product according to ASTM D2565 “Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications”. The test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C. The irradiance for the test standard is recommended to be 60 ± 2.5 W/m^2 from 300- to 400-nm.
- Xenon lamp should be equipped with inner and outer borosilicate filters.
- The exposure duration is 500 hours.
- Prepare test coupon with thickness of 0.1 ± 0.05 inch.
- Remove two small specimens from the exposed coupon. The dimension of the sample is approximately 0.25 inch x 0.25 inch.
- Use a single edge razor blade to remove a surface layer with thickness of 0.015 ± 0.005 inch from each of the 0.25 inch x 0.25 inch specimens.
- Perform OIT test (ASTM D3895) on the two surface layers. Two replicates should be tested for each surface layer. The average OIT value must be equal or greater than a certain value.

CHAPTER 6 – DISABILITY WARNING SURFACE (DWS) PRODUCTS

This chapter describes the effect of sunlight on five DWS products by exposing samples in the xenon weatherometer and outdoor condition.

6.1 Test Coupons

There are five (5) types of ADA samples, and each type comes in three (3) colors which results in fifteen (15) samples. Table 4-7 provides a summary of different incubation methods, different conditions, and the number of variations in each condition. Test coupons were cut from the sample product. All of the coupons have the same length of 6-inch, but the width of the coupon varies between products due to surface texture pattern (as indicated in Table 6-1). Test coupons of each product sample consists of the same surface texture pattern.

Table 6-1 – Dimensions of Product Samples and Test Coupons

Company	Product	Polymer Type	Sample Dimensions	Coupon Dimensions
ADA Solutions, Inc.	ADA Solutions	Polyester	48” × 24”	1.5” × 6”
Cape Fear Systems	Alert Cast	Polyester (NPG)	24” ×35”	1. × 6”
Detectable W.S.	Redimat	Polyurethane	24” ×48”	1.25” × 6”
SafeRoute	SafeRoute Tile	Polyolefin	24” ×48”	1.25” × 6”
Engineered Plastics	Armor Tile	Epoxy	24” ×24”	1.25” × 6”

6.2 Test Results from Xenon Weatherometer

Table 6-2 shows the test methods which are used to evaluate the exposed DWS coupons. The nondestructive tests will be carried out every 500-hr while the destructive test will be performed every 1,000 hr. The exposure durations for Conditions [A], [B], and [C] are the same, 3,000 hours.

Table 6-2 – Test Methods Used to Evaluate the Sunlight Exposed DWS Coupons

Type of Test	Test Method	ASTM Standard	Purpose of Test
Nondestructive tests	Light microscopy	None	Surface morphology (cracking)
	Color measurement	None	ΔE value
Destructive test	Abrasion test	None	Surface abrasion test

6.2.1 Surface morphology

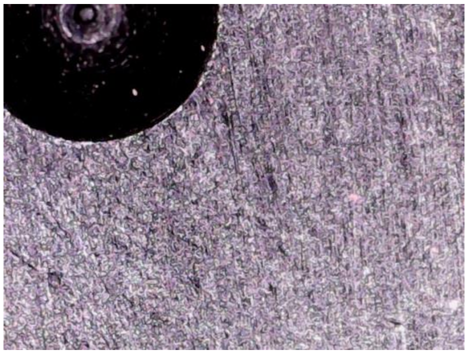
A Gaosuo digital microscope was used to examine the surface texture and to trace the cracking on the exposed coupons. Microscopic pictures at a magnification of 100x were taken from two locations (top and bottom) of each coupon at every 500 hours.

(a) ADA Solutions products (polyester)

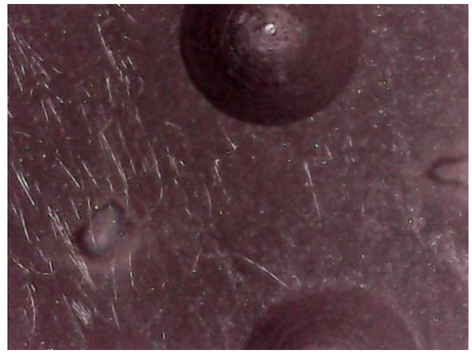
As revealed in Figure 6-1 and Appendix-I(a), water marks were observed on the surfaces of black and red coupons after 3,000 hr. in Condition [A], and 2,500 hr. in Condition [B] and [C]. The water marks on the yellow coupons were more difficult to be noticed due to the color contrast. A vague water mark can be seen around the circular pattern on the tested coupons after 3,000 hr. in Condition [C]. The circular patterns on the surface were also fading gradually with increasing in exposure time. The fading occurred earlier at higher irradiance levels.

(b) AlertCast products (polyester NPG)

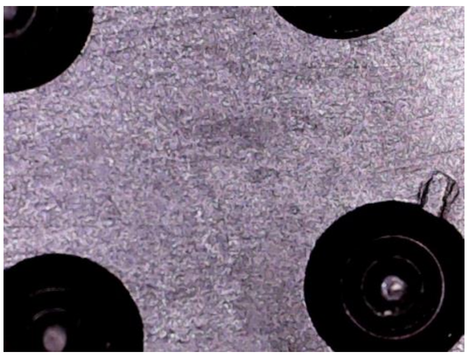
The changes in surface appearance of AlertCast coupons can be seen in Figure 6-2 and Appendix-I(b). The coral-shaped pattern with thick bounder line was clearly visible on the coupon's surface before 1,000 hours. As the exposure time increased, the patterns started to fade, and the thick bounder lines were thinning down. The fading occurred earlier at higher irradiance. Furthermore, reinforcing fibers became visible after 2000 hours in some of the exposed coupons, particularly in Condition [C] after 3,000 hours. This suggests that the surface degraded polymer was removed by the action of water spray during the wet cycles, revealing the imbedded fibers.



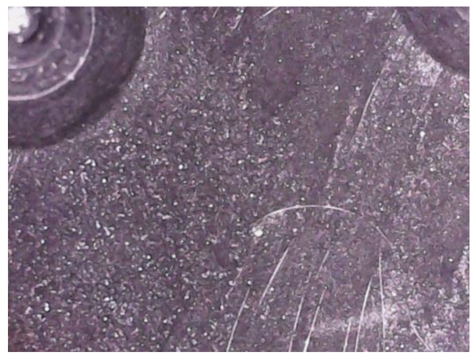
0-hr in Condition [A]



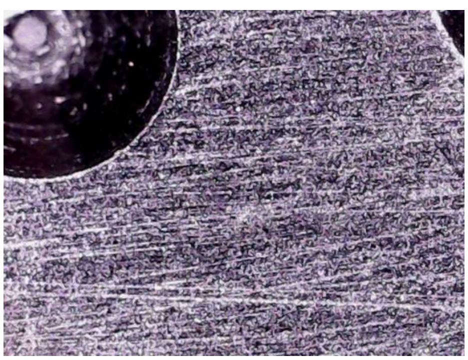
3,000-hr in Condition [A]



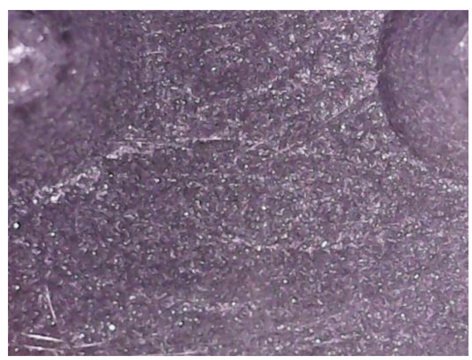
0-hr in Condition [B]



3,000-hr in Condition [B]

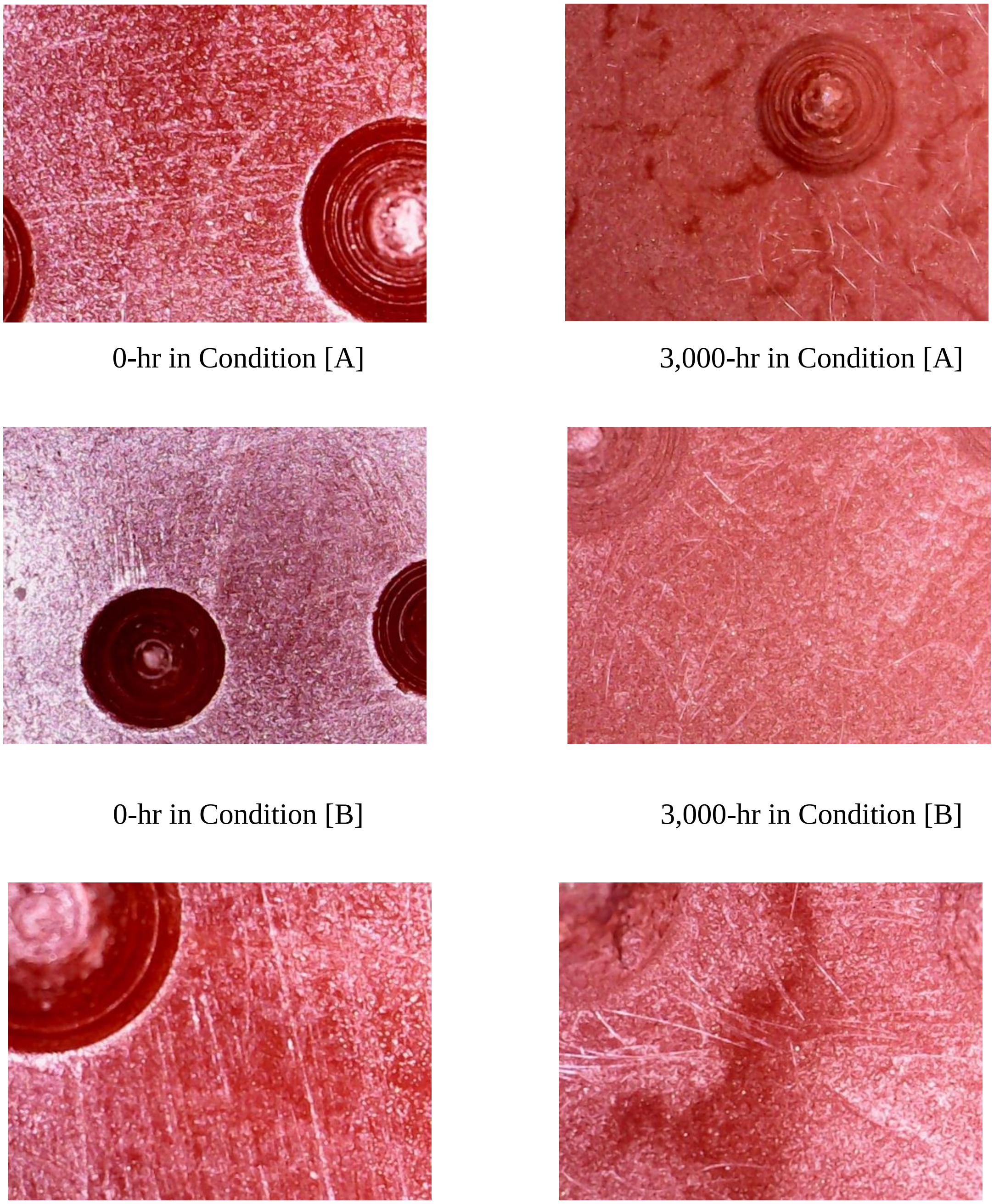


0-hr in Condition [C]



3,000-hr in Condition [C]

Figure 6-1 – Comparing surface appearance of ADA Solutions coupons under a light microscope at 100x between 0 and 3,000 hours of exposure



0-hr in Condition [A]

3,000-hr in Condition [A]

0-hr in Condition [B]

3,000-hr in Condition [B]

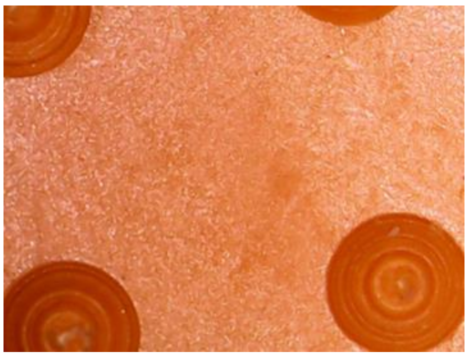
0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-1 – Continued

0-hr in Condition [A]

3,000-hr in Condition [A]



0-hr in Condition [B]

3,000-hr in Condition [B]

0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-1 – Continued

(c) Redimat products (polyurethane)

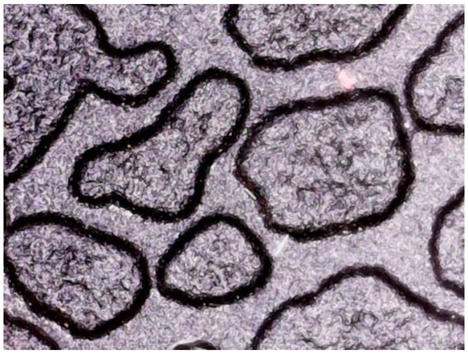
For Redimat coupons, the most noticeable change on the surface occurred between 0 and 500 hr, as can be seen in Figure 6-3 and Appendix-I(c). (The photographs of 500 hour black coupons was believed covered with degraded polymer (as can be seen in Figure 6-3(a).) so a photo of 1,000 hour was used.) The initially smooth surface with circular spots diminished drastically after 500 hours and vanished after 500 to 1,000 hours. At the same time, the reinforcing fibers became visible after 500 hours. After 1,500 hours, there was no significant changes on the surface appearance in any of the exposure conditions.

(d) SafeRoute products (polyolefin)

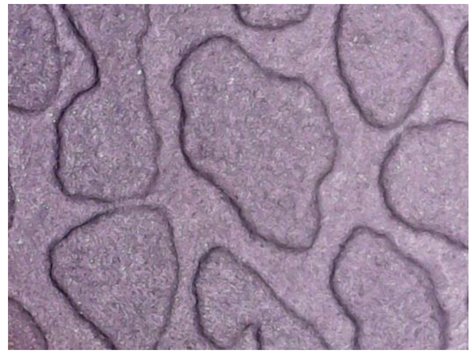
For SafeRoute coupons, the most noticeable change in surface appearance was the appearing of white chalky particles, particularly at high irradiance levels (*i.e.*, Condition [B] and [C]), as shown in Figure 6-4, Appendix-I(d). Similar observation was reported by other researchers on some polyethylene products. Their suggestion was that polymer fragments have been washed out from the surface by water, exposing pigments and/or fillers which appeared as a chalky which material on the surface [2-5]. This chalky material led to a significant change of colors of the products (see color change section of the report).

(e) Armor-Tile products (epoxy)

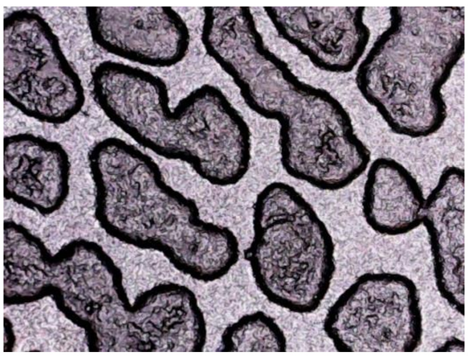
As revealed in Figure 6-5 and Appendix-I(e), water marks were observed on the surfaces of black, red and yellow coupons after 3,000 hr. in Condition [A], [B] and [C]. The water marks on the yellow coupons were more difficult to be noticed due to the color contrast. A trace of water mark can be seen around the circular pattern on tested coupons after 3,000 hr in Condition [C]. The circular patterns on the surface were also fading gradually with increasing exposure time. The fading was clearly observed for the red coupon in Condition [C] after 3,000 hr.



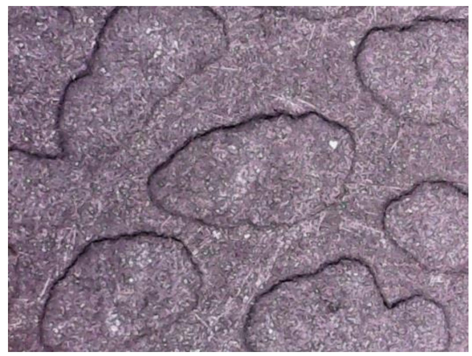
0-hr in Condition [A]



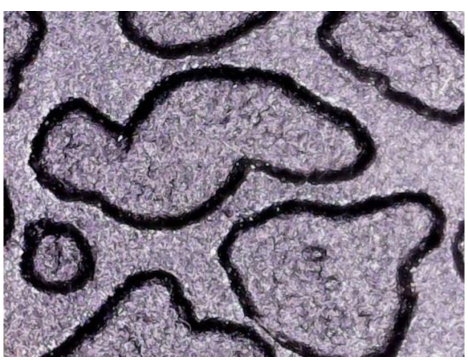
3,000-hr in Condition [A]



0-hr in Condition [B]



3,000-hr in Condition [B]



0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-2 – Comparing surface appearance of AlertCast coupons under a light microscope at 100x between 0 and 3,000 hours of exposure

0-hr in Condition [A]

3,000-hr in Condition [A]

0-hr in Condition [B]

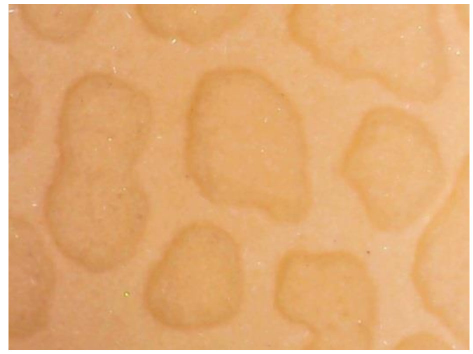
3,000-hr in Condition [B]

0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-2 – Continued

0-hr in Condition [A]



3,000-hr in Condition [A]

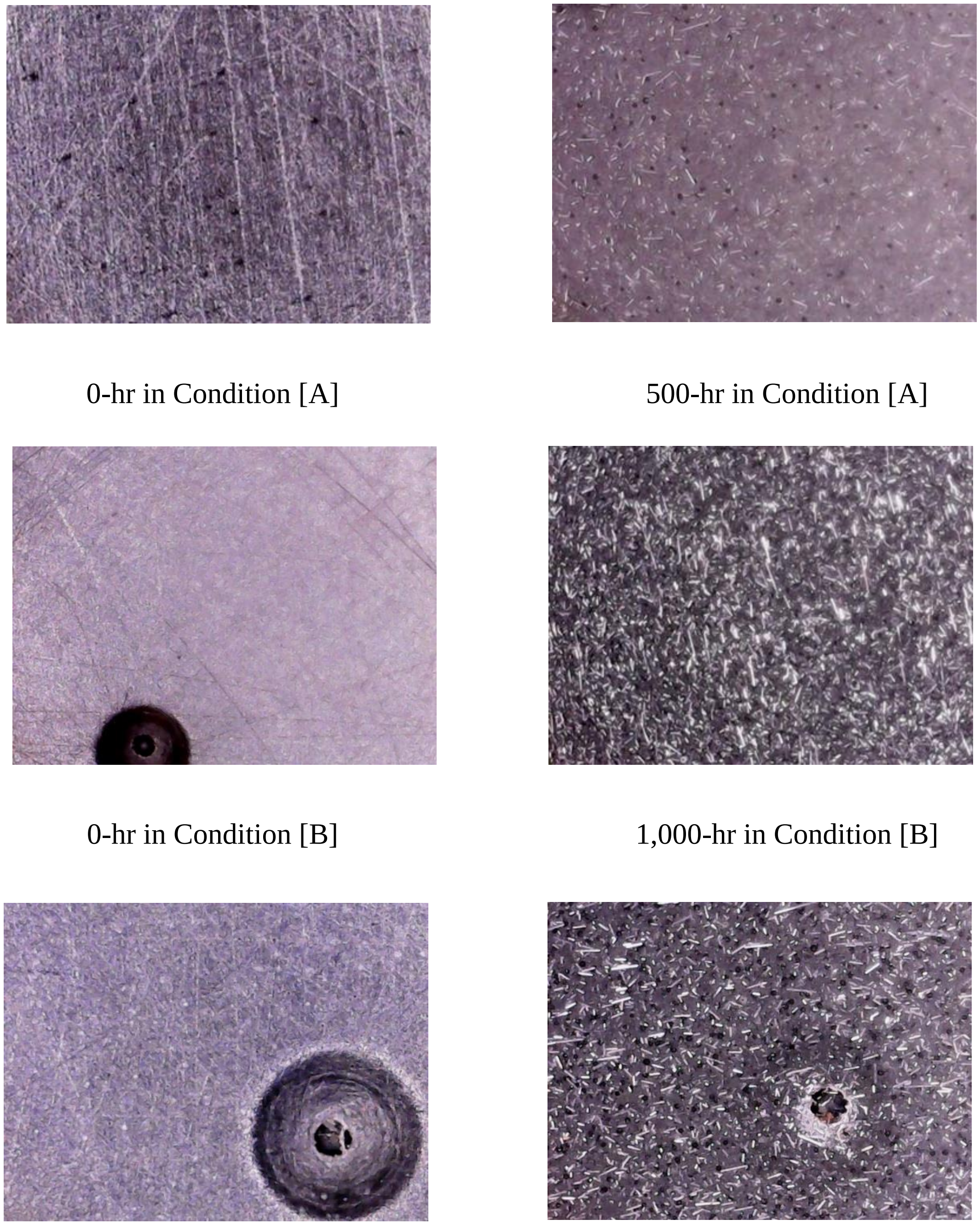
0-hr in Condition [B]

3,000-hr in Condition [B]

0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-2 – Continued



0-hr in Condition [A]

500-hr in Condition [A]

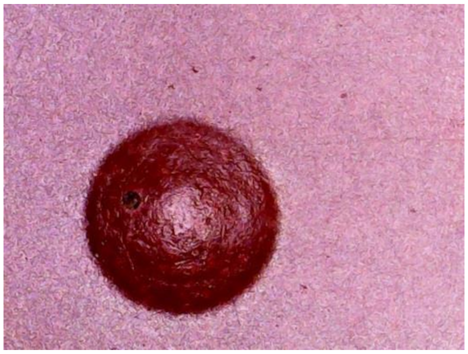
0-hr in Condition [B]

1,000-hr in Condition [B]

0-hr in Condition [C]

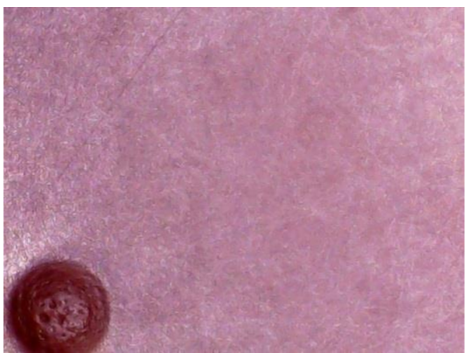
500-hr in Condition [C]

Figure 6-3 – Comparing surface appearance of Redimat coupons under a light microscope at 100x between 0 and 500 hours of exposure

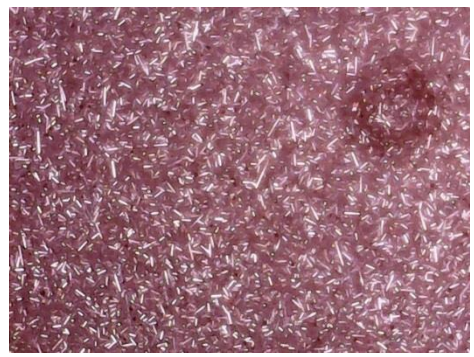


0-hr in Condition [A]

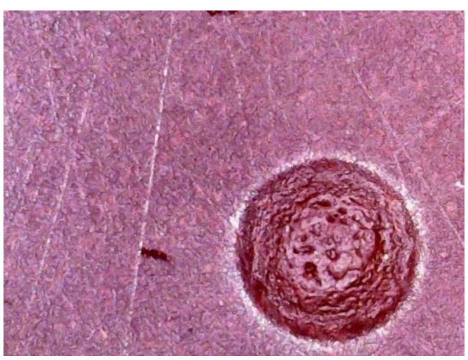
500-hr in Condition [A]



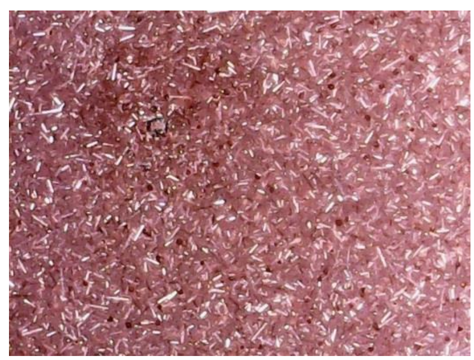
0-hr in Condition [B]



500-hr in Condition [B]



0-hr in Condition [C]

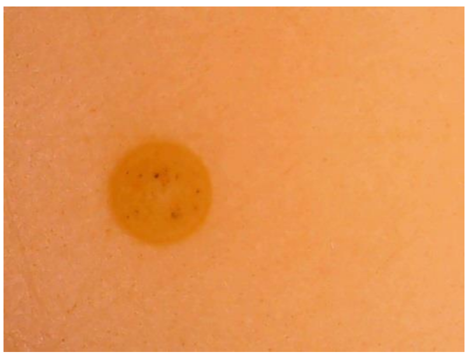


500-hr in Condition [C]

Figure 6-3 – Continued

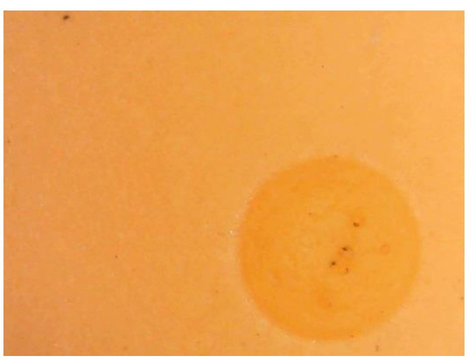
0-hr in Condition [A]

500-hr in Condition [A]



0-hr in Condition [B]

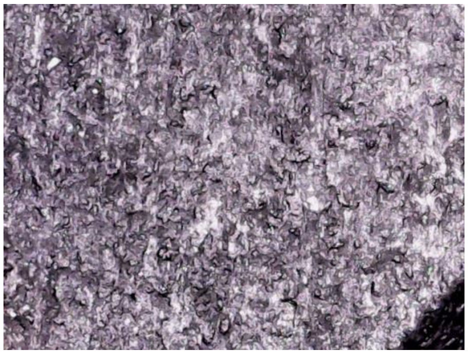
500-hr in Condition [B]



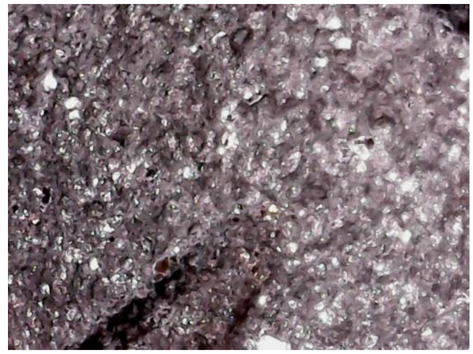
0-hr in Condition [C]

500-hr in Condition [C]

Figure 6-3 – Continued

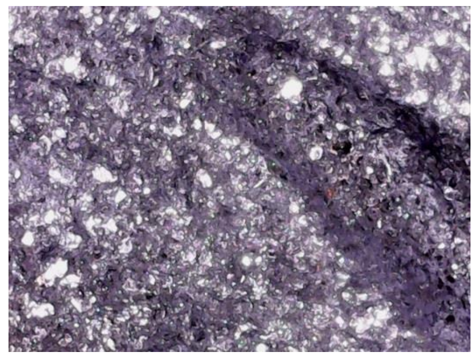


0-hr in Condition [A]

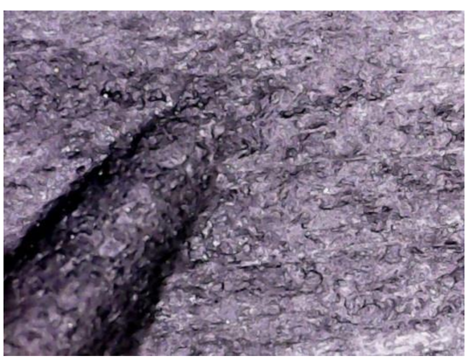


3,000-hr in Condition [A]

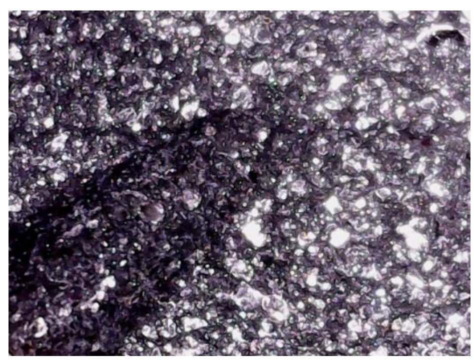
0-hr in Condition [B]



3,000-hr in Condition [B]

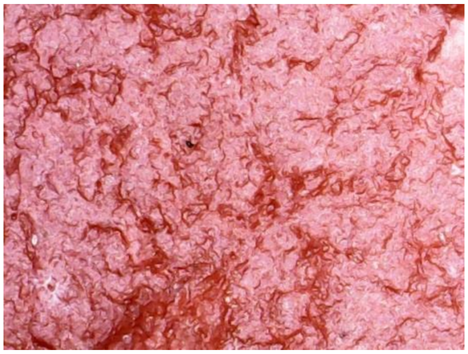


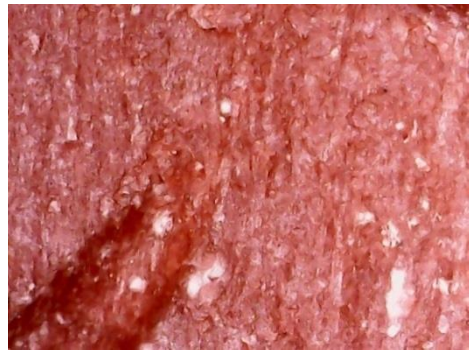
0-hr in Condition [C]



3,000-hr in Condition [C]

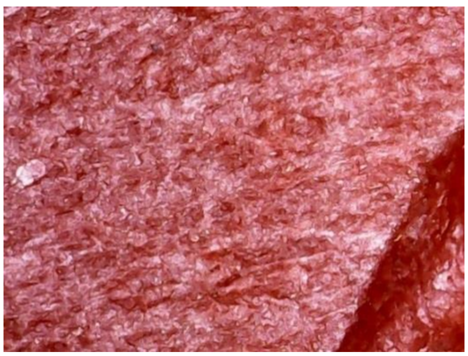
Figure 6-4 – Comparing surface appearance of SafeRoute coupons under a light microscope at 100x between 0 and 3,000 hours exposure

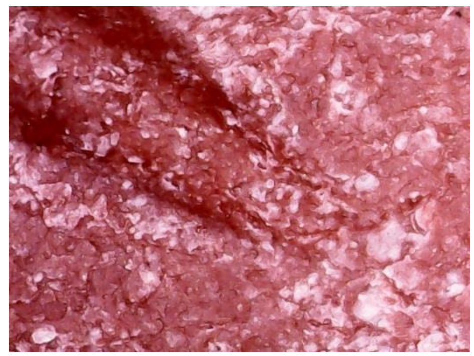




0-hr in Condition [A]

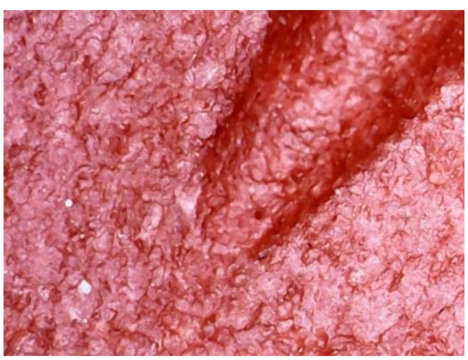
3,000-hr in Condition [A]

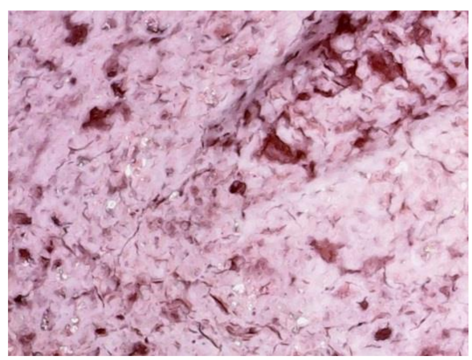




0-hr in Condition [B]

3,000-hr in Condition [B]





0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-4 – Continued

0-hr in Condition [A]

3,000-hr in Condition [A]

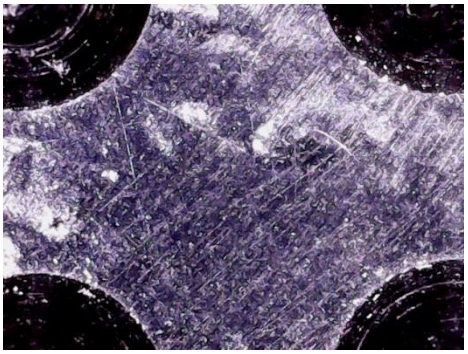
0-hr in Condition [B]

3,000-hr in Condition [B]

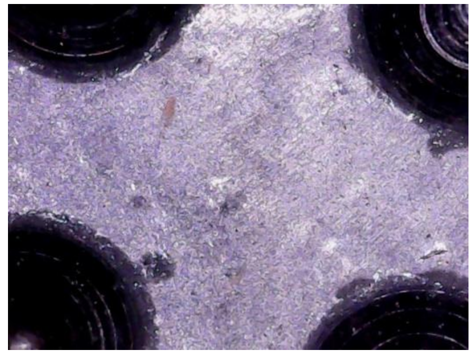
0-hr in Condition [C]

3,000-hr in Condition [C]

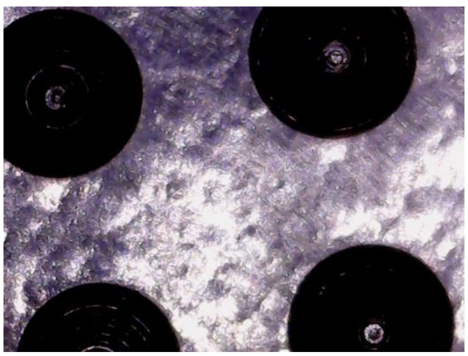
Figure 6-4 – Continued



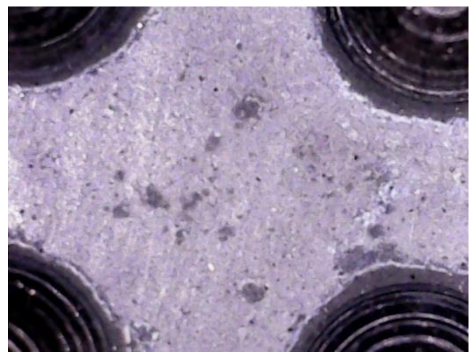
0-hr in Condition [A]



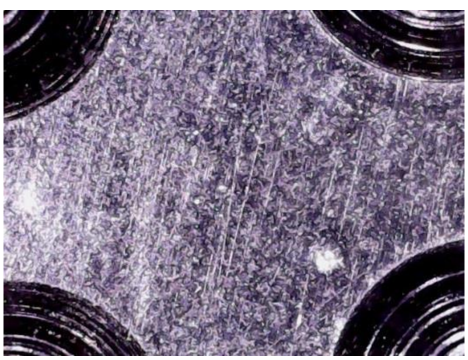
3,000-hr in Condition [A]



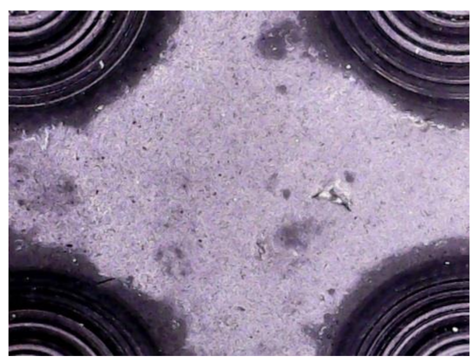
0-hr in Condition [B]



3,000-hr in Condition [B]

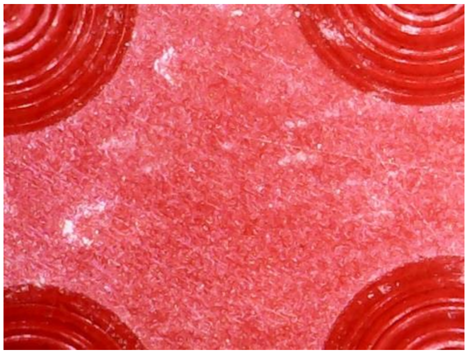


0-hr in Condition [C]



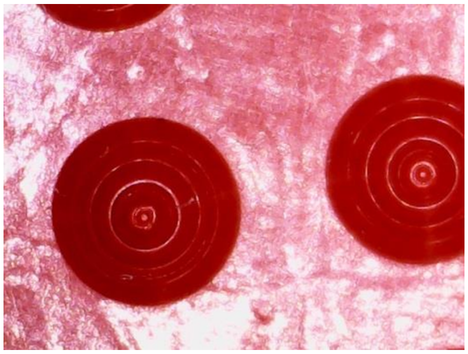
3,000-hr in Condition [C]

Figure 6-5 – Comparing surface appearance of Armor-Tile coupons under a light microscope at 100x between 0 and 3,000 hours of exposure



0-hr in Condition [A]

3,000-hr in Condition [A]



0-hr in Condition [B]

3,000-hr in Condition [B]

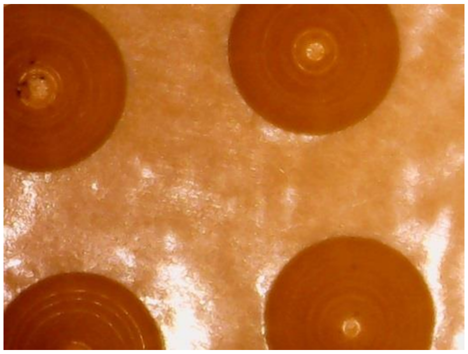
0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-5 – Continued

0-hr in Condition [A]

3,000-hr in Condition [A]



0-hr in Condition [B]

3,000-hr in Condition [B]

0-hr in Condition [C]

3,000-hr in Condition [C]

Figure 6-5 – Continued

6.2.2 Color measurement

The color of DWS coupons was measured by using a spectrocolorimeter (X-rite RM200QC), as shown in Figure 6-6. The device uses multiple sensors to determine color parameters (light variable and chromaticity values) required for calculating ΔE (see Equation 6-1), which is a parameter used to express the color change quantitatively.

$$\Delta E = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2) \quad (6\text{-}1)$$

where;
L*= Lightness variable
a* and b* = Chromaticity values

Three coupons from each sample were designated for this nondestructive test. Three locations (top, middle, and bottom) were marked on each coupon, and color reading was performed at each location. A total of nine readings were obtained for each sample at every 500 hours of exposure time. The test data of the color measurement are included as Appendix-J with this report.

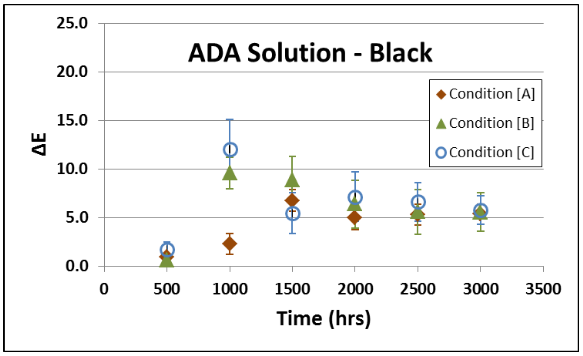
Figure 6-6 – The colorimeter device used to measure the surface color on DWS coupons

(a) ADA Solutions products (polyester)

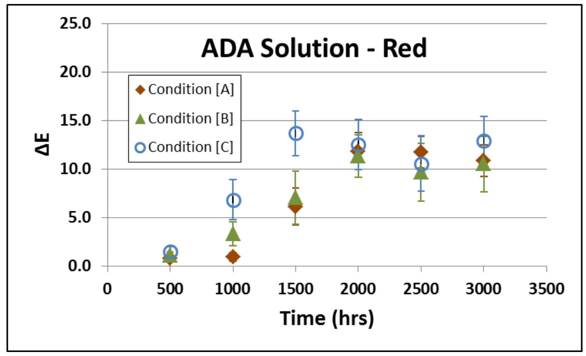
Figure 6-7(a), (b), and (c) shows plots of ΔE versus exposure time for Conditions [A], [B], and [C] for black, red, and yellow coupons. In general, the ΔE value increased with exposure time initially and then leveled out for the black and red colors under all three exposure conditions. The black color reached the maximum ΔE value in Condition [A] at 1,500 hr. and at 1,000 hr. in Conditions [B] and [C]. For the red color, the ΔE value gradually increased to 2000 hr. and then remained almost constant in Conditions [A] and [B], while coupons in Condition [C] reached the maximum ΔE value at 1,500 hr. For the yellow color, the maximum ΔE value in Condition [B] was measured at 2000 hr. In contrast, the ΔE values in Condition [A] and [C] were still increasing, but at a slower rate, after 2,500 hr. and 1,500 hr., respectively. Overall, the black color exhibited the smallest change of ΔE, while the yellow color showed the most change in all three exposure conditions.

(b) AlertCast products (polyester, NPG)

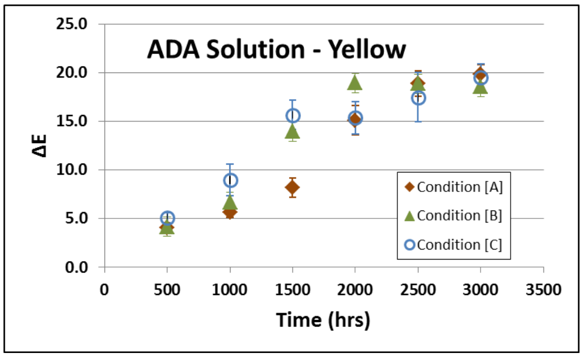
Figure 6-8 (a), (b), and (c) shows plots of ΔE versus exposure time for Conditions [A], [B], and [C] for black, red, and yellow coupons. For the black coupons, the greatest color change was measured in Condition [C]. On the other hand, the color changes in red and yellow coupons were less sensitive to the irradiance levels. The ΔE values steadily increased with exposure time (Fig. 6-8(d)) for all three colors in Condition [A], while the ΔE values in Condition [B] were leveling out after the maximum values, which were measured at 2,500 hr. for the black and 2,000 hr. for the red and yellow (Fig. 6-8(e)). In Condition [C], the ΔE values were essentially unchanged after 2,000 hours (Fig. 6-8(f)) in all three colors. Similarly, to the ADA Solutions products, the black color exhibited the smallest changes of ΔE, whereas the yellow color showed the greatest change in all three exposure conditions.



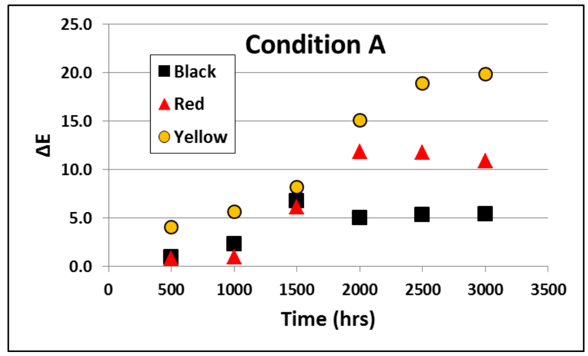
(a) ADA Solutions – Black



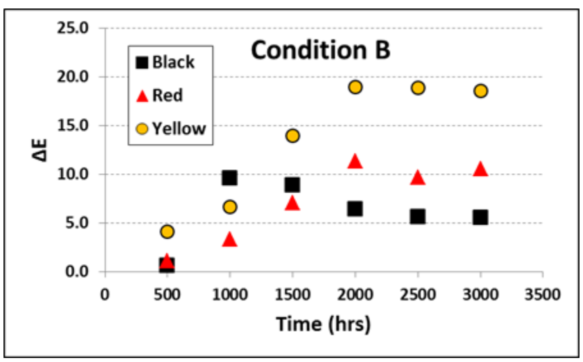
(b) ADA Solutions – Red



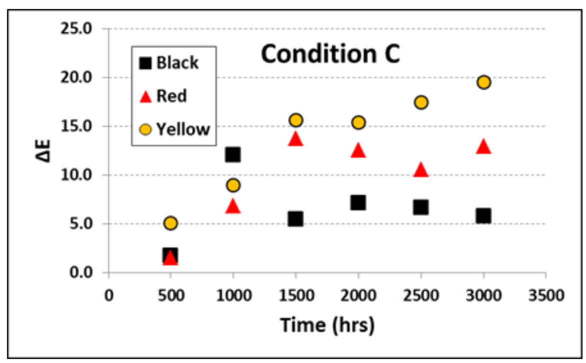
(c) ADA Solutions – Yellow



(d) All colors in Condition [A]

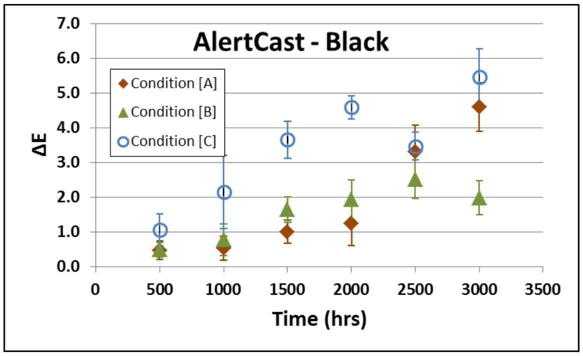


(e) All colors in Condition [B]

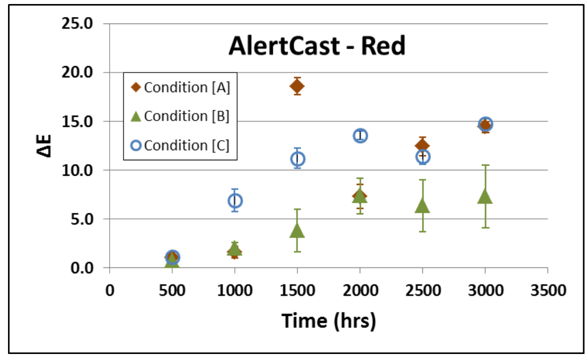


(f) All colors in Condition [C]

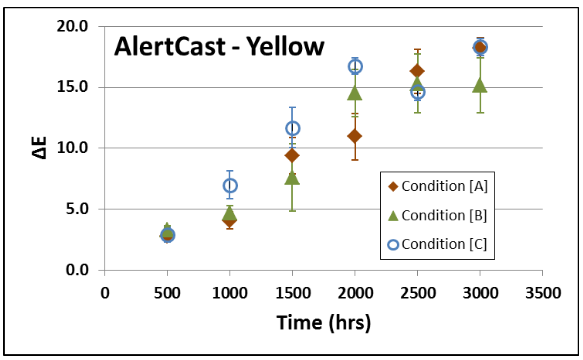
Figure 6-7 – Color change (ΔE) with exposure time for ADA Solutions coupons



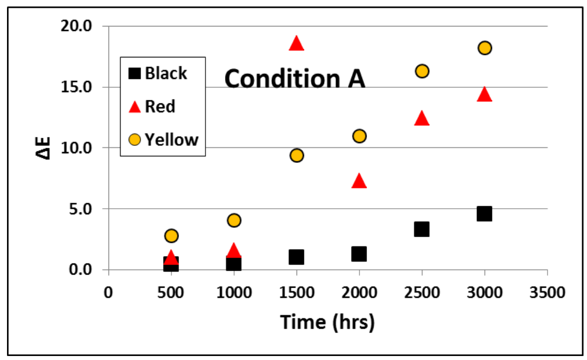
(a) AlertCast – Black



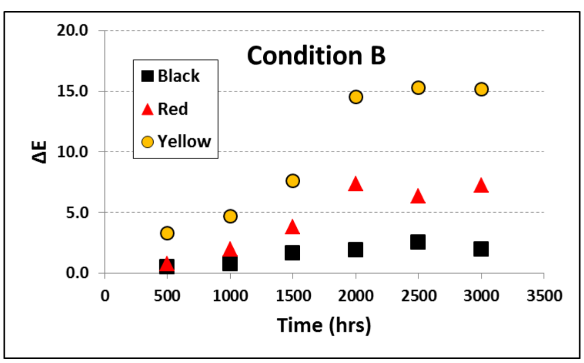
(b) AlertCast – Red



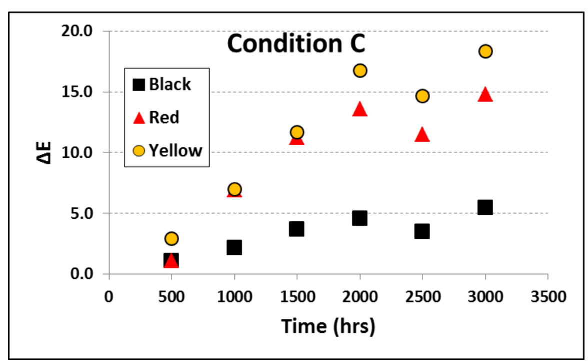
(c) AlertCast – Yellow



(d) All colors in Condition [A]



(e) All colors in Condition [B]



(f) All colors in Condition [C]

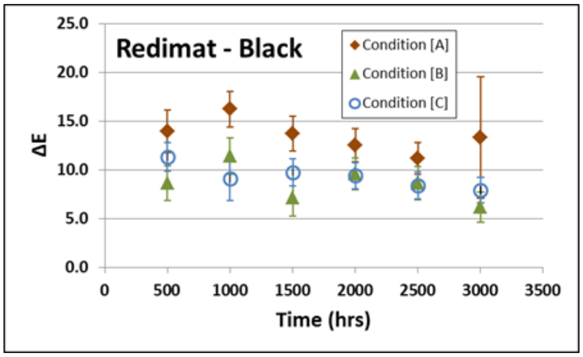
Figure 6-8 – Color change (ΔE) with exposure time for AlertCast coupons

(c) Redimat products (polyurethane)

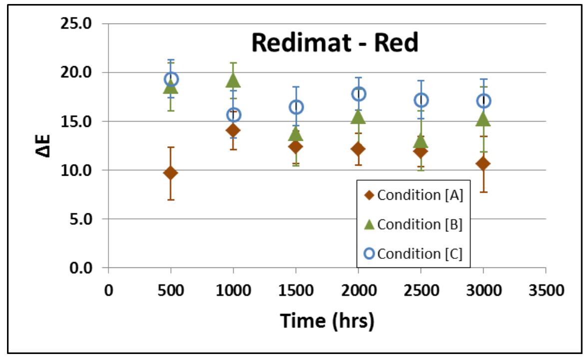
Figure 6-9(a), (b), and (c) shows ΔE versus exposure time for Conditions [A], [B], and [C] for black, red, and yellow coupons. In all three colors, the greatest increase in ΔE was measured between 0 and 500 hr., after that the ΔE values remained relatively constant throughout the rest of exposure time. Recalled Figure 6-3, the photographs revealed a notable change on the surface appearance between 0 and 500 hours. Reinforcing fibers were clearly observed on the surfaces of 500 hr. coupons. The change of ΔE values agrees with the surface appearance. The greatest ΔE increase was measured in the yellow color followed by the red and then the black.

(d) SafeRoute products (polyolefin)

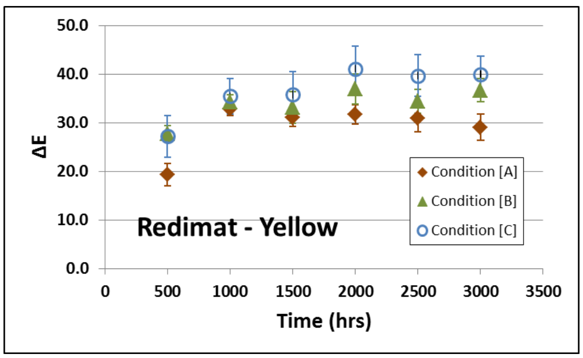
Figure 6-10(a), (b), and (c) shows ΔE versus exposure time for Conditions [A], [B], and [C] for black, red, and yellow coupons. For the black coupons, ΔE increased with exposure time up to 2,000 hr. after which it leveled off or decreased slightly (Fig. 6-10(a)). On the other hand, ΔE increased continuously with the exposure time for the red and yellow coupons (Fig. 6-10(b) and (c)). In Condition [A] and [B] (Figure 6-10(d) and (e)), the black coupons showed a higher ΔE change than the red and yellow coupons. The changing trends of ΔE in the yellow coupons were similar to those in the red. In Condition [C] (Figure 6-10(f)), the red coupons exhibited the greatest increase in ΔE and the increase can be correlated with the appearing of white particles on the surface which were observed after 1,000 hours and the amount increased with exposure time. At 3,000 hours, ΔE reached the highest value when the entire surface was covered with white particles. For black coupons, white particles were also observed after 2,000 hours in all three conditions, but the amount was not as much as in the red coupons. The white particles were observed on the surface of yellow coupons but not as much as on the red coupons



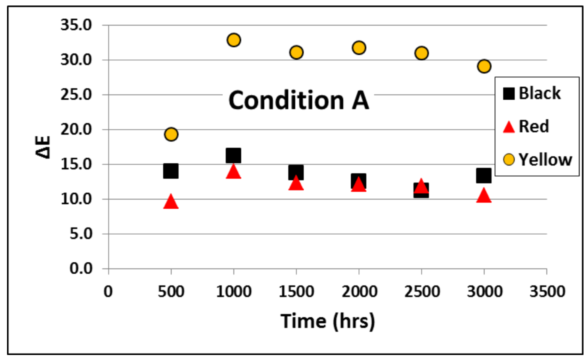
(a) Redimat – Black



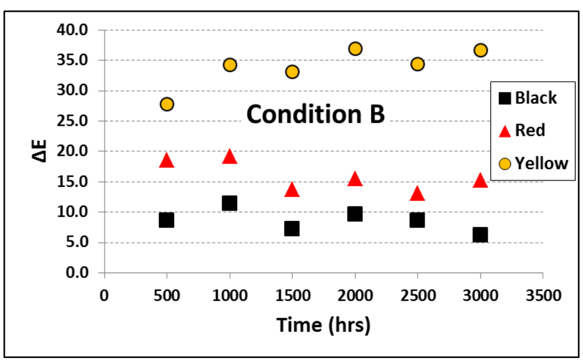
(b) Redimat – Red



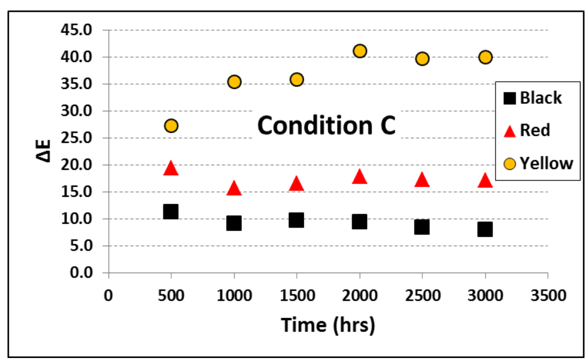
(c) Redimat – Yellow



(d) All colors in Condition [A]

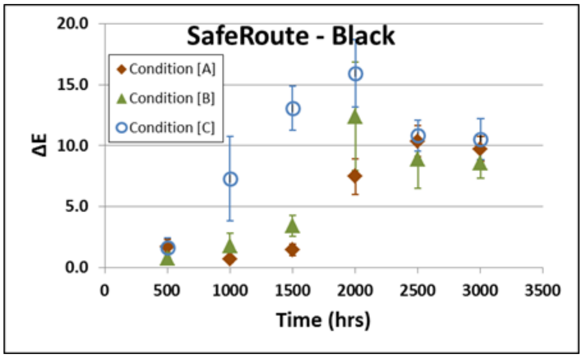


(e) All colors in Condition [B]

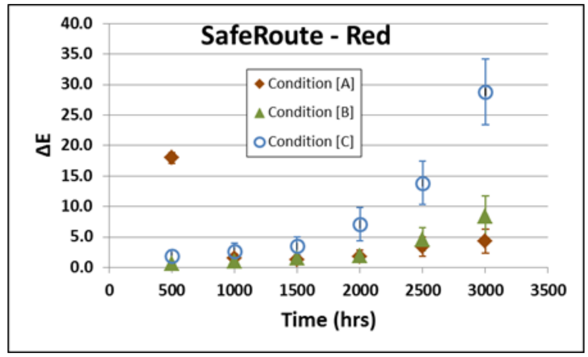


(f) All colors in Condition [C]

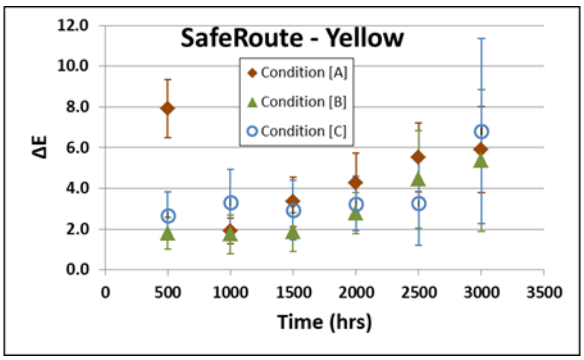
Figure 6-9 – Color change (ΔE) with exposure time for Redimat coupons



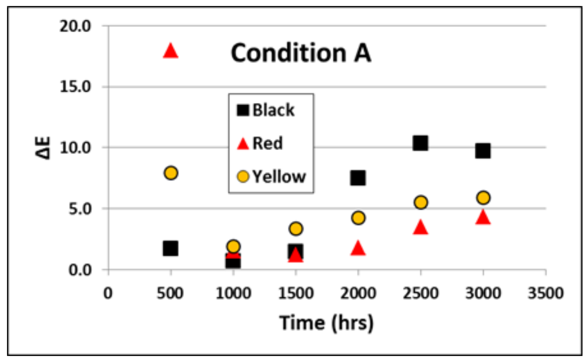
(a) SafeRoute - Black



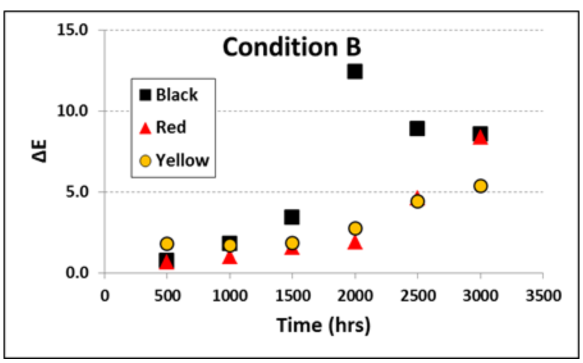
(b) SafeRoute – Red



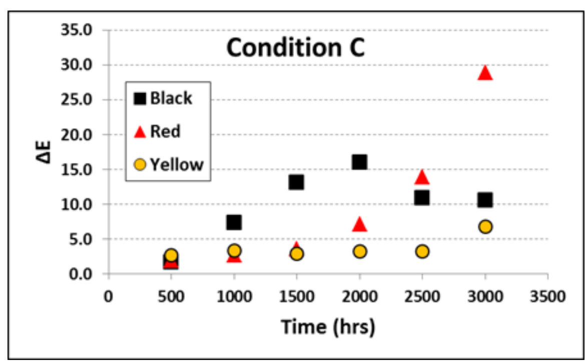
(c) SafeRoute – Yellow



(d) All colors in Condition [A]



(e) All colors in Condition [B]

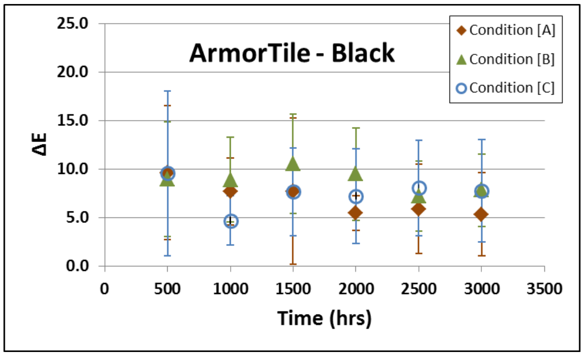


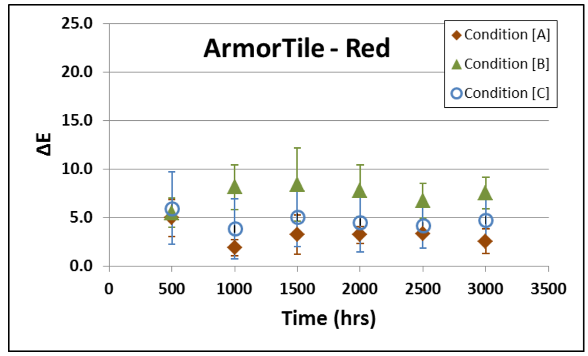
(f) All colors in Condition [C]

Figure 6-10 – Color change (ΔE) with exposure time for SafeRoute coupons

(e) Armor-Tile products (epoxy)

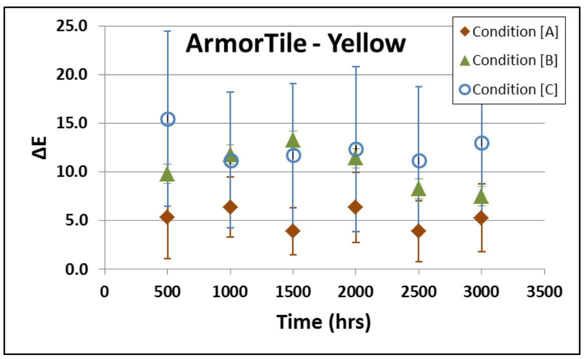
Figure 6-11(a), (b), and (c) shows plots of ΔE versus exposure time for Conditions [A], [B], and [C] for black, red, and yellow coupons. In all three colors, the greatest increase in ΔE was measured between 0 and 500 hours, after that the ΔE values remained relatively constant throughout the rest of exposure time. For black and red coupons, the greatest value of ΔE was measured in Condition [B] followed by Condition [C]. For yellow coupon, Condition [C] produced the greatest ΔE while Condition [A] caused the smallest change of the color. Figures 6-11(c), (d), and (e) display the change of ΔE for all three colors in each test condition. In Condition [A] and [B] (Figure 6-11(d) and (e)), the changing trends of ΔE in all three colors were very similar, showing the red coupons exhibited the smallest change even though the difference of ΔE between the colors was not significant. In Condition [C] (Figure 6-11f), the difference became clearly noticeable showing that the yellow coupons presented the most notable change in ΔE whereas the red coupons exhibited the smallest change over the testing duration.

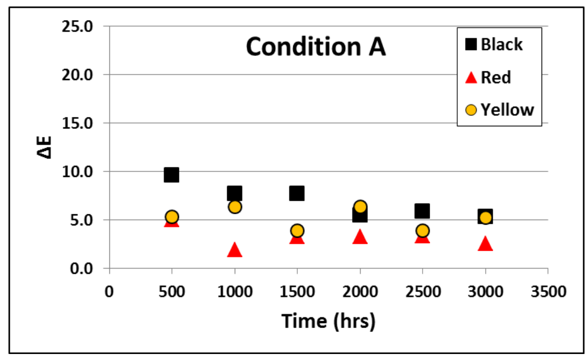




(a) Armor-Tile – Black

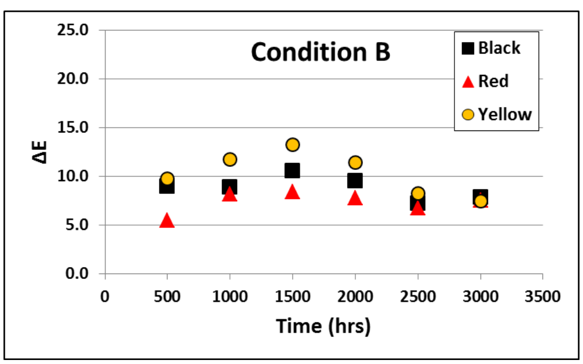
(b) Armor-Tile – Red

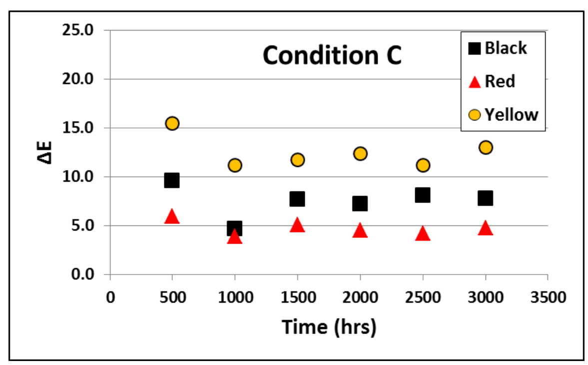




(c) Armor-Tile – Yellow

(d) All colors in Condition [A]





(e) All colors in Condition [B]

(f) All colors in Condition [C]

Figure 6-11 – Color change (ΔE) with exposure time of Armor-Tile coupons

6.2.3 Abrasion test

Sunlight degradation is a surface phenomenon; thus, degradation takes place at the surface and propagates inward. A surface abrasion test is more appropriate to assess the surface property as opposed to other mechanical tests such as tensile and bending tests which mainly measure the bulk property. Due to the dimensions and surface profiles of the DWS test coupons, commercially available abrasion devices are not applicable. A new abrasion test device was therefore designed and built for this study. Figure 6-12(a) shows the schematics of this device and Figure 6-12(b) depicts a photograph of the device. The abrasive part consists of a 1-inch diameter sand paper (120 grit) disk which is driven by a motor at a rotational speed of 1550 RPM. The test specimen was clamped to a sliding Plexiglas plate with its degraded surface facing down. Four ball bearings were installed on the corners of the Plexiglas plate allowing it to move freely along the steel rods. The weight of the Plexiglas and clamps was balanced by a counter-weight using a pulley system. A 380 grams weight was applied on top of the sliding plate to drive the specimen towards the abrasion disk. The abrasion duration was 60 seconds and mass loss was measured. A new sand paper disk was used for each specimen. Two coupons were retrieved every 1,000 hours. Each coupon was cut into half, providing four replicates for each sample at each test interval. (More detailed information on the abrasion test method and condition is described in Appendix-K).

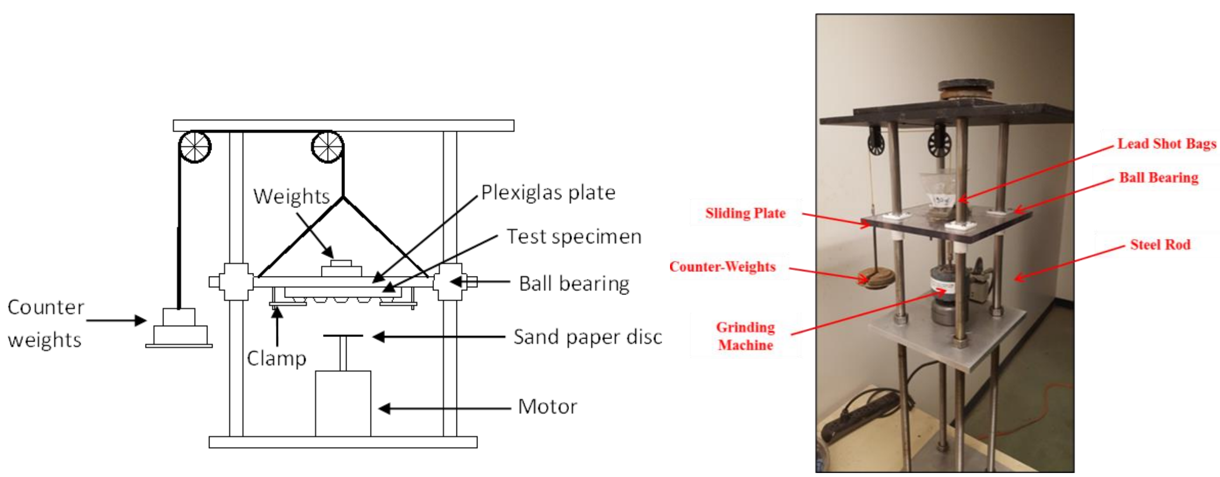


Figure 6-12 – Abrasion test device: (a) schematic diagram and (b) picture

(a) ADA Solutions products (polyester)

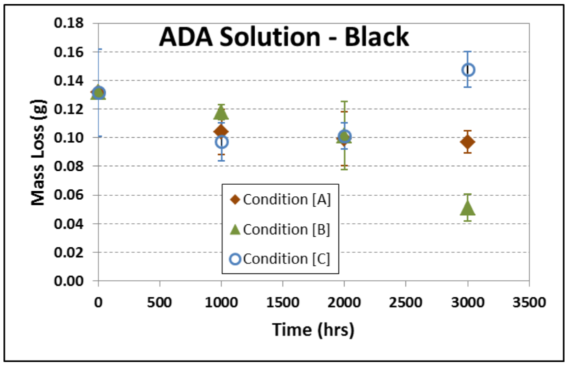
The abrasion test results of ADA Solutions products in Condition [A], [B] and [C] are shown in Figure 6-13 by presenting the mass loss against exposure time plots. (The test data are included in Appendix-K(a).) In Conditions [A] and [B], a similar trend was obtained in all three colors; the amount of mass loss decreased slightly as exposure time increased (Figure 6-13(d) and (e)). On the other hand, a small increase in mass loss with exposure time was measured in Condition [C] (Figure 6-13f). The greatest mass loss was measured in Condition [C] regardless of the color, indicating that the high level of irradiance can lead to the reduction of surface wear resistance for the ADA solutions products.

(b) AlertCast products (polyester, NPG)

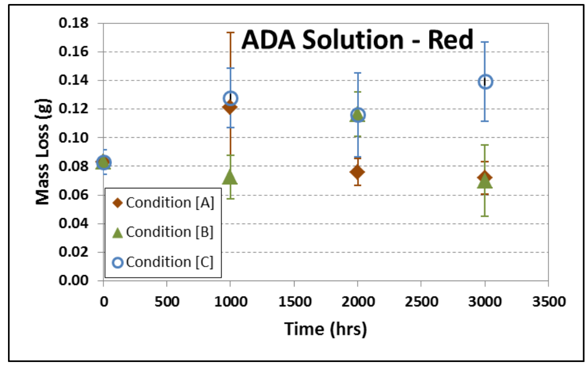
The test results of AlertCast products in Condition [A], [B] and [C] are shown in Figure 6-14 by plotting mass loss against exposure time. (The test data are included in Appendix-K(b).) Comparing mass loss between three colors, the trends of mass loss with exposure time are relatively similar in each of the exposure conditions. A higher mass loss was measured in Condition [C] after 3,000 hours of exposure.

(c) Redimat products (polyurethane)

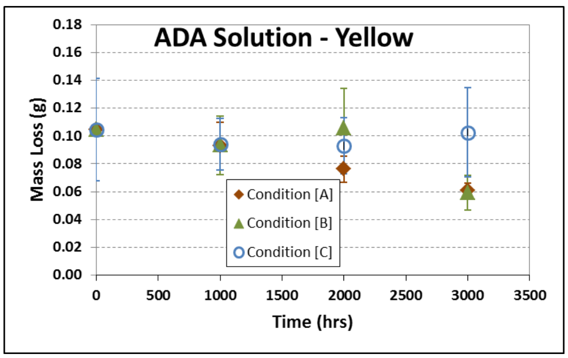
The abrasion test results of the Redimat product in three exposure conditions are shown in Figure 6-15. (The test data are included in Appendix-K(c).) Redimat samples have 10 folds less mass loss than samples of ADA Solutions and AlertCast. In all three colors, the mass loss is greater in in Condition [C] than that those in Conditions [A] and [B]. In Conditions [A] and [B], the mass loss was relatively similar in all three colors (Figure 6-15(d), (e)). The black coupons show the highest mass loss than the yellow and red in Condition [C] (Figure 6-15(f)).



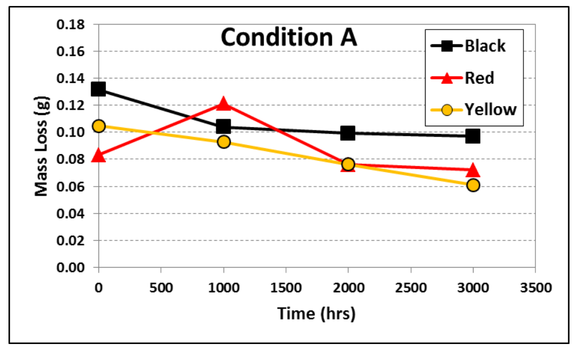
(a) Black



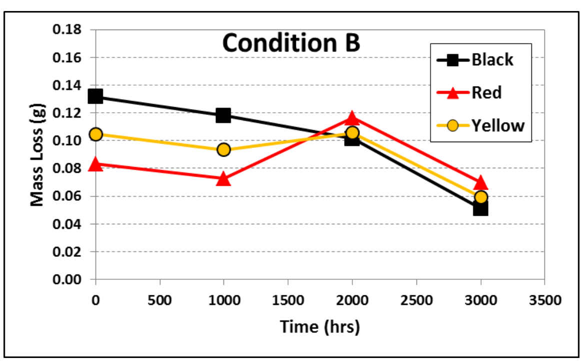
(b) Red



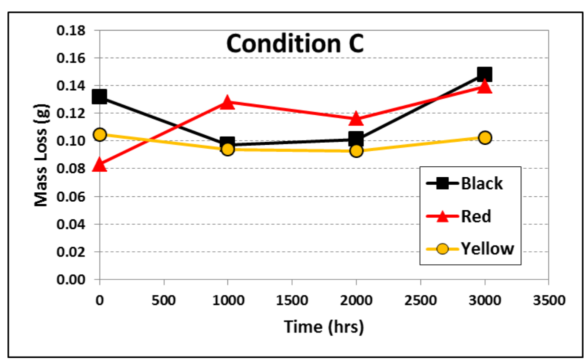
(c) Yellow



(d) All colors in Condition [A]

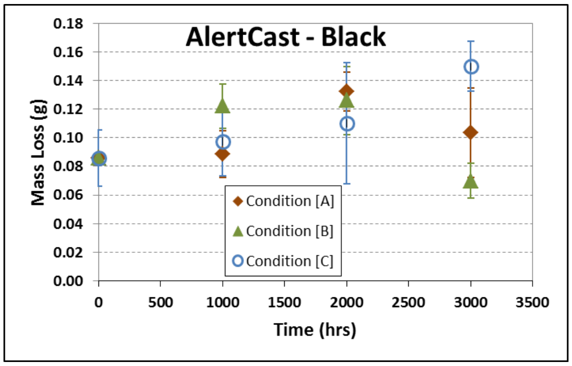


(e) All colors in Condition [B]

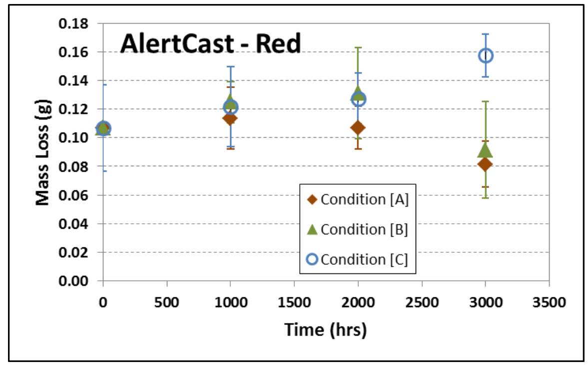


(f) All colors in Condition [C]

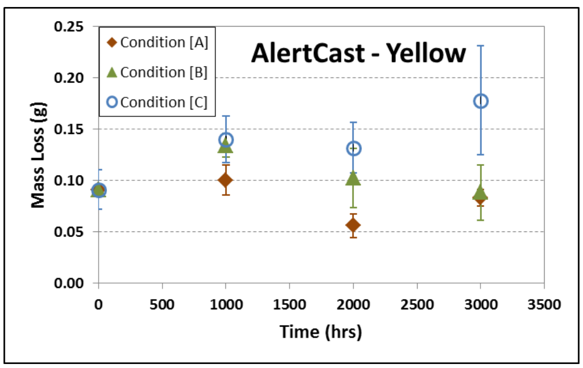
Figure 6-13 – The mass loss versus exposure time for coupons from ADA Solutions product



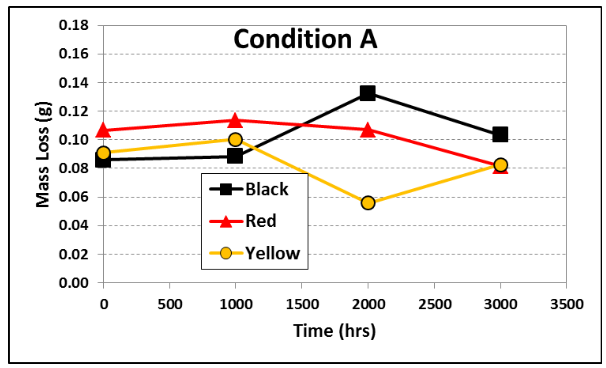
(a) Black



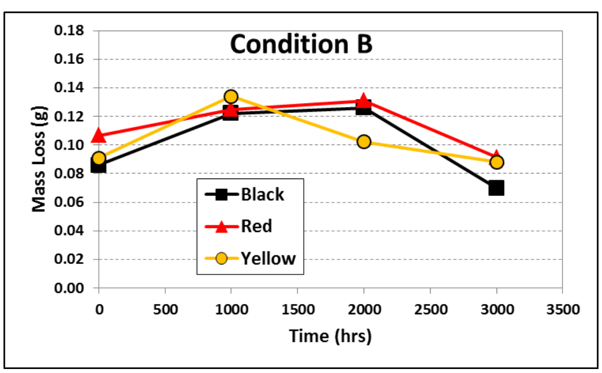
(b) Red



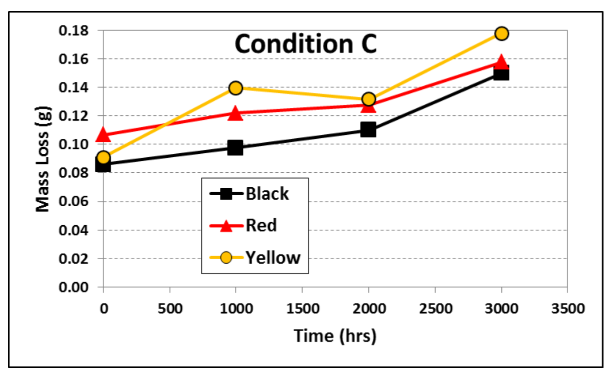
(c) Yellow



(d) All colors in Condition [A]

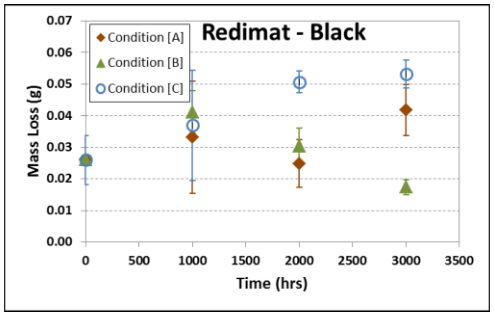


(e) All colors in Condition [B]

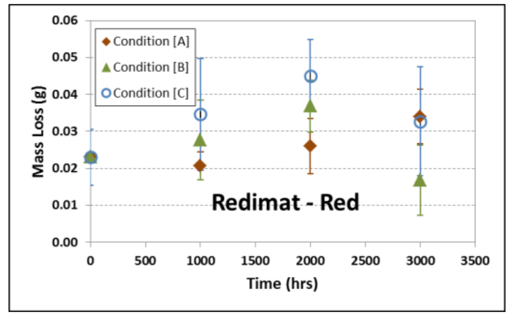


(f) All colors in Condition [C]

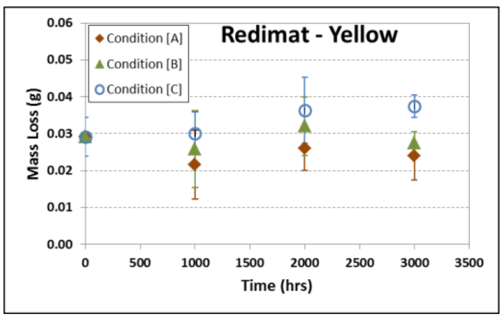
Figure 6-14 – The mass loss versus exposure time for coupons from AlertCast product



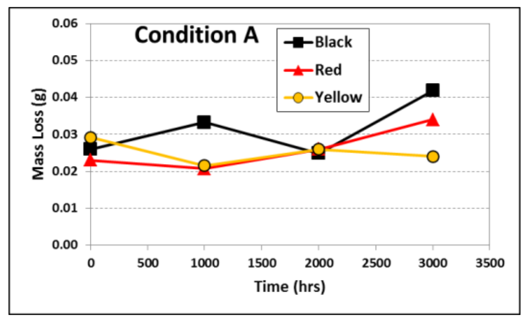
(a) Black



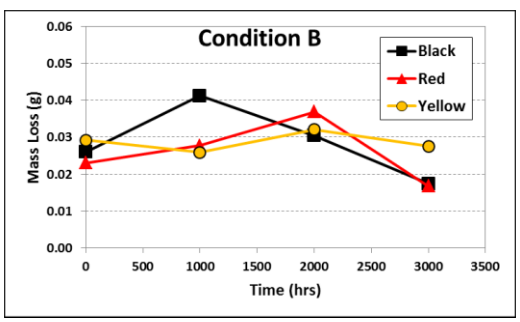
(b) Red



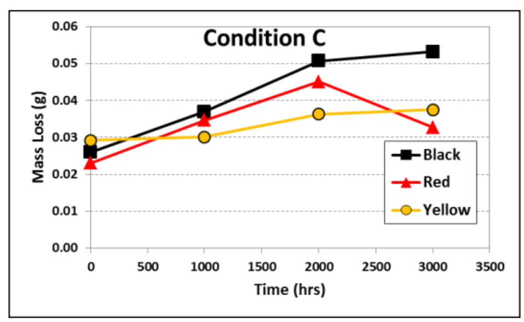
(c) Yellow



(d) All colors in Condition [A]



(e) All colors in Condition [B]



(f) All colors in Condition [C]

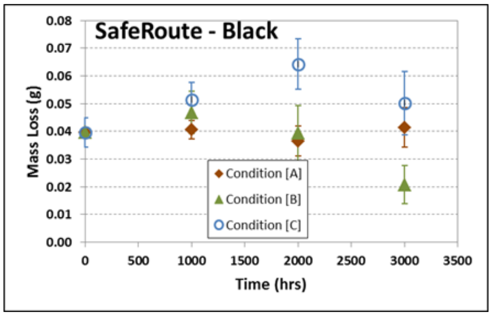
Figure 6-15 – The mass loss versus exposure time for coupons from Redimat product

(d) SafeRoute products (polyolefin)

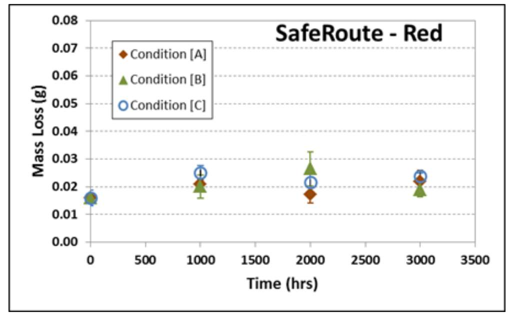
The abrasion test results of SafeRoute products are shown in Figure 6-16. (The test data are included in Appendix-K(d).) The mass loss of SafeRoute is in the similar range as Redimat. Black coupons showed the greatest mass loss in Condition [C] than Conditions [A] and [B] (Figure 6-16(a)). On the other hand, similar mass loss was measured in red and yellow coupons regardless the exposure conditions (Figure 6-16(b), (c)). In general, the black coupon showed the greatest mass loss while the red had the least mass loss in all three conditions (Figure 6-16(d), (e), (f)).

(e) Armor-Tile products (epoxy)

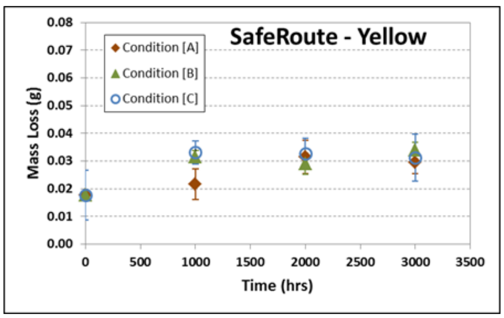
The abrasion test results of the Armor-Tile products in Condition [A], [B] and [C] are shown in Figure 6-17 by presenting the mass loss against exposure time plots. (The test data are included in Appendix-K(e)). For all three colors, no consistent trend but a large variability was obtained from the tests. The mass loss of the black coupons in three conditions (Figure 6-17(a)) decreased slightly up to 2,000 hours of exposure, and then increased after 3,000 hours. For the red coupons (Figure 6-17(b)), a significant increase of the mass loss was measured in first 2,000 hours in Condition [A] and [C], while no significant changes were measured in Condition [B] throughout the 3,000 hours of exposure. For the yellow coupons (Figure 6-17(c)), the mass loss in Condition [A] and [B] decreased after 3,000 hours while no significant changes in Condition [C]. In Condition [A] (Figure 6-17(d)), the greatest mass loss was measured in the red coupons while the yellow coupons showed a relatively constant mass loss over the testing duration. In Condition [B] (Figure 6-17(e)), the mass loss of the red coupons steadily increased while that of black coupons decreased over the time. In Condition [C] (Figure 6-17(f)), the most significant change of the mass loss was observed in the red coupons.



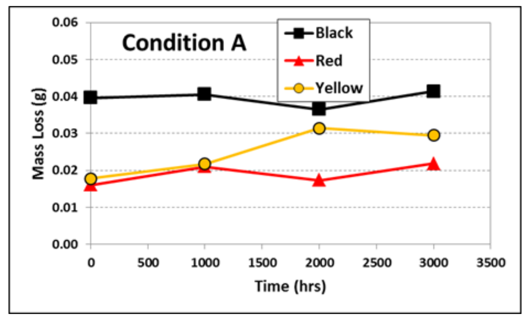
(a) Black



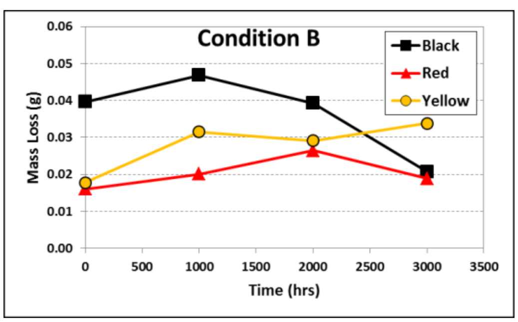
(b) Red



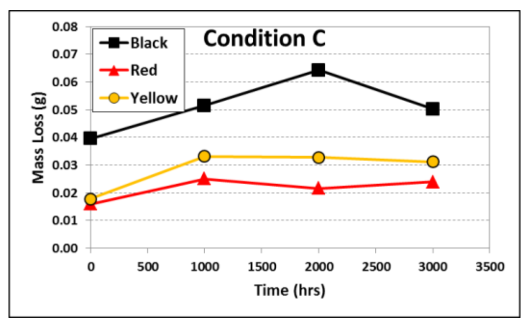
(c) Yellow



(d) All colors in Condition [A]

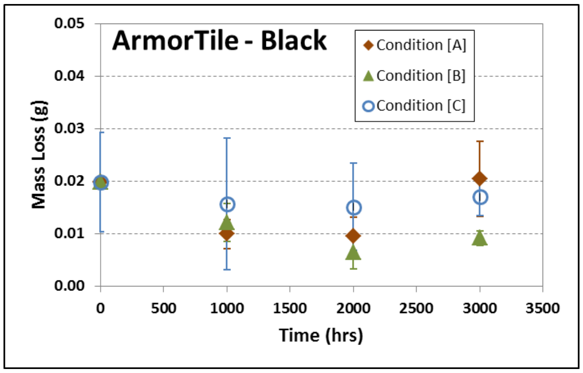


(e) All colors in Condition [B]

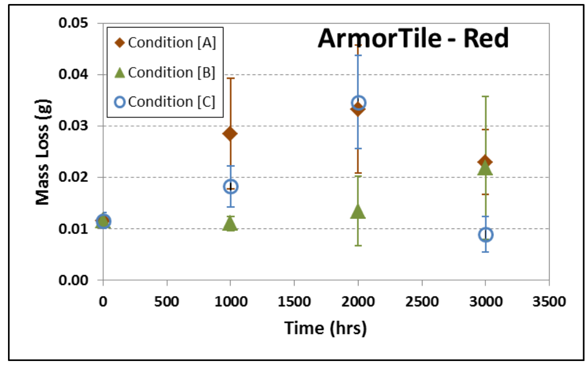


(f) All colors in Condition [C]

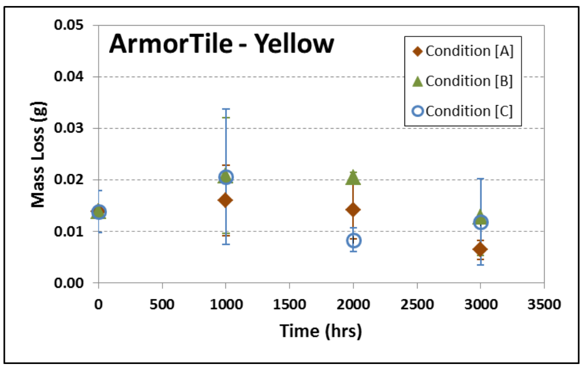
Figure 6-16 – The mass loss versus exposure time for coupons from SafeRoute product



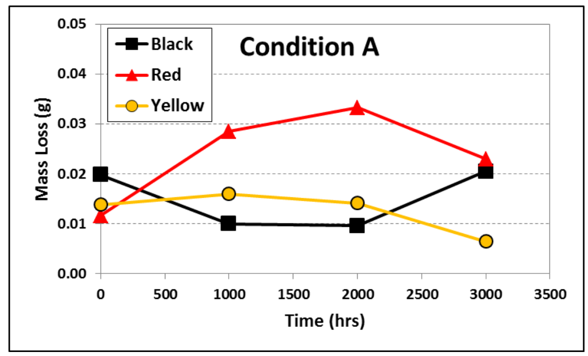
(a) Black



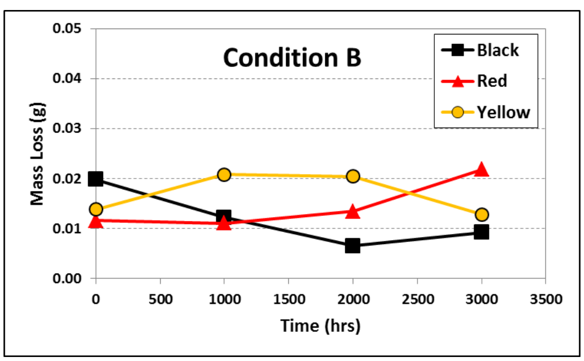
(b) Red



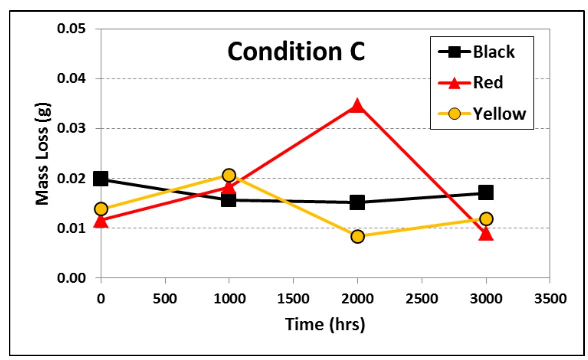
(c) Yellow



(d) All colors in Condition [A]



(e) All colors in Condition [B]



(f) All colors in Condition [C]

Figure 6-17 – The mass loss versus exposure time for coupons from Armor-Tile product

6.3 Test Results from Outdoor Exposure

Test coupons with same dimensions as the xenon tests were mounted at the metal frame for outdoor exposure. Two coupons were retrieved every four months for testing.

6.3.1 Surface morphology

The surface appearance of the exposed coupons were examined under a digital light microscope. Photos were taken to demonstrate changes in surface texture of each coupon throughout the exposure period. In this section, a representation of the surface appearance of yellow coupons under the effect of outdoor exposure is presented for DSW products. The

(a) ADA Solutions products (polyester)

For ADA Solutions coupons, the changing of surface appearance of the yellow coupons throughout the 24 months of outdoor exposure can be seen in Figure 6-18. The yellow color is gradually fading as exposure time increases. The small dark brown spots are noticed on some of the red and yellow coupons, and they are likely to be airborne particles.

(b) AlertCast products (polyester-NPG)

Figure 6-19 shows that the color fading of exposed coupons is more pronounced than those of the ADA Solutions coupons. Also, the dark brown spots can be seen on the surface of many exposed coupons after 8 months.

(c) Redimat products (polyurethane)

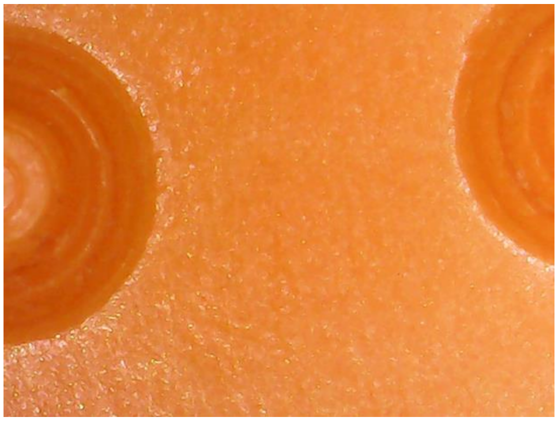
For Redimat coupons, the most noticeable change took place between 4 and 8 months of exposure, as shown in Figure 6-20. After 4 months, the reinforcing fibers can be observed and becomes more visible after 8 months of exposure, regardless the color. The appearance of the reinforcing fibers is likely due to the polymer degradation and subsequently removal of the surface layer.

(d) SafeRoute products (polyolefin)

Figure 6-21 shows the changing of surface appearance of red coupons throughout the 24 months of outdoor exposure. The white coating becomes more noticeable on red and yellow color after 16 months. By the 24-month, the white coating has completely covered the surface of red and yellow coupons. Figures 6-22 and 6-23 depict the surface of exposed coupon at low and high magnifications for red and yellow color, respectively. In contrast, the black coupon shows a significantly less white coating than the other two colors, as revealed in Figure 6-24.

(e) Armor-Tile products (epoxy)

Figure 6-25 shows the changing of surface appearance of yellow coupons throughout the 24 months of outdoor exposure. A gradual color fading with exposure time can be observed. The level of fading is similar to coupons from the ADA Solutions made from polyester. After 8 months of outdoor exposure, some highly reflective spots can be seen on surface, and may be caused by the appearance of reinforcing aluminum particles as polymer degradation begins to occur at the surface.



Original unexposed yellow coupon

Outdoor-exposed 8-months yellow coupon

Outdoor-exposed 12 months yellow coupon

Outdoor-exposed 16 months yellow coupon

Outdoor-exposed 20 months yellow coupon

Outdoor-exposed 24 months yellow coupon

Figure 6-18 – Surface appearance of ADA Solutions coupons under a light microscope at 100x from 0 to 24 months outdoor exposure

Original unexposed yellow coupon

Outdoor-exposed 8-months yellow coupon

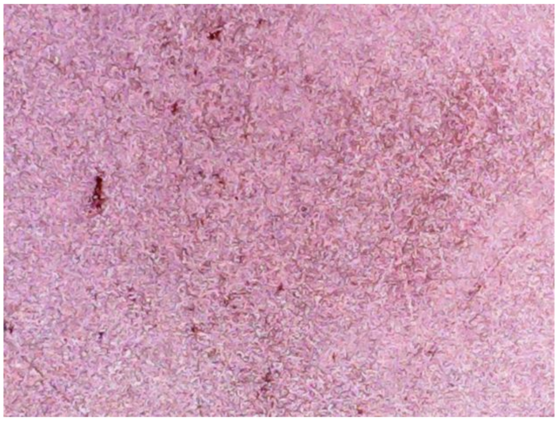
Outdoor-exposed 12-months yellow coupon

Outdoor-exposed 16-months yellow coupon

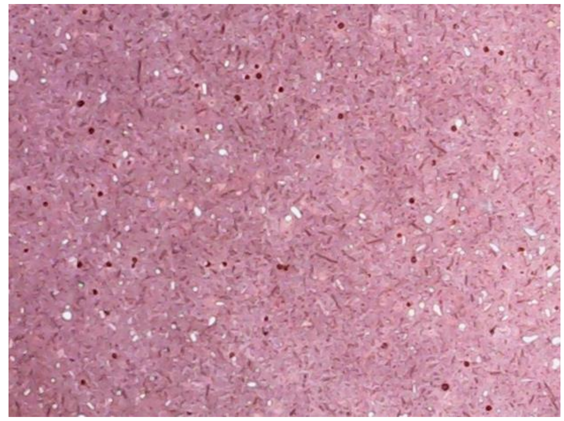
Outdoor-exposed 20-months yellow coupon

Outdoor-exposed 24-months yellow coupon

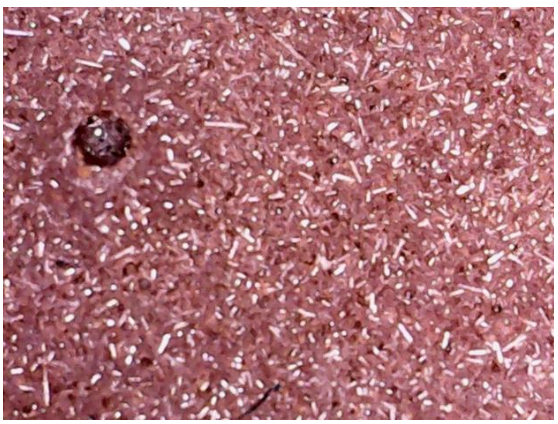
Figure 6-19 – Surface appearance of AlertCast coupons under
a light microscope at 100x from 0 to 24 months outdoor exposure



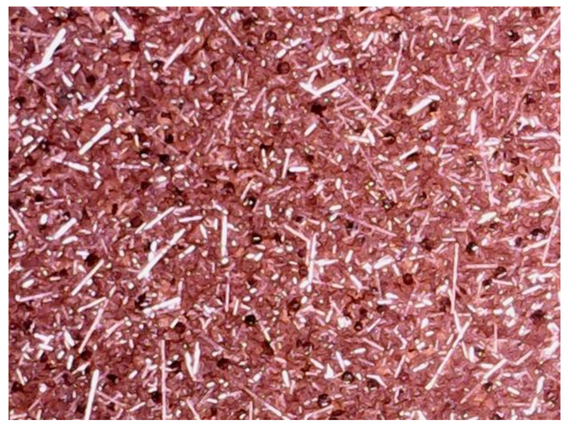
Original unexposed red coupon



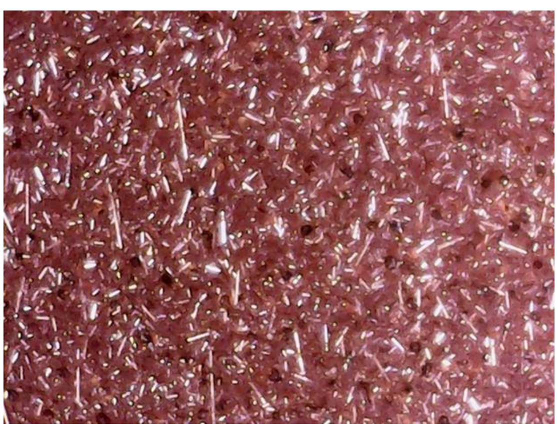
Outdoor-exposed 4-months red coupon



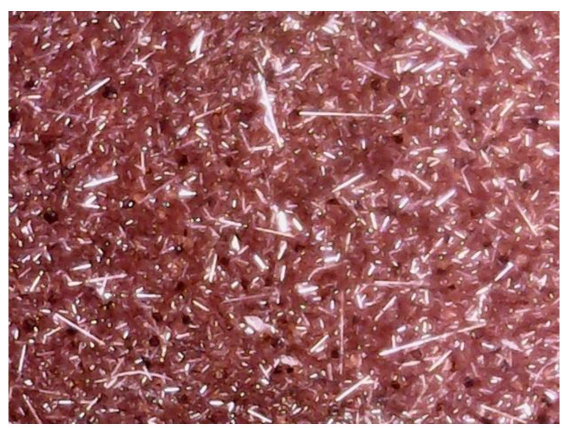
Outdoor-exposed 8-months red coupon



Outdoor-exposed 16-months red coupon

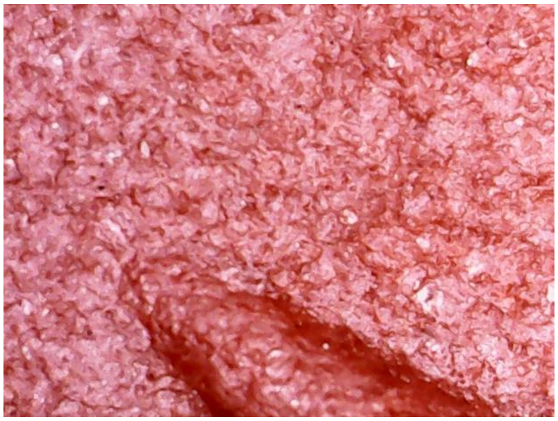


Outdoor-exposed 20-months red coupon

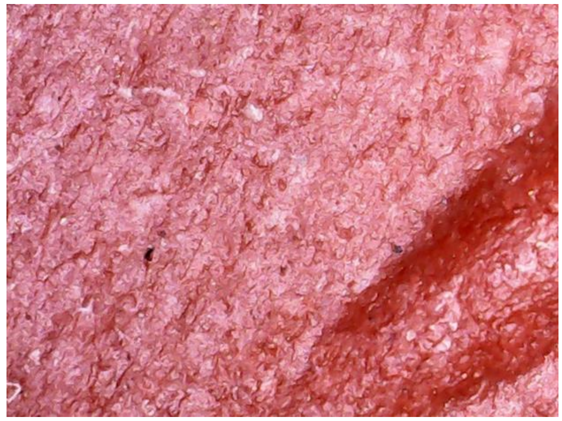


Outdoor-exposed 24-months red coupon

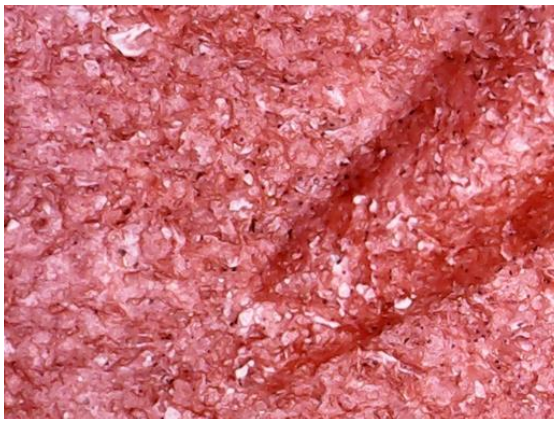
Figure 6-20 – Surface appearance of Redimat coupons under
a light microscope at 100x from 0 to 24 months outdoor exposure



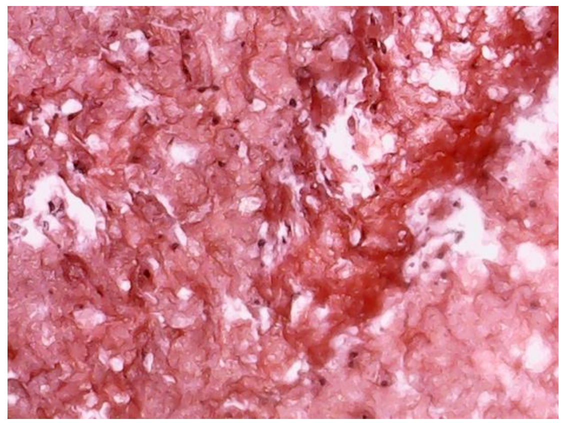
Original unexposed red coupon



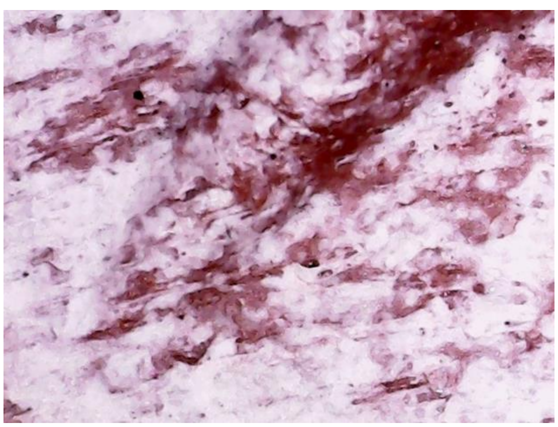
Outdoor-exposed 8-months red coupon



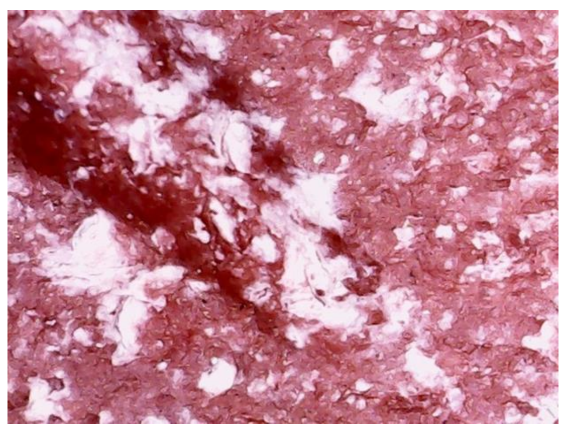
Outdoor-exposed 12-months red coupon



Outdoor-exposed 16-months red coupon

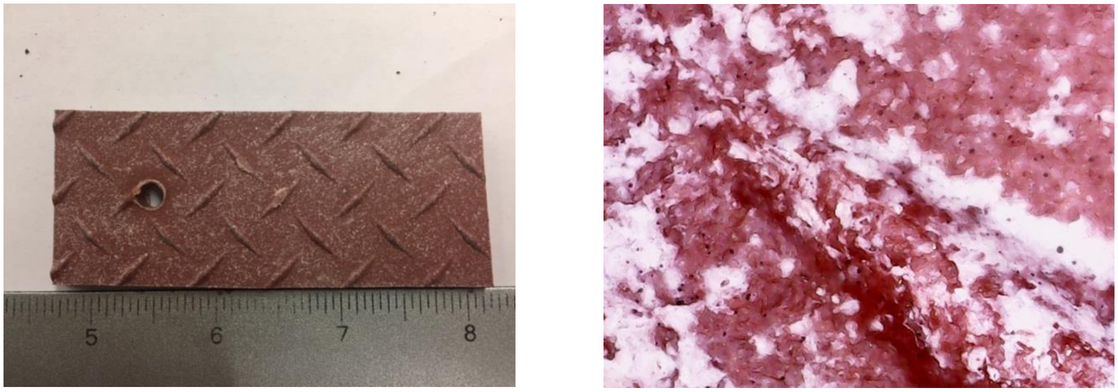


Outdoor-exposed 20-months red coupon



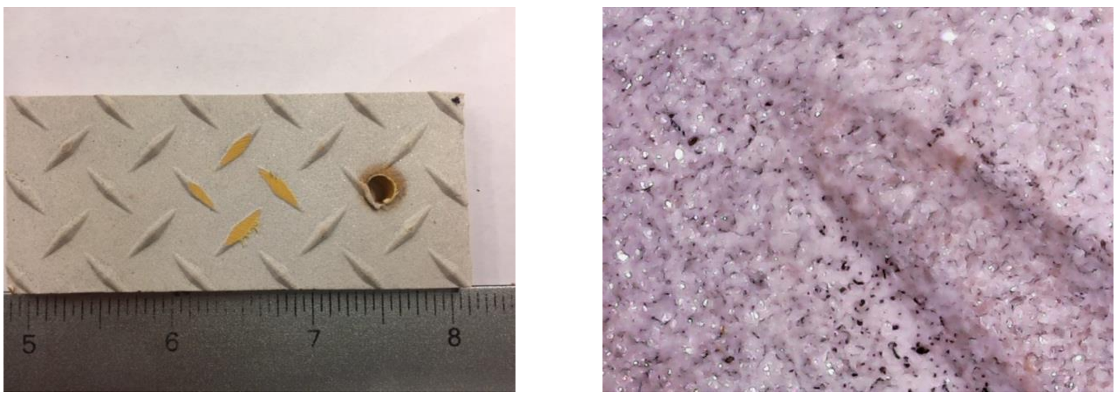
Outdoor-exposed 24-months red coupon

Figure 6-21 – Surface appearance of SafeRoute coupons under
a light microscope at 100x from 0 to 24 months outdoor exposure



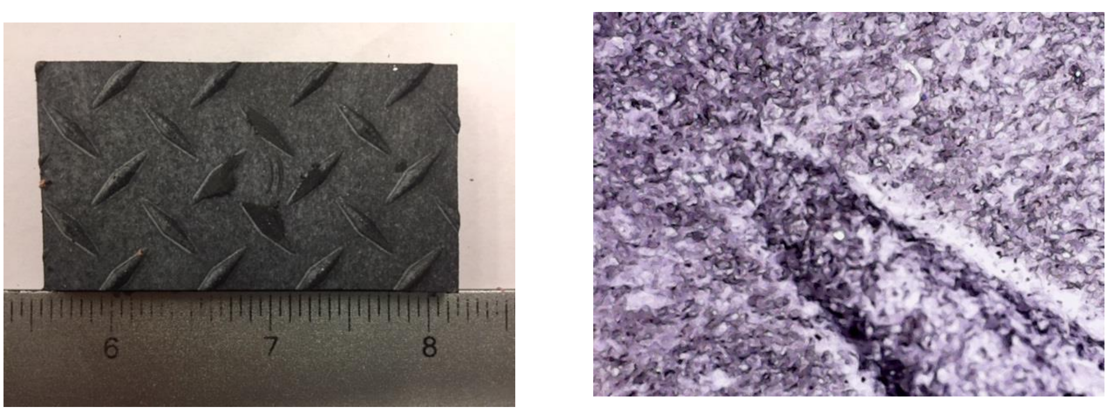
(a) General view (b) 100x

Figure 6-22 – 24 months outdoor-exposed SafeRoute red color coupon



(a) General view (b) 100x

Figure 6-23 – 24 months outdoor-exposed SafeRoute yellow color coupon



(a) General view (b) 100x

Figure 6-24 – 24 months outdoor-exposed SafeRoute black color coupon

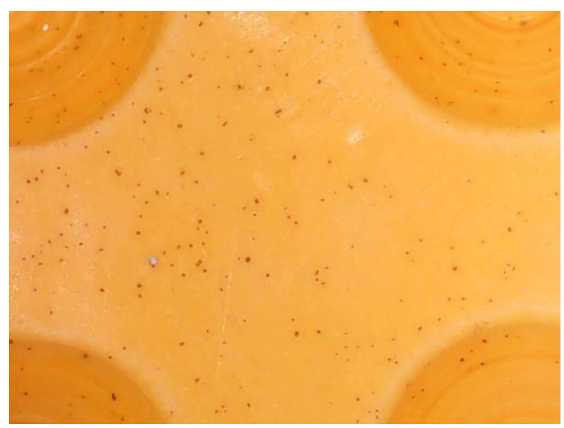
Original unexposed yellow coupon

Outdoor-exposed 4-months yellow coupon

Outdoor-exposed 8-months yellow coupon

Outdoor-exposed 12-months yellow coupon

Outdoor-exposed 20-months yellow coupon



Outdoor-exposed 24-months yellow coupon

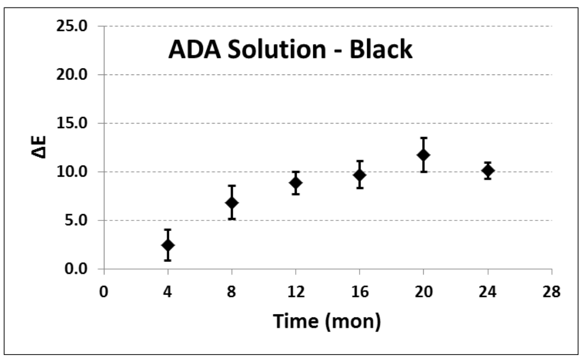
Figure 6-25 – Surface appearance of Armor-Tile coupons under a light microscope at 100x from 0 to 24 months outdoor exposure

6.3.2 Color measurement

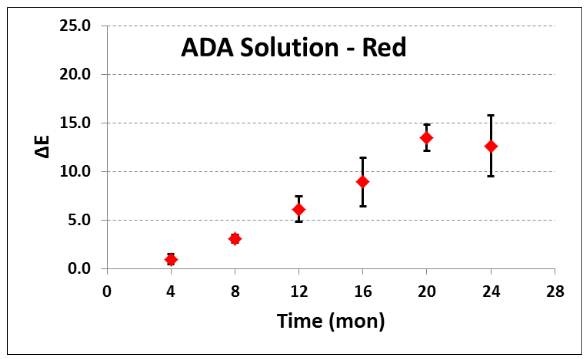
The effect of sunlight radiation on color was measured using a spectro-colorimeter, X-rite RM200QC. The test data of the color measurement are included as Appendix-N of this report.

(a) <u>ADA Solutions products (polyester)</u>

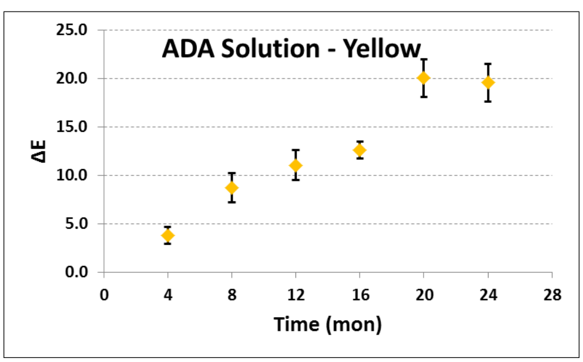
Figure 6-26(a), (b), and (c) show plots of ΔE versus exposure time in outdoor condition for black, red and yellow ADA Solutions products, respectively. In general, the ΔE value increased with exposure time initially and then leveling out for all three colors. All colors reached the maximum ΔE value after 20 months. All three colors have relatively similar ΔE values up to 16 months after that the yellow color showed a higher ΔE values (Figure 6-26(d)).



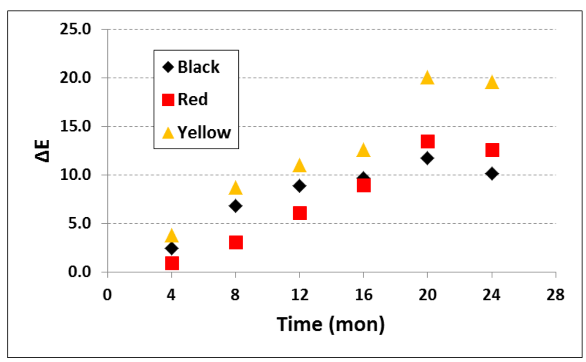
(a) ADA Solutions – Black



(b) ADA Solutions – Red



(c) ADA Solutions – Yellow

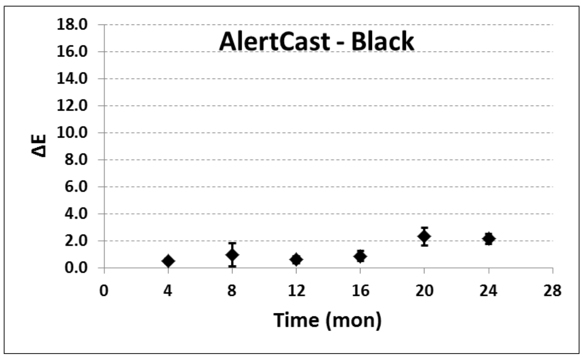


(d) ADA Solutions – All colors

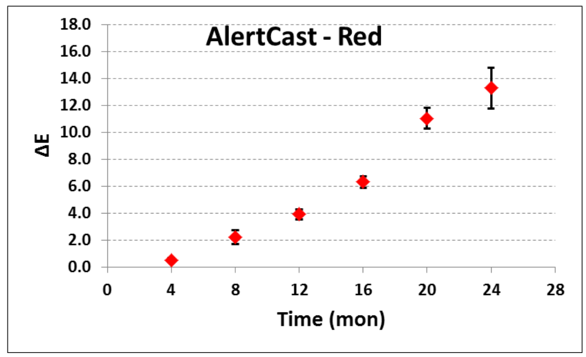
Figure 6-26 – Color change (ΔE) with exposure time (in month) for coupons of ADA Solutions

(b) AlertCast products (polyester-NPG)

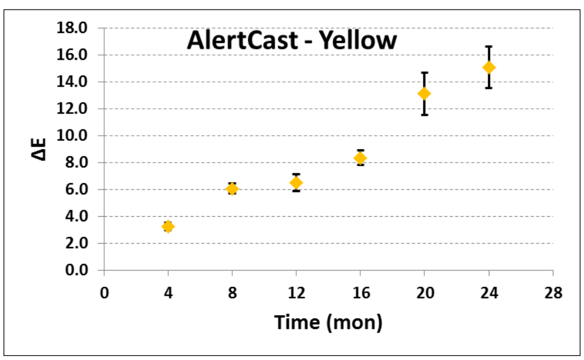
Figure 6-27(a), (b), and (c) show plots of ΔE versus exposure time for black, red and yellow of AlertCast products, respectively. For the black coupons, there is no significant change of ΔE over the exposure time. The ΔE values of red and yellow coupons increase steadily with exposure time. Overall, the black color shows the least change of ΔE, while the yellow and red colors have similar behavior, as can be seen in Fig. 6-27(d). The large increase in ΔE of red and yellow coupons is likely caused by the fading of color and coral-shaped texture (see Figure 6-19).



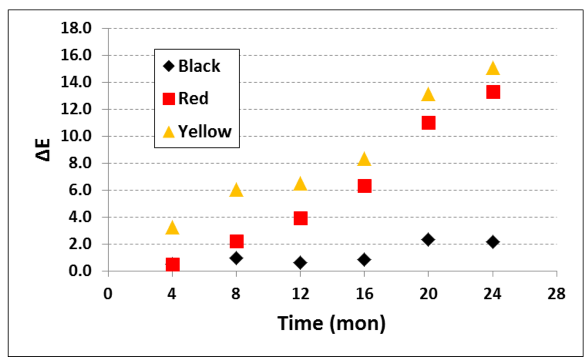
(a) AlertCast – Black



(b) AlertCast – Red



(c) AlertCast – Yellow

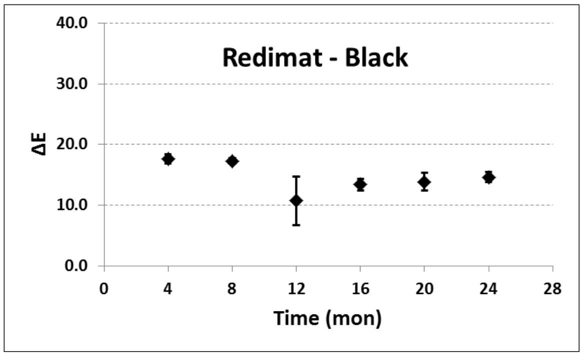


(d) AlertCast – All colors

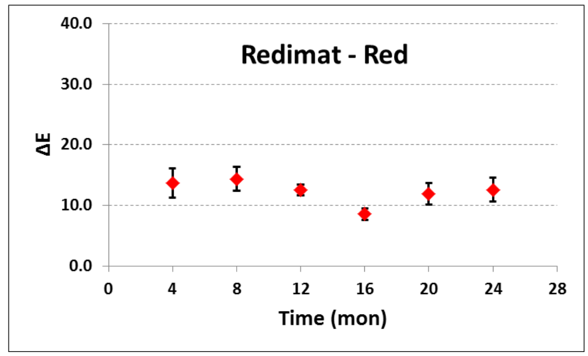
Figure 6-27 – Color change (ΔE) with exposure time (in month) for coupons of AlertCast

(c) Redimat products (polyurethane)

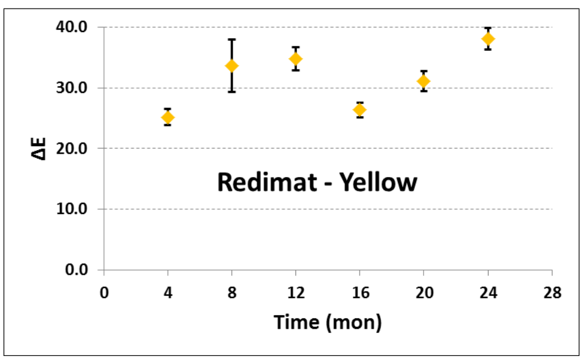
Figure 6-28(a), (b), and (c) show plots of ΔE versus exposure time in outdoor condition for black, red and yellow Redimat products, respectively. In all three colors, the ΔE value increases significantly in the first 4 months of exposure. After that, the values remain relatively constant throughout the rest of exposure time. The black and red colors have very similar ΔE values, while the yellow color has a much higher value than the other two colors, as shown in Figure 6-28(d). The large increase of ΔE is due to the appearance of fibers as can be seen in Figure 6-20.



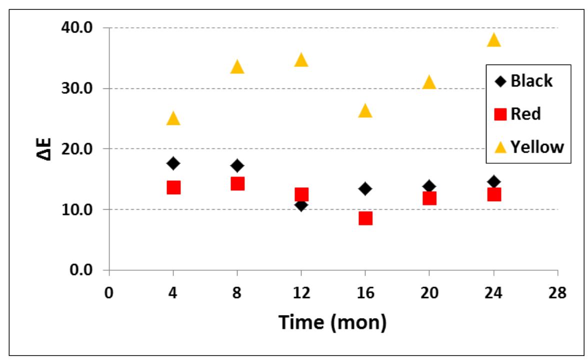
(a) Redimat – Black



(b) Redimat – Red



(c) Redimat – Yellow

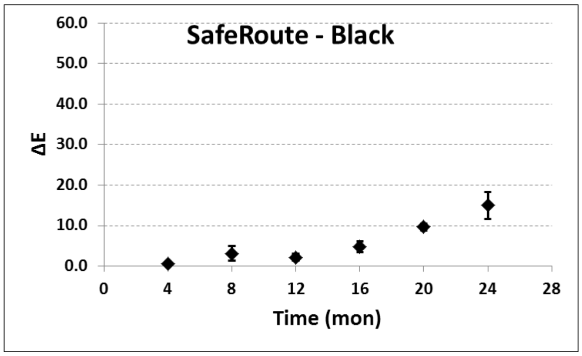


(d) Redimat – All colors

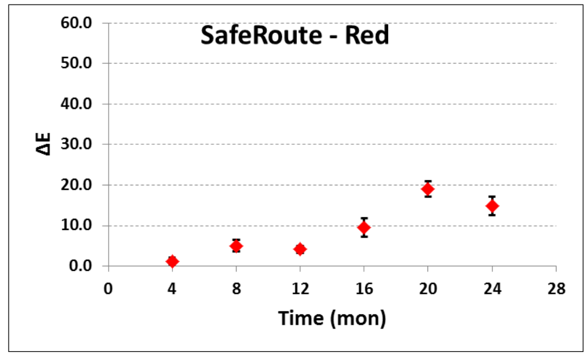
Figure 6-28 – Color change (ΔE) with exposure time (in month) for coupons of Redimat

(d) <u>SafeRoute products (polyolefins)</u>

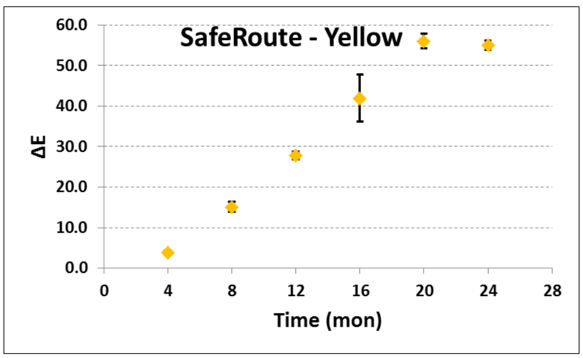
Figure 6-29(a), (b), and (c) show plots of ΔE versus exposure time in outdoor condition for black, red and yellow SafeRoute products, respectively. For the black color, ΔE steadily increases with exposure time. For the red and yellow colors, ΔE increases with exposure time until 20 months after which it levels off. The ΔE values measured from the black and red coupons are very small (less than 20). In contrast, much greater increase of ΔE values were measured from the yellow coupons reaching as high as 55 after 20 months (Fig. 6-29(d)). The high ΔE value was caused by white coating covering the entire coupon surface.



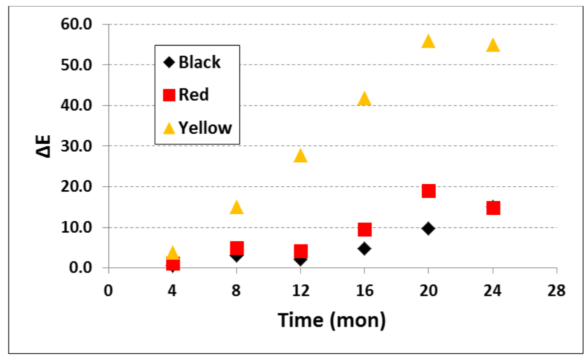
(a) SafeRoute – Black



(b) SafeRoute – Red



(c) SafeRoute – Yellow

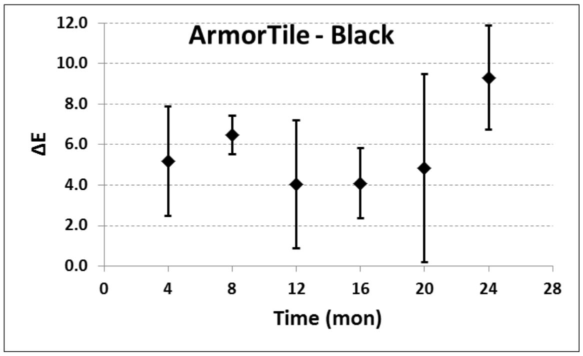


(d) SafeRoute – All colors

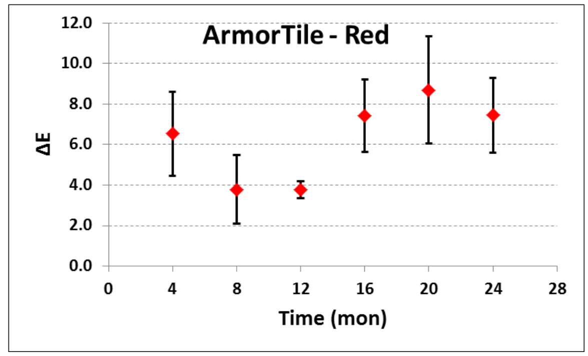
Figure 6-29 – Color change (ΔE) with exposure time (in month) for coupons of SafeRoute

(e) <u>Armor-Tile products (epoxy)</u>

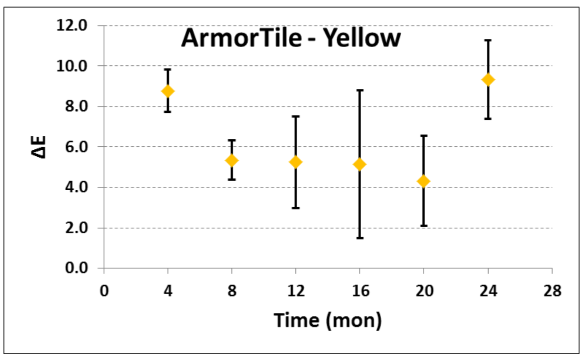
Figure 6-30(a), (b), and (c) show graphs of plotting ΔE versus exposure time for black, red and yellow color, respectively. In comparison to other DWS products, the ΔE values obtained from the Armor-Tile coupons have a greater disparity as indicated by the large error bars for each set of data. For all three colors, the greatest increase of ΔE occurred between 0 and 4 months. After 4 months, the average ΔE values vary greatly throughout the remaining exposure time. Figure 6-30(d) shows the combined plots of three colors, and they can be considered to have a similar behavior in the color changes.



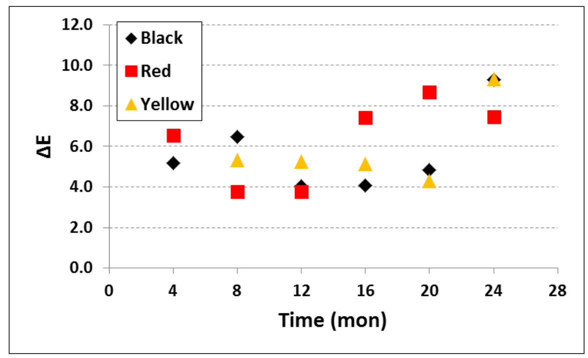
(a) ArmorTile – Black



(b) ArmorTile – Red



(c) ArmorTile – Yellow



(d) ArmorTile – All colors

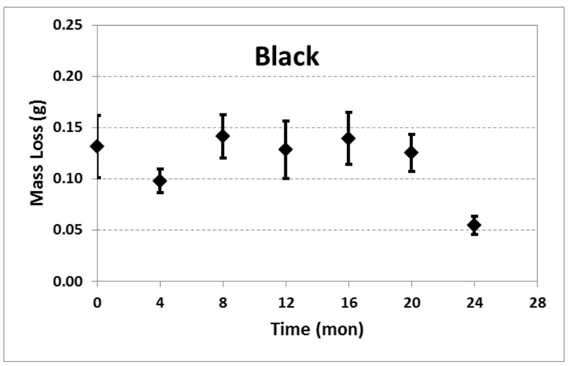
Figure 6-30 – Color change (ΔE) with exposure time (in month) for coupons of Armor-Tile

6.3.3 Abrasion test

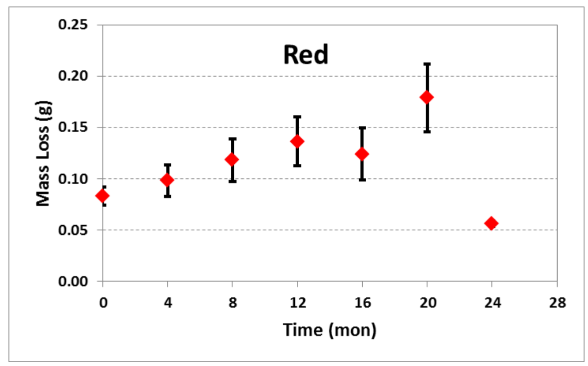
After the non-destructive tests (surface morphology and color change) were completed, each of two exposed coupons was cut into half, providing four test specimens for each sample at each test interval (i.e., every 4-month). The test data are included in Appendix-O.

(a) <u>ADA Solutions products (polyester)</u>

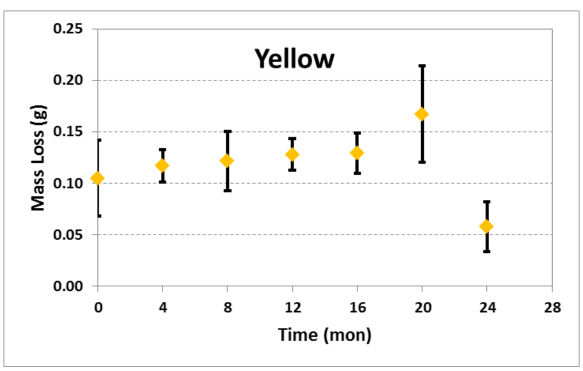
Figure 6-31(a), (b), and (c) show plots of mass loss versus exposure time in outdoor condition for black, red and yellow coupon, respectively. For the black coupon, the mass loss was relatively constant throughout the first 20 months but then decreased at 24 months. For the red and yellow coupons, the mass loss gradually increased with time for the first 20 months. Similar to the black coupon, the 24-month coupon of red and yellow colors also exhibited a large decrease in mass loss. Figure 6-31(d) shows the combined mass loss curves of three colors. It is unclear the cause for the large decrease in mass loss of the 24-month exposed coupons. Recalling the ΔE values of the 24-month coupons, they are very similar to those of the 20-months without abrupt change on the surface appearance between 20 and 24-months. A probable reason is cross-linking took place on the surface after 24 months, and the chemical reaction does not lead to changes in color and surface morphology. Another possibility is due to error in the testing.



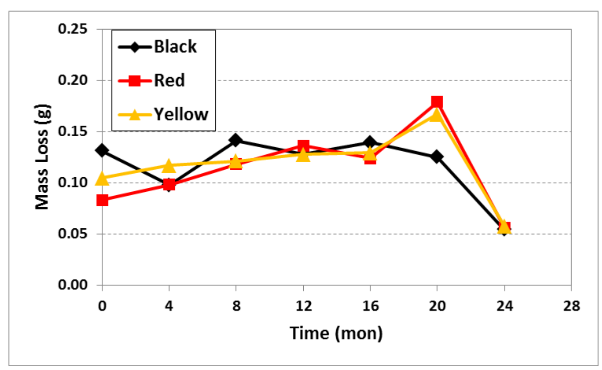
(a) ADA Solutions – Black



(b) ADA Solutions – Red



(c) ADA Solutions – Yellow

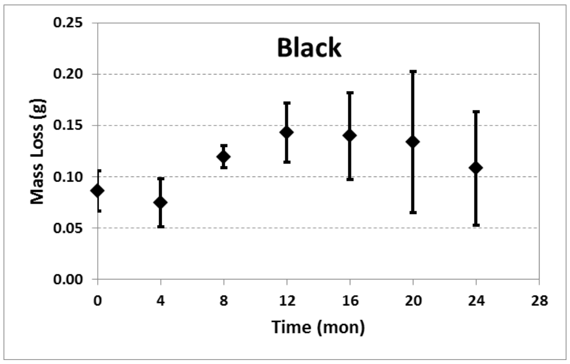


(d) ADA Solutions – All colors

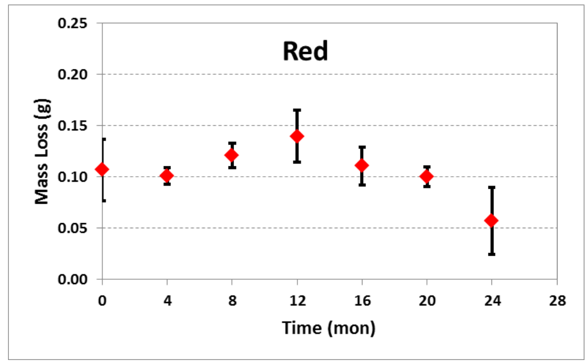
Figure 6-31 – The mass loss versus exposure time (in month) for ADA Solutions coupons

(b) AlertCast products (polyester NPG)

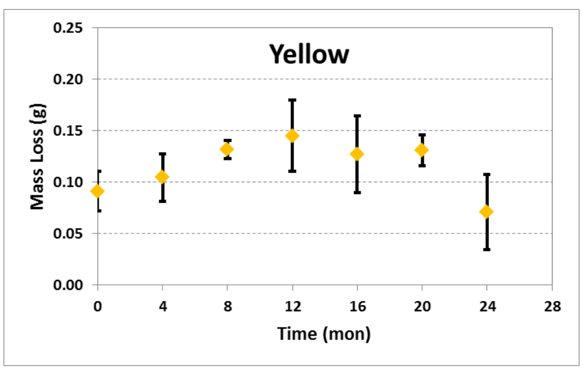
Figure 6-32(a), (b), and (c) show plots of mass loss versus exposure time for black, red and yellow coupon, respectively. Considering the large variability in each set of tests, all three colors seem to have a similar mass loss; a gradual increased in mass loss in the first 12 months and then slowly decreasing, as can be seen in Fig. 6-32(d).



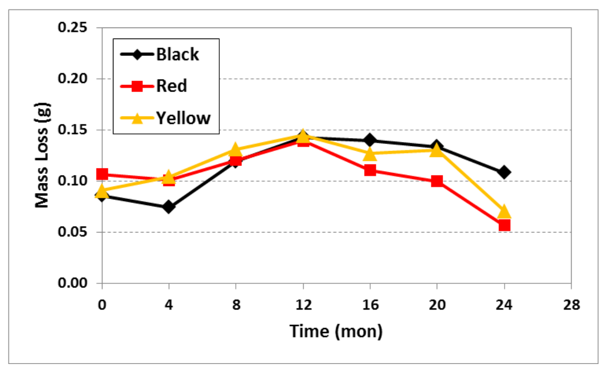
(a) AlertCast – Black



(b) AlertCast – Red



(c) AlertCast – Yellow

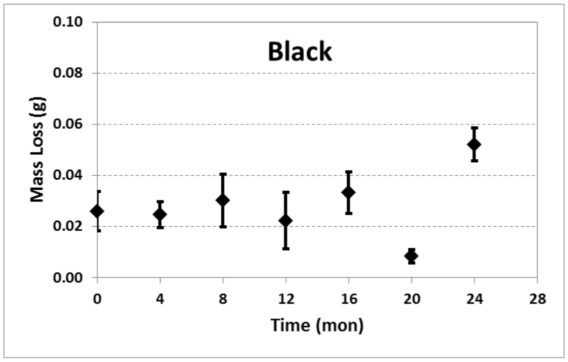


(d) AlertCast – All colors

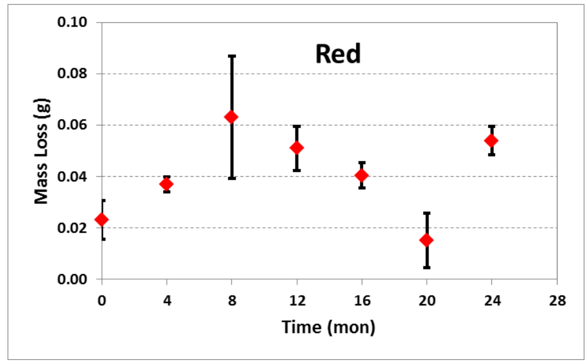
Figure 6-32 – The mass loss versus exposure time (in month) for AlertCast coupons

(c) Redimat products (polyurethane)

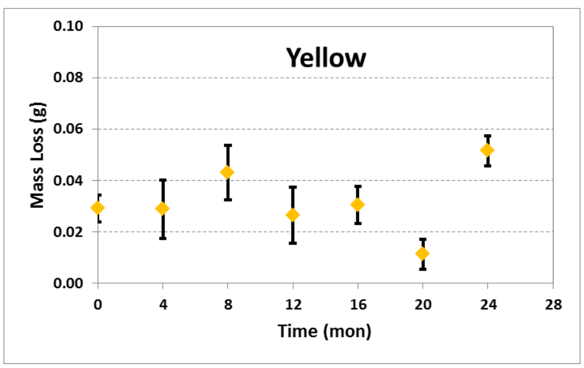
Figure 6-33(a), (b), and (c) show plots of mass loss versus exposure time for black, red and yellow coupon, respectively. Figure 6-33(d) depicts a plot of mass loss of all three colors. Overall, the three mass loss curves are very similar, showing a slight increase in mass loss after 24 months of outdoor exposure. The red coupons exhibited the highest mass loss in the first 12 months but then it converged with the other two colors after 20 months.



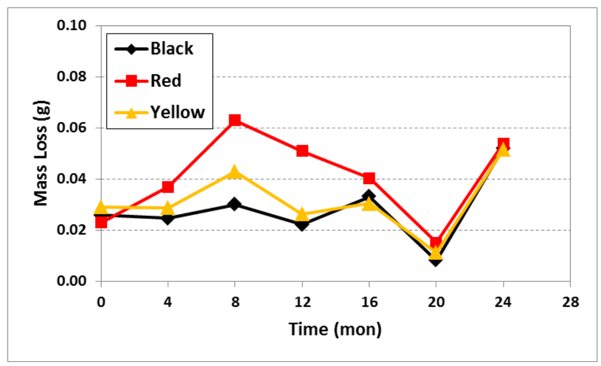
(a) Redimat – Black



(b) Redimat – Red



(c) Redimat – Yellow

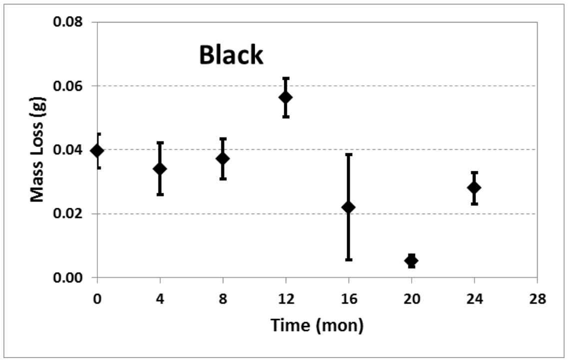


(d) Redimat – All colors

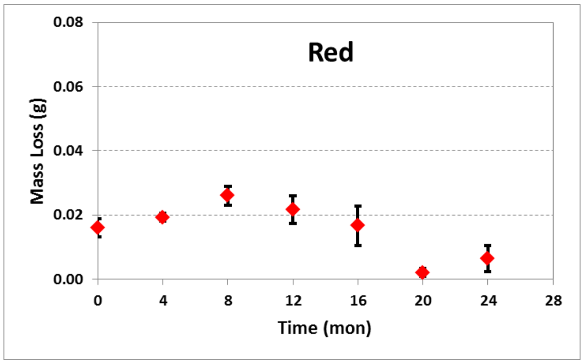
Figure 6-33 – The mass loss versus exposure time (in month) for Redimat coupons

(d) SafeRoute products (polyolefin)

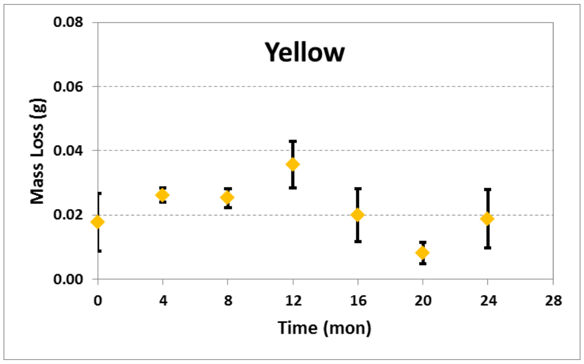
Figure 6-34(a), (b), and (c) show plots of mass loss versus exposure time for black, red and yellow coupon, respectively. The combined three color curves are plotted in Figure 6-34(d). The black coupons have the highest of mass loss in the first 12 months and then the mass loss decreased significantly with time. The red and yellow curves are very similar, showing a slight increase in mass loss in the first 8 to 12 months, and then the mass loss started to decrease. The decrease in mass loss after 12 months in all three colors may be caused by the emerging of filler as the polymer degrades (see Figure 6-22 to 6-24). The filler which commonly is calcium carbonate is harder than polyolefin; thus, it is more resistant to abrasion and losses less mass.



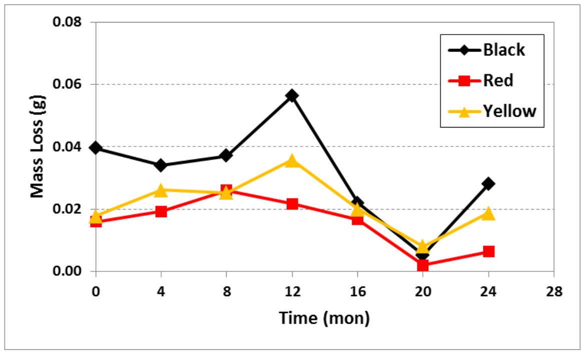
(a) SafeRoute – Black



(b) SafeRoute – Red



(c) SafeRoute – Yellow

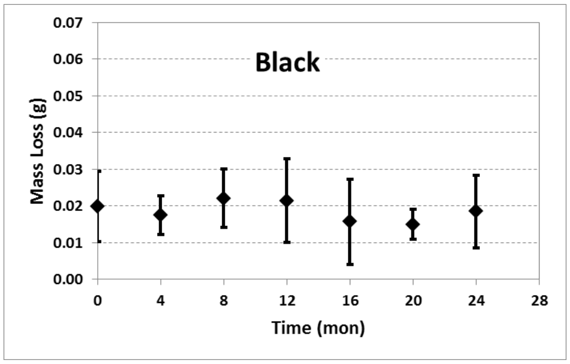


(d) SafeRoute – All colors

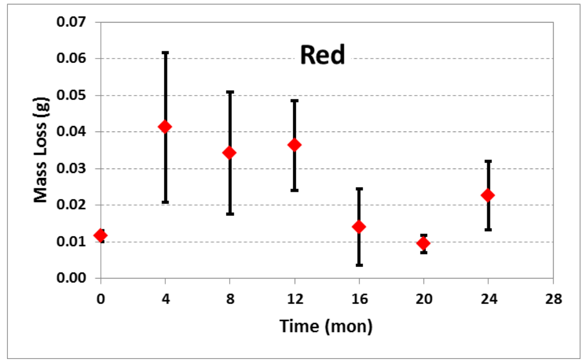
Figure 6-34 – The mass loss versus exposure time (in month) for SafeRoute coupons

(e) Armor-Tile products (epoxy)

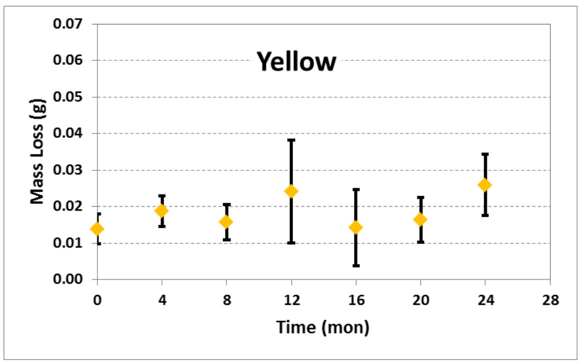
Figure 6-35(a), (b), and (c) show plots of mass loss versus exposure time for black, red and yellow coupon, respectively. The combined three color curves are plotted in Figure 6-35(d). Considering the large error bars in the red color coupons, the mass loss of all three colors is very similar. There was no change in mass loss for the first 12 months, afterward the mass loss decreased to zero at 20 months. At 24 months, the mass loss increased slightly.



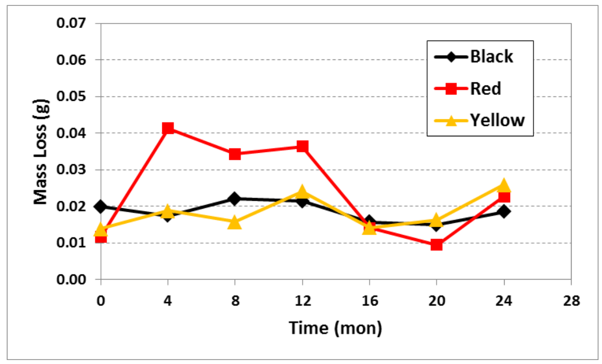
(a) Armor-Tile – Black



(b) Armor-Tile – Red



(c) Armor-Tile – Yellow



(d) Armor-Tile – All colors

Figure 6-35 – The mass loss versus exposure time (in month) for Armor-Tile coupons

6.4 Comparing Test Results of Xenon Weatherometer and Outdoor Exposure

As stated in Section 5.5, to compare test data between weatherometer and outdoor environment, the test time in weatherometer exposure conditions were converted to the equivalent outdoor condition at Gainesville, FL using Equation (5-2).

6.4.1 Surface morphology

The surface appearance of the DWS exposed coupons were examined under a light microscope. Photo was taken to represent the color and surface texture of each coupon. The yellow color was selected to demonstrate the difference on surface appearance between three xenon conditions and the outdoor environment.

(a) ADA Solutions products (polyester)

For the yellow ADA Solutions coupons, the surface appearance after 3,000 hours of exposure in xenon weatherometer under three conditions, and 24 months of outdoor exposure at Gainesville, Florida, can be seen in Figure 6-36. Photographs for other outdoor exposure periods are included in Appendix-M(a). Fading of surface color and circular pattern was noted after 3,000 hours exposure in three xenon conditions and the outdoor coupon. However, the fading of the circular pattern was not as pronounced on the outdoor coupon as the 3,000 hours xenon coupons. In addition, the reinforcing fibers that were clearly revealed on the surface of the three xenon coupons were not apparent on the outdoor coupon. The small deep brown spots on the outdoor coupon were likely to be airborne particles because they were not observed on the xenon coupons.

(b) AlertCast products (polyester NPG)

Figure 6-37 shows the surface appearance of yellow AlertCast coupons after 3,000 hours of exposure in three xenon conditions and 24 months of outdoor exposure. Photographs for other outdoor exposure periods are included in Appendix-M(b). The color fading was more pronounced than those of ADA Solutions even though both products were made from polyester. Similar to the outdoor-exposed ADA coupons, reinforcing fibers were not observed on the surface of 24-month AlertCast coupons while they were clearly seen on the 3,000 hours xenon coupons, particularly for Conditions [B] and [C]. The airborne particles can also be seen on the surface of the outdoor-exposed coupons.

(c) Redimat products (polyurethane)

Figure 6-38 depicts the surface photos of unexposed yellow Redimat coupon, 500-hr exposed coupons under three xenon conditions, and 8-month outdoor-exposed coupon. Photographs for other outdoor exposure periods are included in Appendix-M(c). For the Redimat coupons, the appearance of reinforcing fibers was the most noticeable change. The reinforcing fibers can be seen after 500 hours of xenon exposure in all three colors. For the outdoor, they can be observed in 8 months exposure. The amount of fibers observable increased with time in all exposure conditions.

(d) SafeRoute products (polyolefin)

Figure 6-39 shows the surface appearance of yellow coupons after 3,000 hours of exposure in three xenon conditions, and 12 and 24 months of outdoor exposure. Photographs for other outdoor exposure periods are included in Appendix-M(d). White coating can be observed in both xenon and outdoor-exposed coupons. However, the amount of white coating is significantly different in the yellow coupons than in other two colors. Comparing the surface of 12 months outdoor coupon to 3,000 hours Conditions [B] and [C] xenon coupons, the amount of white coating is significantly greater on the outdoor coupon. One possible explanation for this difference is the quality of the water. High purity water was used in the xenon weatherometer, while the rain water that contains impurities and bacteria may react with yellow pigment. (Most of the color pigment is embedded in a polymeric carried resin which has a lower molecular weight and more susceptible to biodegradation. It is possible that the carried resin used for the yellow pigment is different than the red and carbon black.)

(e) Armor-Tile products (epoxy)

Figure 6-40 shows the surface appearance of yellow coupons after 3,000 hours of exposure in three xenon conditions and 24 months of outdoor exposure. Photographs for other outdoor exposure periods are included in Appendix-M(e). A gradual fading in color and circular pattern with exposure time can be observed in all exposure conditions. The surface morphology of the 24-month outdoor is more similar to the 3,000 hours xenon coupon in Condition [A] than other two higher irradiance conditions.

ADA Solutions – Original

ADA Solutions – Xenon Condition [A]

ADA Solutions – Xenon Condition [B]

ADA Solutions – Xenon Condition [C]

ADA Solutions – Outdoor 24 months

Figure 6-36 – Surface appearance of ADA Solutions coupons in three xenon conditions after 3,000-hr and outdoor exposure

AlertCast – Original

AlertCast – Xenon Condition [A] 3,000hr.

AlertCast – Xenon Condition [B] 3,000 hr.

AlertCast – Xenon Condition [C] 3,000 hr.

AlertCast – Outdoor 24 months

Figure 6-37 – Surface appearance of AlertCast coupons in three xenon conditions and outdoor exposure

Redimat – Original

Redimat – Xenon Condition [A] 500hr.

Redimat – Xenon Condition [B] 500 hr.

Redimat – Xenon Condition [C] 500 hr.

Redimat – Outdoor 8 months

Figure 6-38 – Surface appearance of Redimat coupons in three xenon conditions and outdoor exposure

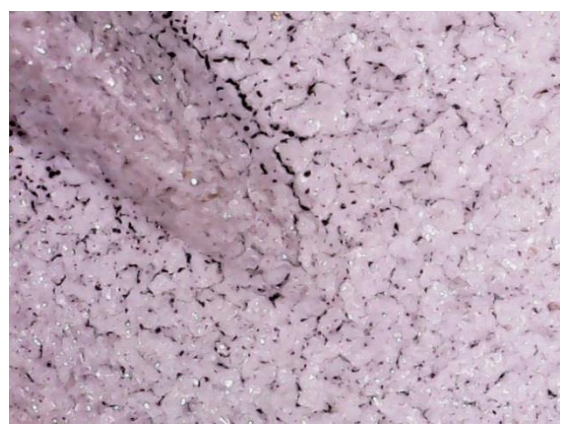
SafeRoute – Original

SafeRoute – Xenon Condition [A] 3,000hr.

SafeRoute – Xenon Condition [B] 3,000 hr.

SafeRoute – Xenon Condition [C] 3,000 hr.

SafeRoute – Outdoor 12 months



SafeRoute – Outdoor 24 months

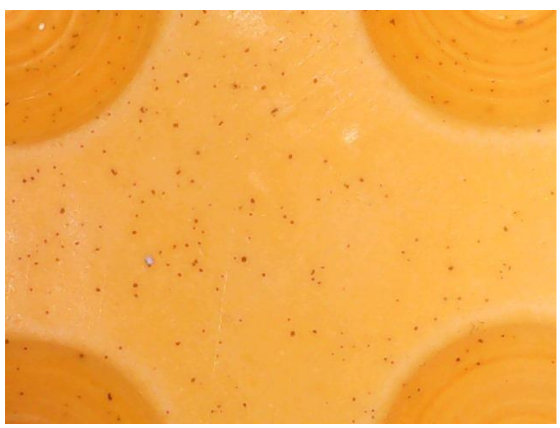
Figure 6-39 – Surface appearance of SafeRoute coupons in three xenon conditions and outdoor exposure

Armor-Tile – Original

Armor-Tile – Xenon Condition [A] 3,000hr.

Armor-Tile – Xenon Condition [B] 3,000 hr.

Armor-Tile – Xenon Condition [C] 3,000 hr.



Armor-Tile – Outdoor 24 months

Figure 6-40 – Surface appearance of Armor-Tile coupons in three xenon conditions and outdoor exposure

6.4.2 Color measurement test

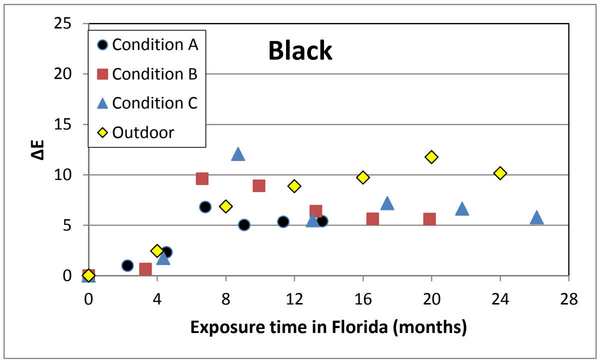
The mass loss obtained from the abrasion test is compared between xenon exposed coupons and outdoor-exposed coupons. The Florida time is used for the comparison. (The color test data are included in Appendix-N.)

(a) ADA Solutions products (polyester)

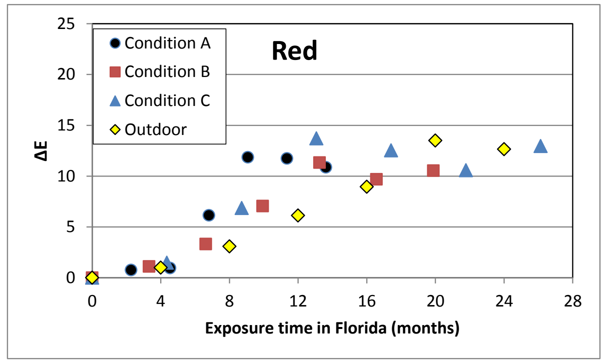
Figure 6-41(a), (b), and (c) show plots of ΔE versus equivalent the Florida time for black, red and yellow coupons, respectively. In general, the ΔE value increased with exposure time initially and then leveling out for all three colors. For the black color, the outdoor-exposed coupons show a greater increase in ΔE than coupons exposed to three xenon conditions after 12 months of the Florida time. Contrary, ΔE increased higher in xenon exposure conditions for the red and yellow coupons during the first 14 to 16 month, after which the ΔE values reached to similar value as the outdoor condition.

(b) AlertCast products (polyester NPG)

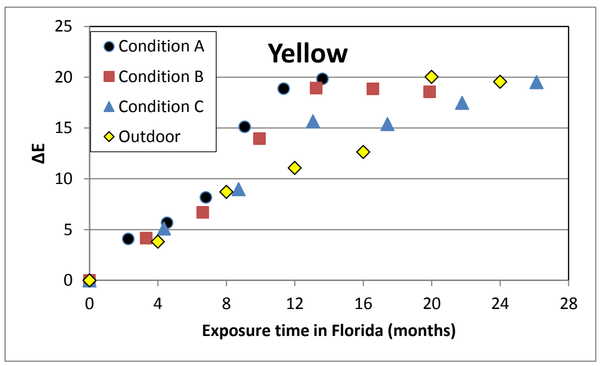
Figure 6-42(a), (b), and (c) show plots of ΔE versus equivalent the Florida time for black, red and yellow coupons, respectively. For the black coupons, ΔE increased very slightly with exposure time, from 0 to 5 for Conditions [A] and [C], and from 0 to 2.5 for the outdoor and Condition [B]. Considering the variation in the measurement, the color changes are very similar in all four exposure conditions for the black coupon. The ΔE values of red and yellow coupons increased much more than the black coupon, and the greatest increase was measured in coupons exposed to Condition [A]. For Conditions [B] and [C], the ΔE value reached a plateau, while it increased steadily with exposure time for the outdoor coupons. The red coupon shows similar changes in ΔE between Condition [B] and outdoor. The ΔE measured from the yellow outdoor coupon is lower ΔE than the xenon conditions.



(a) ADA Solutions – Black

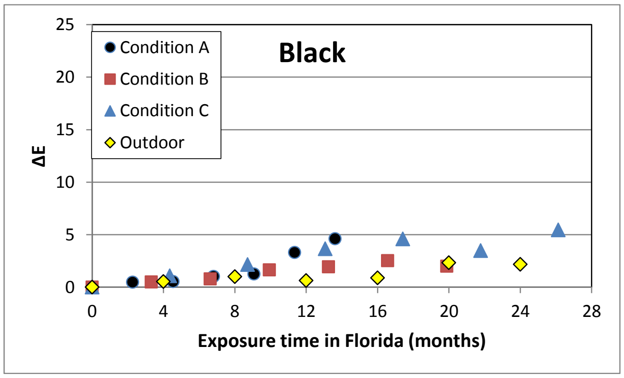


(b) ADA Solutions – Red

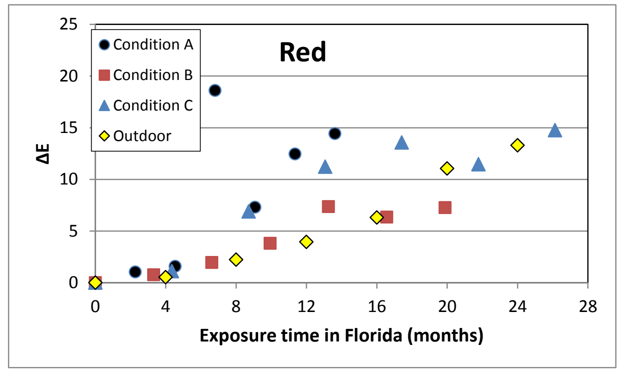


(c) ADA Solutions– Yellow

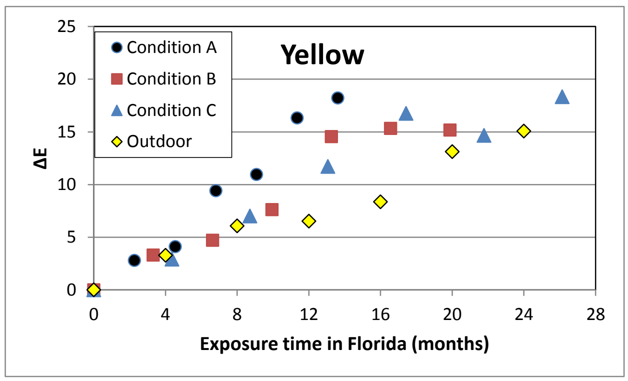
Figure 6-41 – Color change (ΔE) versus the Florida exposure time for coupons of ADA Solutions



(a) AlertCast – Black



(b) AlertCast – Red

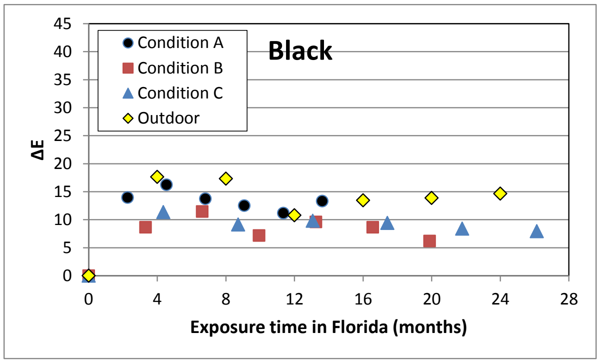


(c) AlertCast – Yellow

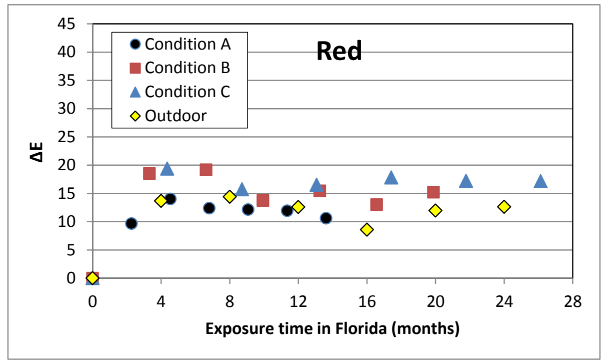
Figure 6-42 – Color change (ΔE) versus the Florida exposure time for coupons of AlertCast

(c) <u>Redimat products (polyurethane)</u>

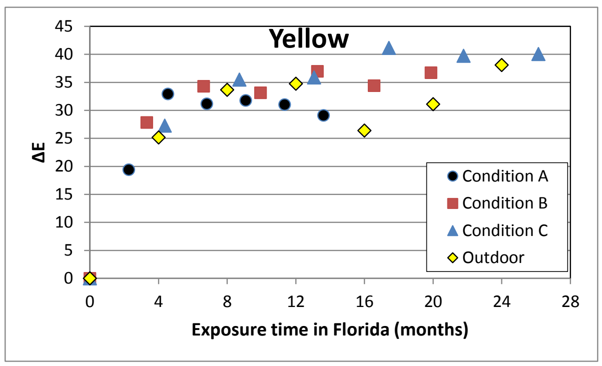
Figure 6-43(a), (b), and (c) show plots with ΔE versus equivalent the Florida time for black, red and yellow coupons, respectively. The ΔE increased greatly in the first 4 months of the Florida time regardless the color and exposure condition. After that, the ΔE values remained relatively constant throughout the rest of exposure time. The black coupon has the lowest increase (ΔE ranging from 10 to 15) follow by the red color (ΔE ranging from10 to 20), whereas the yellow color has the highest ΔE increase (ΔE ranging from 30 to 40). There is no significant different in the ΔE values between four exposure conditions.



(b) Redimat – Black



(b) Redimat – Red

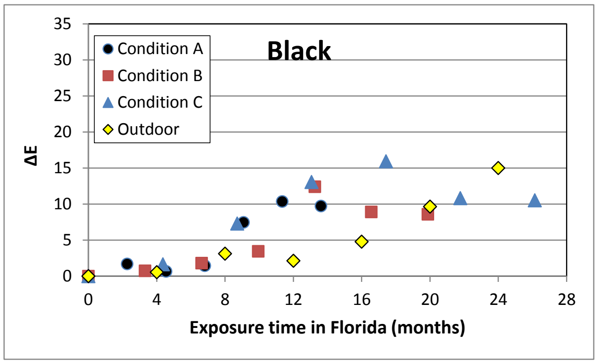


(c) Redimat - Yellow

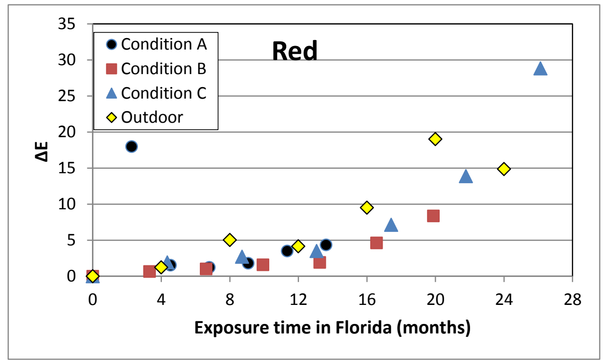
Figure 6-43 – Color change (ΔE) versus the Florida exposure time for coupons of Redimat

(d) <u>SafeRoute products (polyolefins)</u>

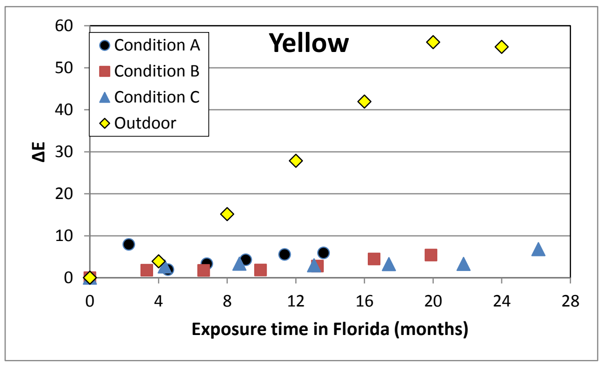
Figure 6-44(a), (b), and (c) show plots with ΔE versus equivalent the Florida time for black, red and yellow coupons, respectively. The changing trends of ΔE are very different between xenon and outdoor conditions for black and yellow coupons. For the black outdoor coupon, the ΔE value increased steadily with time, while the ΔE values of xenon exposed coupons reached a plateau at different exposure times depending on the test condition. For the red color coupons, all four curves are relatively similar, showing a steadily increase in ΔE with exposure time. The unexpected results were found in the yellow coupons. The ΔE value measured from the outdoor coupons increased linearly with exposure time until 20 months after which it remained the same. Also, the outdoor coupons have much higher ΔE values than the xenon exposed coupons. The reason for this drastic difference in ΔE is due to the amount of white coating on the coupon's surface.



(a) SafeRoute – Black



(b) SafeRoute – Red

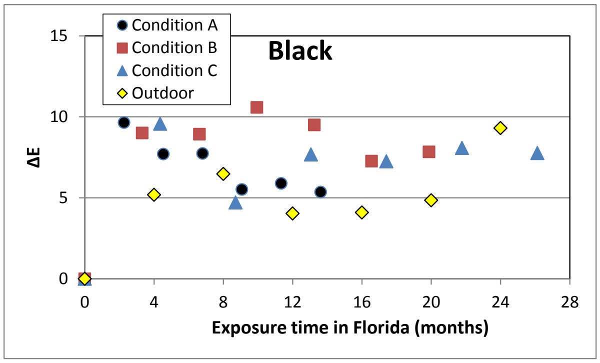


(c) SafeRoute - Yellow

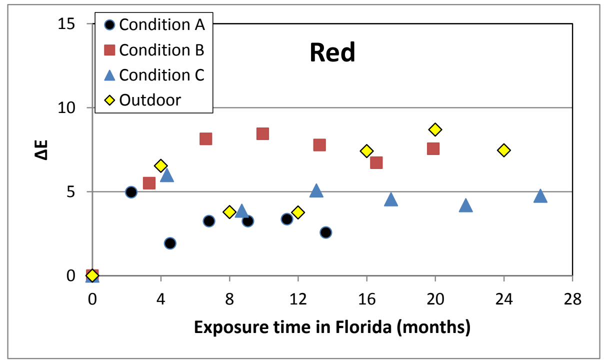
Figure 6-44 – Color change (ΔE) versus the Florida exposure time for coupons of SafeRoute

(e) <u>Armor-Tile (epoxy)</u>

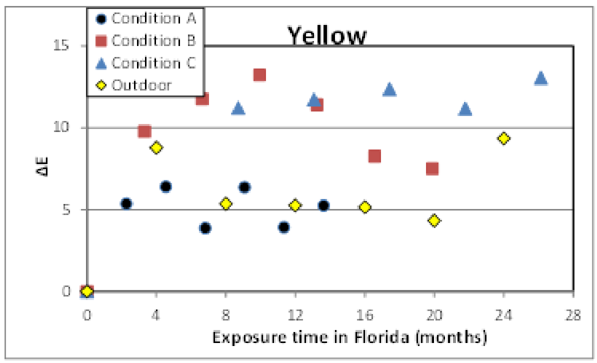
Figure 6-45(a), (b), and (c) show graphs plotting ΔE versus equivalent the Florida time for black, red and yellow coupon, respectively. In comparing to other DWS products, the ΔE values obtained from this product have an enormous disparity than the others. The ΔE value increased to a range between 5 and 10 during the first 4 months of the Florida time for the black coupons, and between 2 and 9 for the red coupons, and between 4 and 14 for the yellow coupons. Because of the disparity of the test data, it is difficult to identify the difference between four exposure conditions.



(a) ArmorTile – Black



(b) ArmorTile – Red



(c) ArmorTile – Yellow

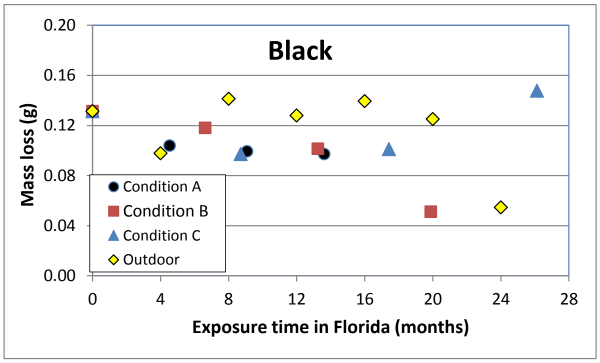
Figure 6-45 – Color change (ΔE) with the Florida exposure time for coupons of Armor-Tile

6.4.3 Abrasion test

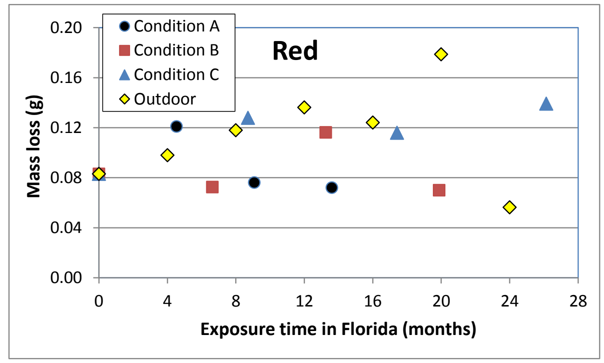
The mass loss obtained from the abrasion test is compared between xenon exposed coupons and outdoor-exposed coupons. The Florida time is used for the comparison. (Test data are included in Appendix-O.)

(a) <u>ADA Solutions products (polyester)</u>

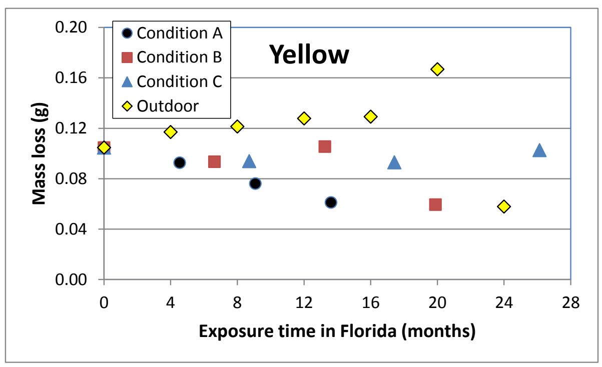
Figure 6-46(a), (b), and (c) show plots of mass loss versus the Florida exposure time for black, red and yellow coupon, respectively. Considering the large variation in each set of tests, the change of mass loss can be considered to be relatively similar.



(b) ADA Solutions – Black



(b) ADA Solutions – Red

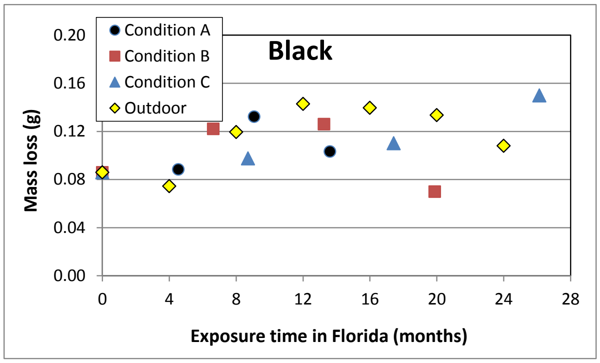


(C) ADA Solutions – Yellow

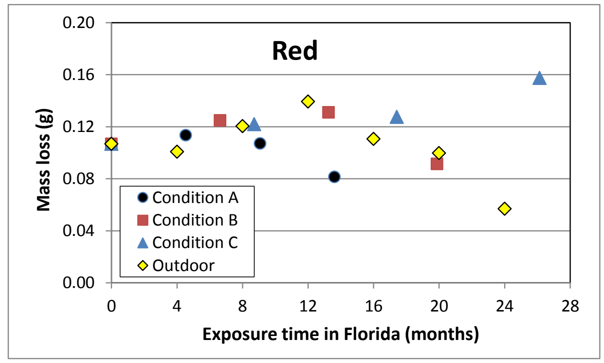
Figure 6-46 – Mass loss versus the Florida exposure time for ADA Solutions coupons

(b) <u>AlertCast products (polyester NPG)</u>

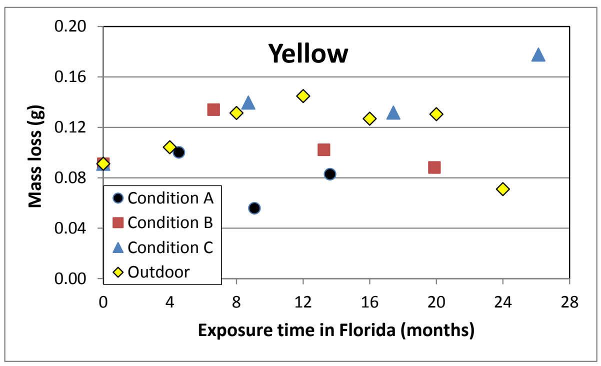
Figure 6-47(a), (b), and (c) show plots of mass loss versus the Florida exposure time for black, red and yellow coupon, respectively. Regardless the color or exposure condition, most of mass loss ranges between 0.08 and 0.16 grams. The mass loss in Condition [B] and outdoor are similar, showing a trend with initially increase and then decrease for all three colors. In Condition [C], the mass loss increased slightly with time in all three colors.



(a) AlertCast – Black



(b) AlertCast – Red

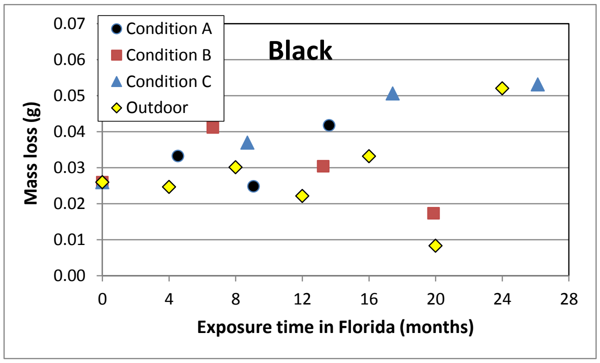


(c) AlertCast – Yellow

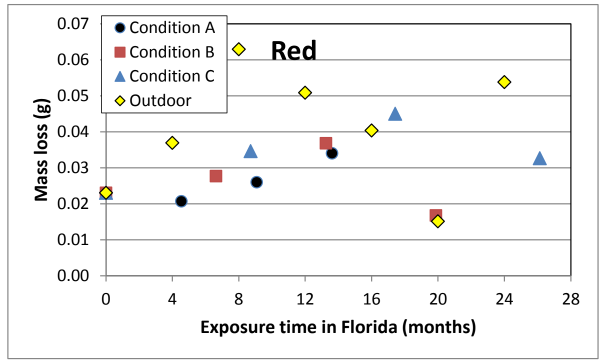
Figure 6-47 – Mass loss versus the Florida exposure time for AlertCast coupons

(c) <u>Redimat products (polyurethane)</u>

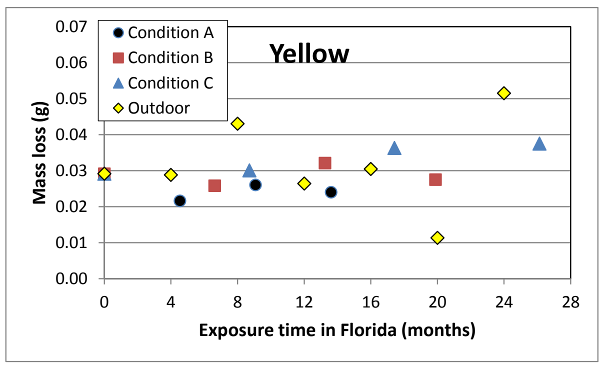
Figure 6-48(a), (b), and (c) show plots of mass loss versus the Florida exposure time for black, red and yellow coupon, respectively. The amount of mass loss for this product is much less than the two polyester based products from ADA Solutions and AlertCast. The variation of mass loss for the outdoor coupon is very large, making it difficult to compare with the xenon conditions.



(a) Redimat – Black



(b) Redimat – Red

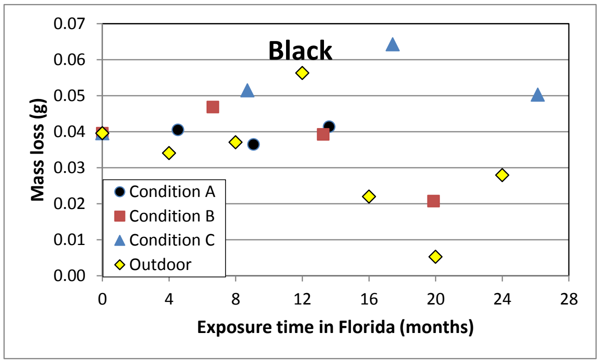


(c) Redimat – Yellow

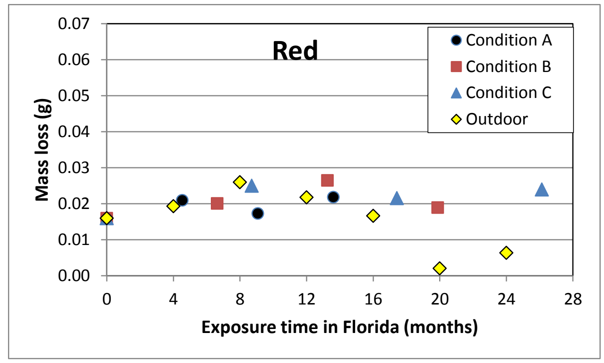
Figure 6-48 – Mass loss versus the Florida exposure time for Redimat coupons

(d) SafeRoute (polyolefin)

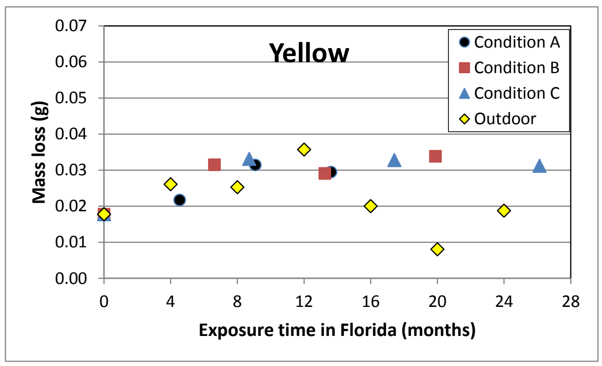
Figure 6-49(a), (b), and (c) show plots of mass loss versus the Florida exposure time for black, red and yellow coupon, respectively. The amount of mass loss for this product is in the similar order of Redimat coupons. The red coupon showed the least mass loss with mass loss around 0.02 grams for all four exposure conditions. For the red and yellow coupons, similar amount of mass loss was obtained in all four exposure conditions during the first 14 months the Florida time after which the mass loss decreased in the outdoor coupon. The disparity of mass loss increased with time for the black coupons.



(a) SafeRoute – Black



(b) SafeRoute – Red

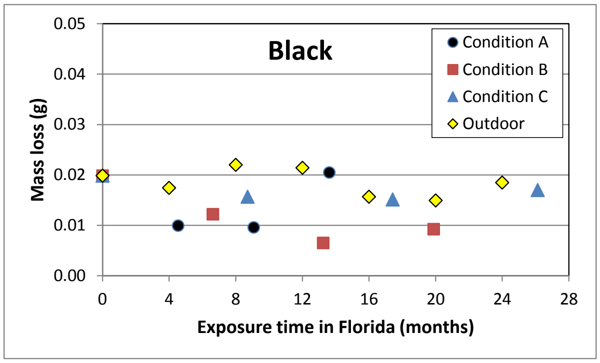


(c) SafeRoute – Yellow

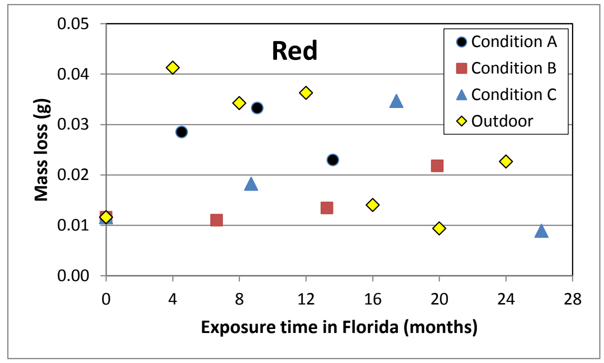
Figure 6-49 – Mass loss versus the Florida exposure time for SafeRoute coupons

(e) <u>Armor-Tile products (epoxy)</u>

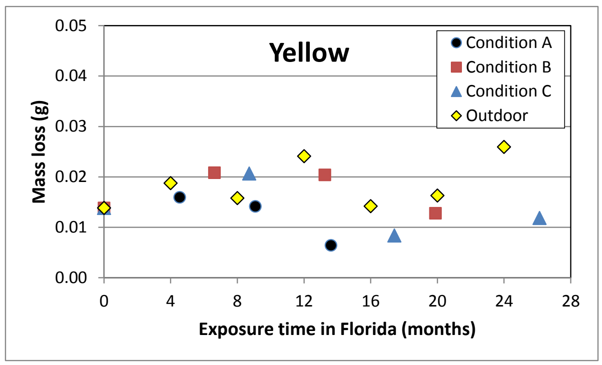
Figure 6-50(a), (b), and (c) show plots of mass loss versus the Florida exposure time for black, red and yellow coupon, respectively. The mass loss of this product is lower than other four DWS products. The black and yellow coupons have a lower mass loss than the red in all four exposure conditions, ranging from 0.01 to 0.02 grams. The red coupons showed a large scattering in the mass loss data. Overall, the outdoor coupons behaved similarly to those exposed to the three xenon conditions.



(a) ArmorTile – Black



(b) ArmorTile – Red



(c) ArmorTile – Yellow

Figure 6-50 – Mass loss versus the Florida exposure time for Armor-Tile coupons

6.4.4 Summary

For the DWS products, Table 6-3 summarizes the differences in test data between outdoor exposure and three xenon conditions. The correlation varies between products as well as colors within the same product. The color change is a more reliable test method than the mass loss in this study. (Note that the abrasive test device is a laboratory prototype constructed at Drexel University. A professionally constructed device is expected to have a greater precision.) For the two polyester based products (ADA Solutions and AlertCast), Condition [B] of xenon exposure seems to match the outdoor environment, except for the black ADA Solutions and yellow AlertCast. The Redimat products which are made from polyurethane do not seem to be sensitive to different exposure conditions. For the polyolefin, SafeRoute products, the sunlight effect varies with color. The black and red coupons showed a similar behavior between outdoor and Condition [B]. Contrary, the outdoor behavior of yellow coupons is unable to be duplicated in xenon exposure. For the Armor-Tile (epoxy) products, the large variation in color change measurements caused by the reflection of aluminum particles makes it difficult to compare different exposure conditions.

Table 6-3 – Comparing Material Behavior between Outdoor and Xenon

Coupon Information		**Surface Morphology**	**Color Change**	**Mass Loss**
Product	Color	Outdoor versus Xenon		
ADA Solution	Black	Fibers appeared on C but not on the Outdoor	Higher than Xenon	No correlation
	Red		Similar to B and C (> 16 months)	
	Yellow		Similar to B and C (> 20 months)	
AlertCast	Black	Fibers appeared on C but not on the Outdoor	Similar to B	No correlation
	Red		Similar to B	Similar to B
	Yellow		Lower than A, B, and C	Similar to B
Redimat	Black	Small fibers observed on A, B, and C after 500 hours, and Outdoor after 8 months	Similar to all	No correlation
	Red			
	Yellow			
SafeRoute	Black	White particles covered B, C, and Outdoor	Similar to B	Similar (<12 months)
	Red		Similar to all	
	Yellow	White coating completely covered 24 months Outdoor, while partially covered on C	Higher than Xenon	
AmorTile	Black	Bright reflective areas appeared on coupons	Similar to A (12 months)	Similar to all
	Red			
	Yellow			

6.5 Degradation Mechanism of DWS Products

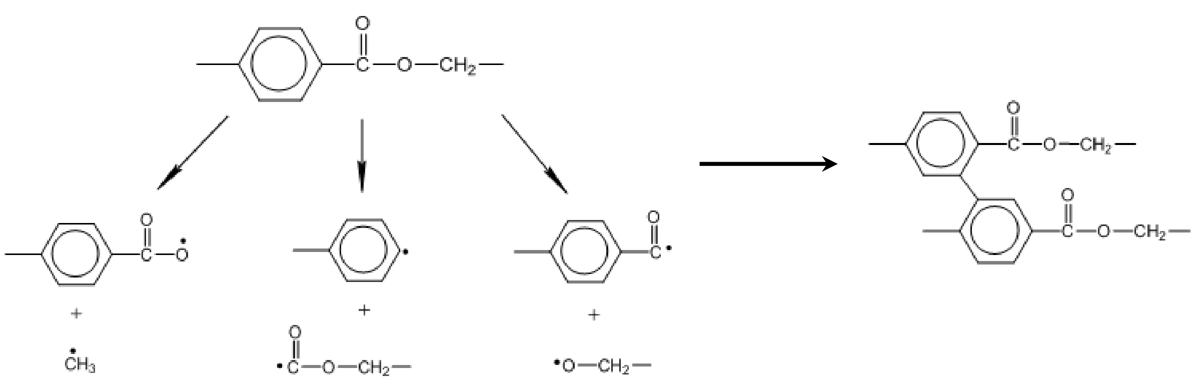
This section discusses the five DWS products, which were manufactured from various polymers. Because the actual material formulation (particularly the additives) was not fully revealed by the manufacturers, the degradation mechanism presented in the section is based on the general polymer type indicated on the public website of the product. Furthermore, the test methods used to assess the sunlight degradation of DWS are not at the molecular level, i.e., measuring the chemical bond changes as sunlight exposure time increases.

6.5.1 Degradation mechanism of polyesters

The DWS samples supplied by ADA Solutions (ADA products) and Cape Fear Systems (AlertCast products) were made from polyester. ADA Solutions did not specify the type of polyesters. The AlertCast samples from Cape Fear Systems were indicated using neopentyl glycol (NPG) as one of the monomers, but no additional information for the type of polyester. The incomplete material information of these two groups of DWS samples makes it difficult to identify the exact photodegradation mechanism. The following section describes the general sunlight degradation mechanism of aromatic polyesters and aromatic polyesters consisting of neopentyl glycol (NPG) is presented.

(a) <u>Aromatic polyesters</u>

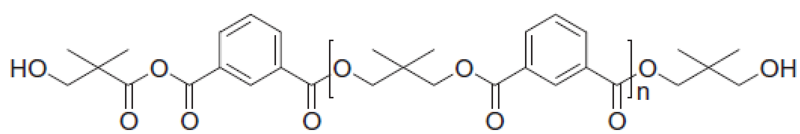
The most common types of aromatic terephthalate based polyesters are poly(ethylene terephthalate) (PET) and poly(butylene terephthalate) (PBT). When radiation is absorbed by the polymer, Norrish (type I and II)[1] cleavage leads to chain scission around the ester group and forms free radicals (Rivaton, Photochemistry of poly(butyleneterephthalate): 1—Identification of the IR-absorbing photolysis products, 1993a). These free radicals can abstract hydrogen from other polymer molecules continuing the chain scission and forming molecules with hydroxyl, carboxyl, and aldehyde end-groups. Hydrogen abstraction may also form some radicals which can recombine and form cross-links (Rivaton, 1993(b)):



[1] Norrish cleavage reactions involve the dissociation of single or double bond under ultraviolet irradiation, forming free radicals. Type I reactions occur in carbonyl compounds (ketones, aldehydes, etc.) by dissociate the α bond at wavelength of 230- to 330-nm. Type II reactions occur by formation of a biradical through intramolecular hydrogen abstraction.

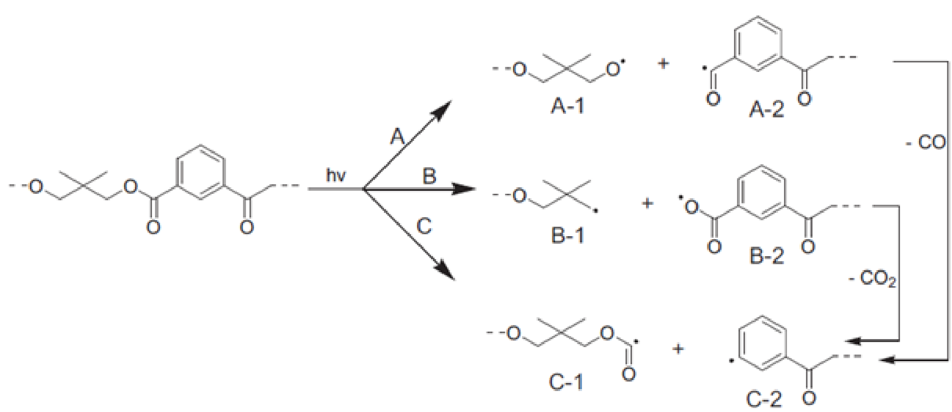
(b) <u>Polyesters containing neopentyl glycol</u>

Instead of using ethylene glycol, neopentyl glycol is used with dimethyl terephthalate to produce different types of aromatic polyesters with greater photodegradation resistance. Malanowski et al., (2011, 2012) studied the photodegradation using SUNTEST weatherometer on two types of polyesters (poly(neopentyl terephthalate) (PNT) and poly(neopentyl isophthalate) (PNI). They found PNT is much less stable under the simulated sunlight than PNI, although the degradation mechanism is the same for both polymers via free radical reactions leading to carbonyl and hydroxyl group formation. The photodegradation leads to chain scission and crosslinking occurring together, as shown in the following reactions:

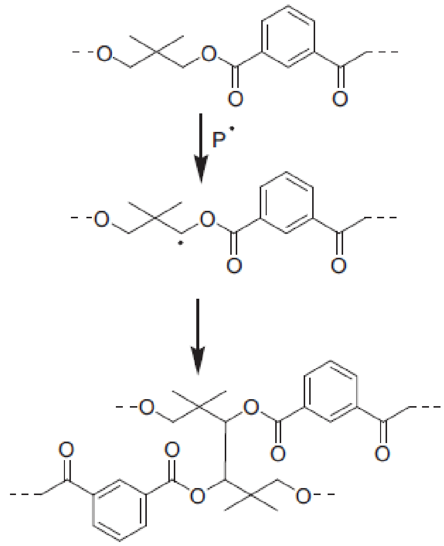


PNT

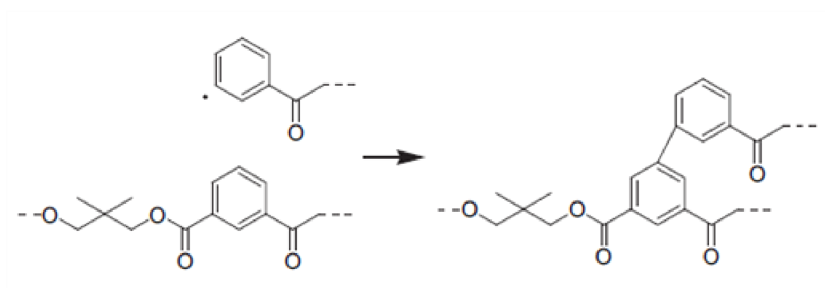
(Malanowski et al., 2012)



Norrish type 1 photo-cleavage of ester group (Malanowski et al., 2011)



Chain coupling reaction forming cross-linking (Malanowski et al., 2011)



Grafting of free radical to ester forming cross-linking (Malanowski et al., 2011)

(c) <u>Analytical methods used to evaluate the degradation</u>

The major sunlight degradation mechanism of polyesters is cross-linking, leading to discoloration and embrittlement. To confirm the degradation mechanisms, a sophisticated analytical tool, such as FTIR, is required to detect the chemical bond changes. However, the color pigment and other additives in these two DSW products make the analysis very challenging. We were unable to obtain a meaningful FTIR spectrum, even from the original unexposed samples. The alternative method is to measure the change in the glass transition temperature (T_g). T_g is related to the molecular configuration. In general, cross-linking leads to higher rigidity (less movement) in the polymer chains, leading to an increase in T_g. To investigate the cross-linking in the xenon exposed ADA and AlertCast samples, the unexposed samples and exposed samples in Condition [C] for 3,000 hours were examined using differential scanning calorimeter (DSC). The test specimen was obtained by grinding the sample surface with sand paper disc that is used for the surface abrasion test. A sample of approximately 4 mg was weighed, and heated from -60°C to 400°C under nitrogen atmosphere. Figures 6-51 and 6-52 show the thermal curves of red ADA and AlertCast samples, respectively. The two types of polyesters exhibit very similar melting peak (T_m) ranging from 300°C to 320°C.

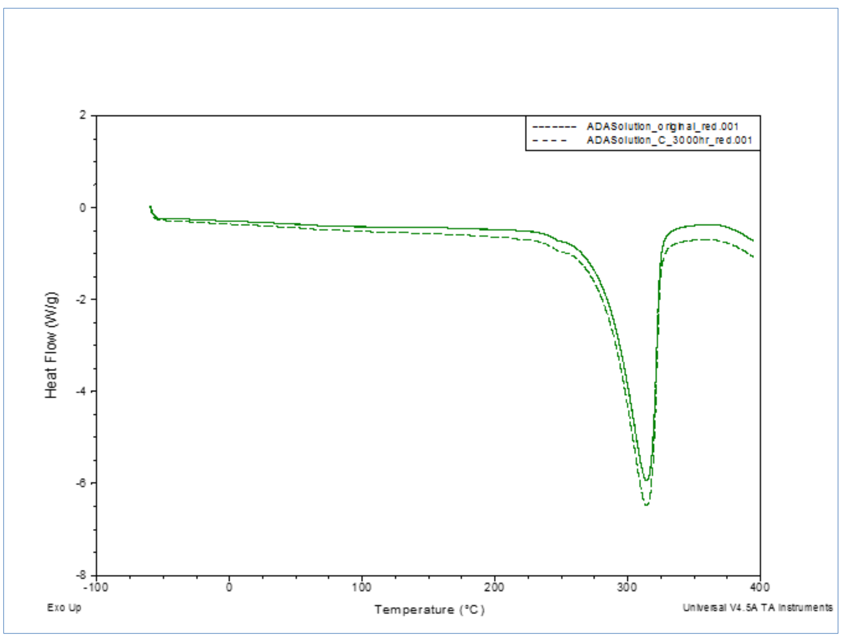


Figure 6-51 – Thermal curve of ADA red samples: original and Condition [C] at 3,000 hours

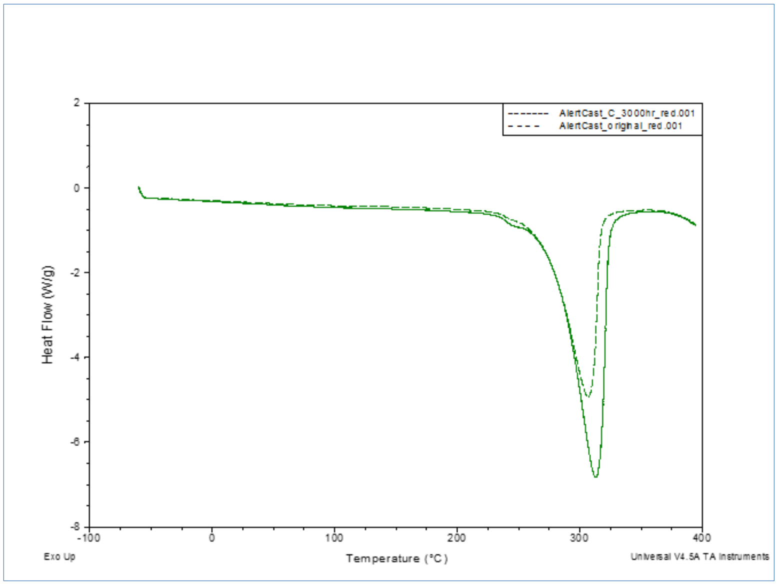
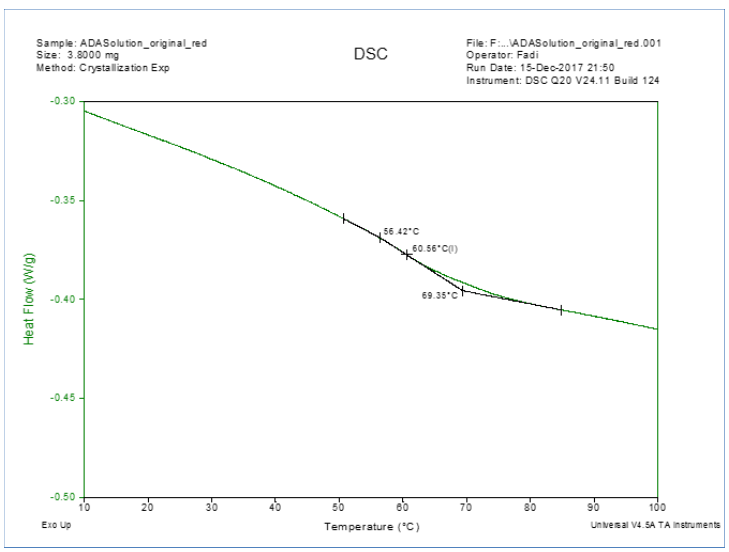


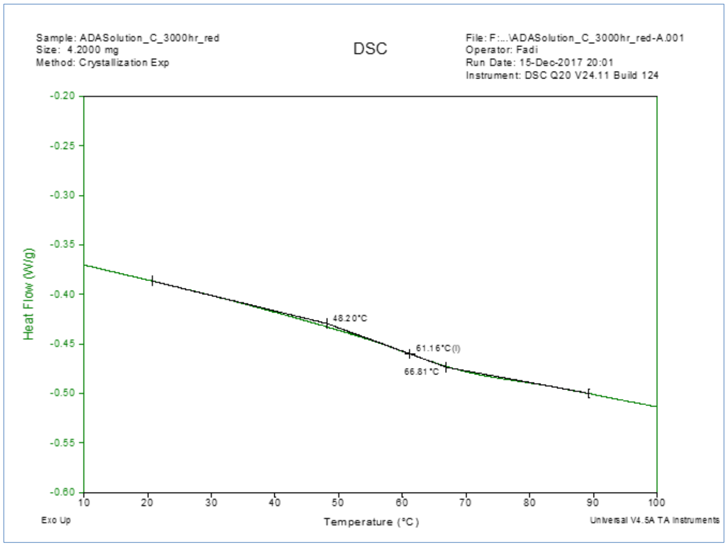
Figure 6-52 – Thermal curve of AlertCast red samples: original and Condition [C] at 3,000 hours

The glass transition temperature was identified by analyzing the section of thermal curve between 10°C and 100°C. Figure 6-53 shows the T_g transition of red ADA samples, and Figure 6-54 shows the red AlertCast samples.



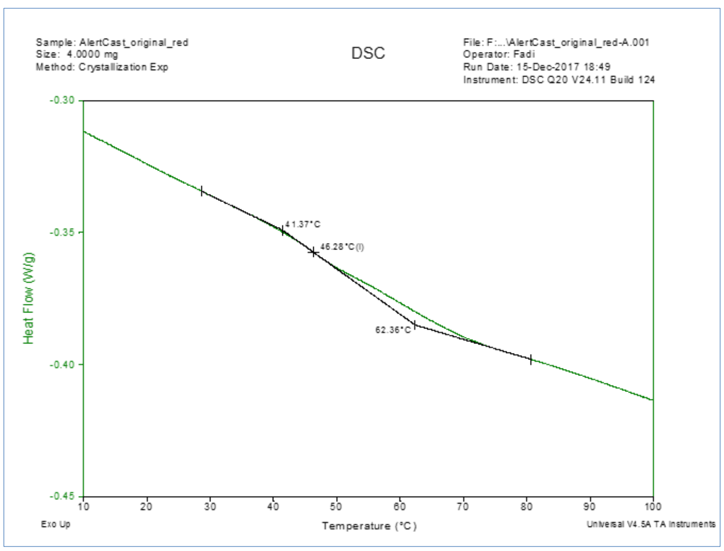
(a)

Figure 6-53 – Glass transition temperature of red ADA samples
(a) Unexposed samples and (b) 3,000 hr. Condition [C] sample



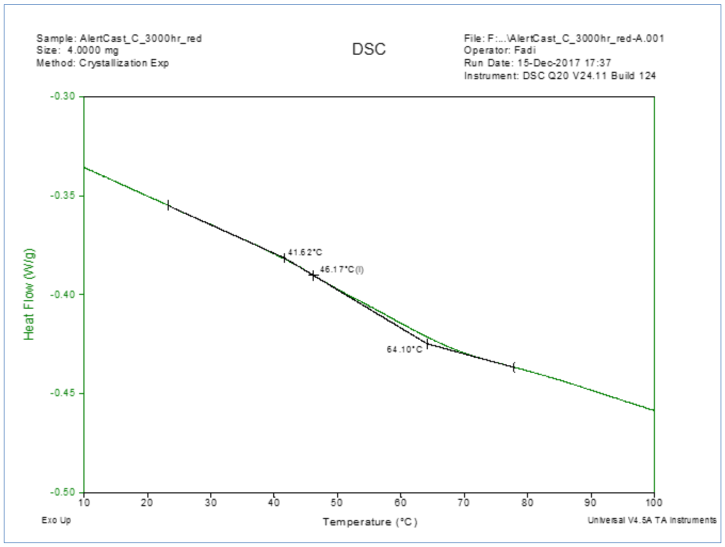
(b)

Figure 6-53 – Continued



(a)

Figure 6-54 – Glass transition temperature of red AlertCast samples
(a) Unexposed sample and (b) 3,000 hr. Condition [C] sample



(b)

Figure 6-54 – Continued

Table 6-3 shows the T_g and T_m values which are essentially the same before and after exposure in xenon weatherometer under Condition [C]. The result suggests that the thermal transition temperatures (both T_m and T_g) are not sensitive to detect the molecular changes in both DWS products. Therefore, test methods that assess the physical and mechanical changes in result of the sunlight degradation are used in this project. The test methods included color changes, surface morphology, and abrasion test.

Table 6-4 – Thermal Transition Temperatures for Red ADA and Red AlertCast Samples

Product	Polymer	Sample Color	Exposure Duration (hr.)	Exposure Condition	Melting Peak Temperature (°C)	Glass Transition Temperature (°C)
ADA	Polyester	Yellow	0	NA	310.6	61.7
			3,000	C	307.6	61.6
		Red	0	NA	314.2	60.6
			3,000	C	314.2	61.2
		Black	0	NA	305.0	62.4
			3,000	C	311.5	58.6
AlertCast	Polyester (NPG)	Yellow	0	NA	310.4	45.6
			3,000	C	312.4	46.3
		Red	0	NA	306.6	46.3
			3,000	C	312.9	46.2
		Black	0	NA	307.9	46.3
			3,000	C	308.9	46.1

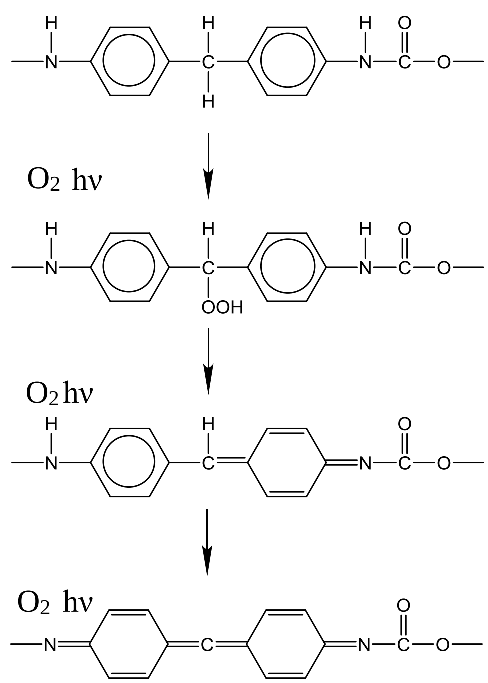
Note: NA = Not applicable

6.5.2 Degradation mechanism of polyurethane

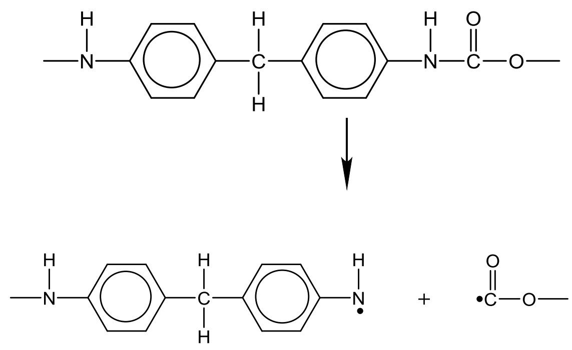
The Redimat DWS samples supplied by Detectable Warning Systems Company were identified to be made from polyurethane. However, the company did not specify the type of polyurethane. In this section, the sunlight degradation mechanisms of two types of the polyurethanes: aromatic polyurethanes and aliphatic polyurethanes are presented.

(a) Aromatic polyurethanes

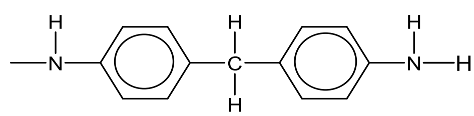
Aromatic polyurethanes go through two simultaneous processes. One of these processes is shown below (Wilhelm and Gardette, 1997 and 1998; Wilhelm et al., 1998):



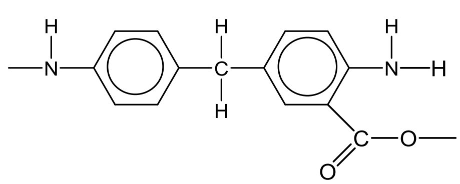
The above model shows the mechanism of discoloring but cannot explain the changes in mechanical properties of aromatic polyurethanes. Another process, which occurs simultaneously with the above mechanism, causes a change in mechanical properties:



If the amino radical abstracts hydrogen and does not react with the other radical, the following product is formed:

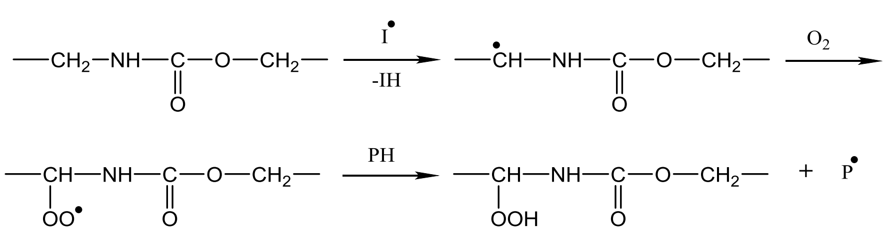


If the amino radical reacts with the other radical, the following product is formed:

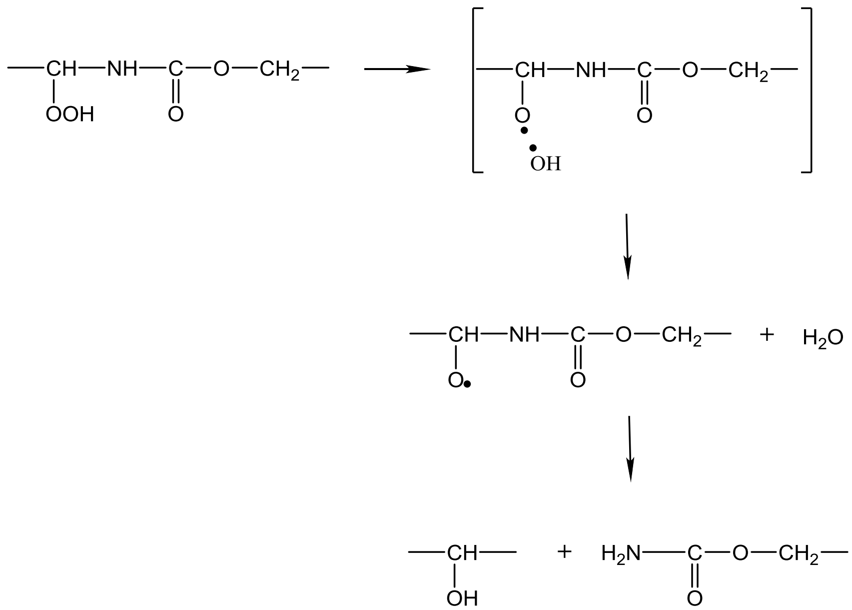


(b) Aliphatic polyurethanes

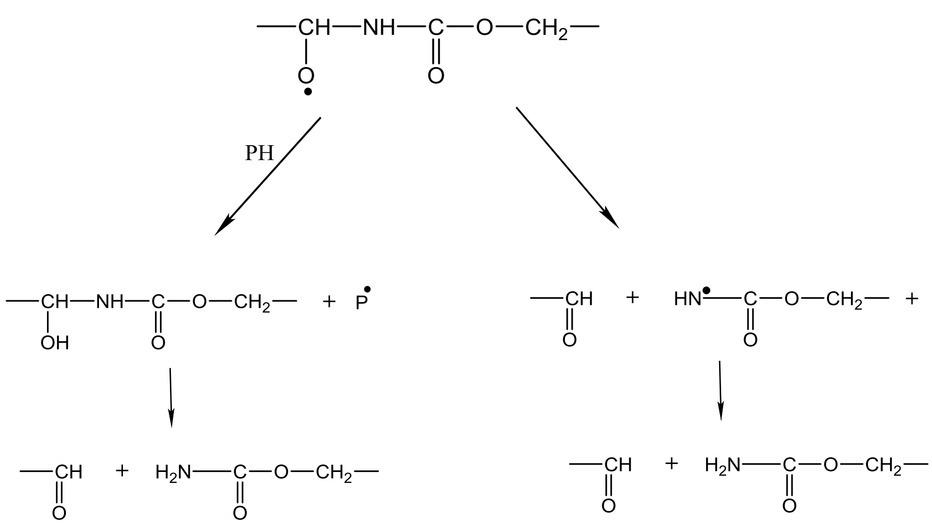
In aliphatic polyurethanes, the methylene group undergoes photo-oxidation as follows:



Acetylurethane is formed in a cage reaction and reacts with water:



Alkoxy radical can also abstract hydrogen and form an unstable hydroxylated product which might convert to aldehyde and amine or it may go through a β-scission. Both reactions result in the same product:



(c) <u>Test methods used to evaluate the degradation</u>

The sunlight degradation of polyurethane forms conjugated double bonds and chain scissions, causing discoloration and embrittlement. To confirm this degradation mechanism, FTIR is typically an appropriate analytical tool to detect the chemical bond changes. However, similar to the scenario with the two polyester DWS products, the color pigment and other additives in Redimat products preclude the use of FTIR. An alternative method is to measure the change in melting point (T_m). T_m can be related to the molecular weight of the polymer. In general, chain scission may lower T_m. To investigate the chain scission in the xenon exposed Redimat samples, the unexposed samples and exposed samples in Condition [C] for 3,000 hours were examined using differential scanning calorimeter (DSC). The test specimen was obtained by grinding the sample surface with sand paper disc that is used for the surface abrasion test. A sample of approximately 4 mg was weighed, and heated from -60°C to 400°C under nitrogen atmosphere. Figure 6-55 shows the thermal curve of red Redimat samples. The original and exposed samples have a similar melting peak (T_m) in the range of 375°C. The result suggests that the T_m was not sensitive enough to reflect the molecular changes due to photodegradation in this study. Therefore, test methods that assess the physical and mechanical changes in result of the sunlight degradation are used in this project. The test methods included color changes, surface morphology, and abrasion test.

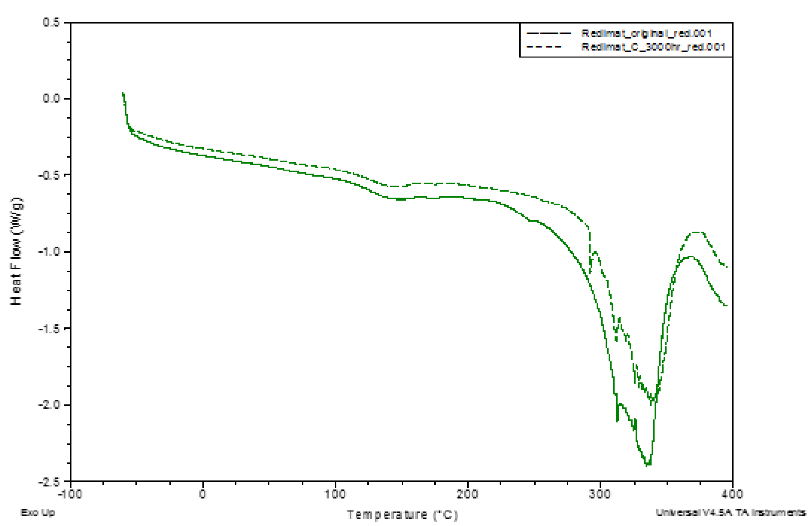


Figure 6-55 – Thermal curve of Redimat red samples: original and Condition [C] at 3,000 hours

6.5.3 Degradation mechanism of polyolefin

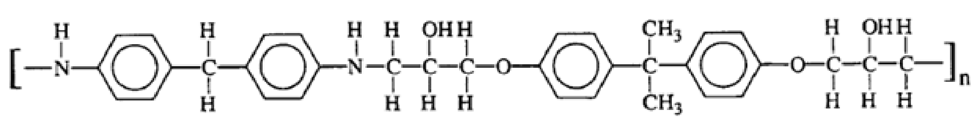
The principal degradation mechanism of polyethylene has been described in Section 5.6. Polypropylene (PP) and PE/PP copolymers undergo similar photodegradation reactions. However, PP degrades faster than PE because it has more tertiary carbon atoms which are susceptible to disassociate to form free radicals. Since every other carbon atom along the polymer chain is a tertiary carbon in PP, the oxidation rate of PP is significantly faster than PE. For PP or its copolymers, a stabilizer package is added to the polymer to delay the onset of oxidation. The OIT values shown in Table 2-3 confirm the presence of stabilizer in these three samples, but at a very low value. The amount of filler at 40-wt% was measured in this group of DWS products to increase the hardness of the product and also lower the cost. The common filler is calcium carbonate ($CaCO_3$) which is an inert white powder being mixed into the polymer during the extrusion process. The filler does not influence the sunlight degradation mechanism.

(a) Test methods used to verify the degradation mechanism

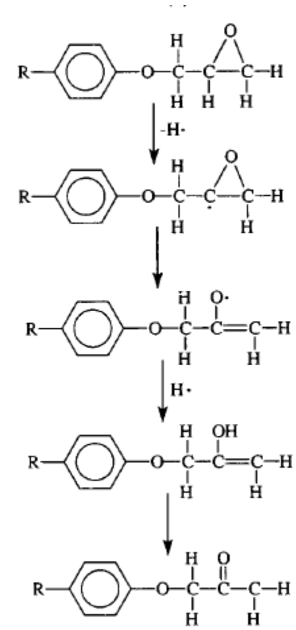
For the SafeRoute DWS samples, the sunlight degradation will first take place through the consumption of stabilizers as shown in Figure 5-23. However, the initial OIT values for these samples are very low, suggesting that the amount of stabilizers in the samples is relatively small. To be consistent with other DWS test samples, the same tests (color, surface morphology and abrasion resistance) are used to assess the impact of sunlight degradation on the physical and mechanical properties.

6.5.4 Degradation mechanism of epoxy

The Armor-Tile DWS samples supplied by the Engineered Plastics Inc. were identified made from epoxy coated with aluminum particles. The common epoxy resins are based on bisphenol A diglycidyl ether, as shown below:



The photon energy excites the epoxy group causing bond scission and formation of carbonyl groups, (Bhavesh et al., 2002; Wypych, 2013)



(a) Test methods used to verify the degradation mechanism

The main photodegradation mechanism of epoxy is the formation of carbonyl groups via chain scissions leading to embrittlement. To confirm this degradation mechanism, FTIR is an appropriate analytical tool to detect the chemical bond changes. However, as with other DWS products, the color pigment and other additives in Armor-Tile DWS samples preclude the use of FTIR. DSC analysis was performed on the original and exposed black sample after 3,000 hours in Condition [C]. The test specimens were heated from -60°C to 400°C at 10°C/min in nitrogen gas, and thermal curves are superimposed in Figure 6-56. Unexpectedly, a well-defined melting peak around 285°C was detected in both original and exposed samples. Epoxy is a thermoset material which should be a fully amorphous phase without crystalline phase. Although there was a small amount of recrystallization in the original sample at 163°C, the melting point area suggests that there was a fair amount of crystalline phase in the material. The glass transition temperature (T_g) was measured to be around 61°C to 63°C. Overall there was no notable change in thermal transition properties (T_m and T_g) after 3,000 hours exposure in Condition [C]. Therefore, test methods that assessed the physical and mechanical changes because of the sunlight degradation included color changes, surface morphology, and abrasion testing.

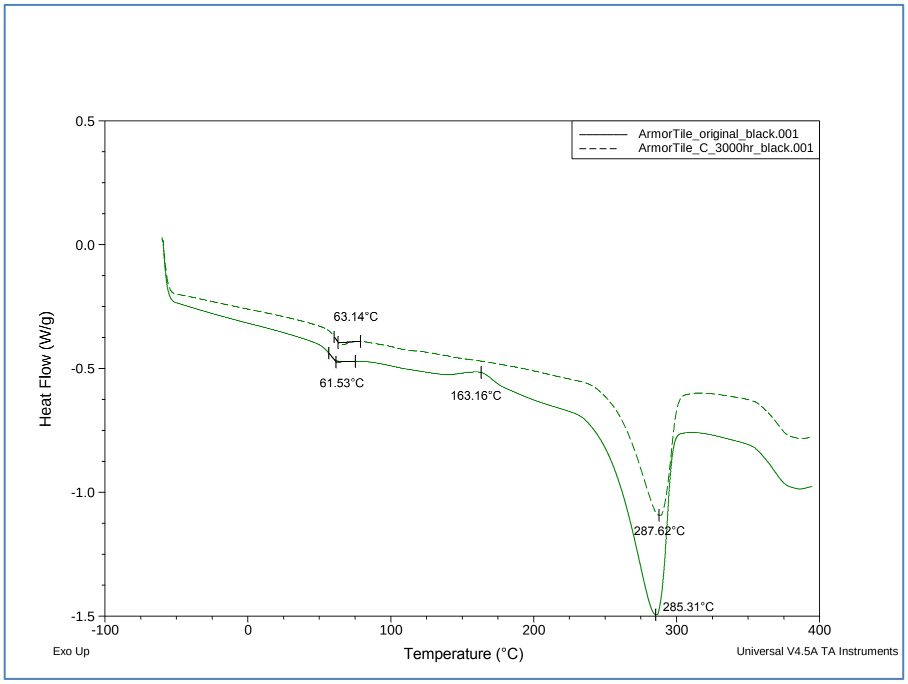


Figure 6-56 – DSC thermal curve for black Armor-Tile DWS samples: original and Condition [C] at 3,000 hours

6.6 Test Protocol for DWS Products

The test protocol for DWS products is based on the test results of five DWS products (15 samples) evaluated in this project. The test protocol includes exposure condition in a xenon weatherometer and test methods for the exposed coupons.

Currently, the Florida DOT does not have material specification for the DWS products. Specification from each of the tested products were reviewed and summaries in Appendix-D. However, the material specifications are for neat polymers used to manufacture the products, not for the finished DWS products. Many test methods are not appropriate to be used to evaluate the tested samples in this project.

Three test methods, digital light microscope, color changes (ΔE), and abrasion test were used to evaluate the original and exposed DWS samples. The color change measurement was found to have the most meaningful result, reflecting the changes observed under the light microscope.

6.6.1 Recommended test protocol for xenon weatherometer test

(a) Test sample

Test coupon should be prepared from the product sample so that the coupon can be securely fixed onto the sample rack inside the weatherometer. In addition, the surface texture pattern must be identical for all test coupon. The thickness of the coupon is governed by the product type.

b) Xenon test condition

The recommended weatherometer is ATLAS Ci-4000 equipped with a xenon lamp and inner and outer borosilicate filters. The exposure condition should be set according to ASTM D 2565 “Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications”. The test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2°C. The irradiance for the test standard is recommendation to be 41.5 ± 2.5 W/m^2 from 300- to 400-nm. Two higher irradiance levels at 60 ± 2.5 W/m^2 and 80 ± 2.5 W/m^2 from 300- to 400-nm were also tested in this project so that the sunlight degradation can be further accelerated, shortening the exposure time.

Comparing the color change (ΔE) values (see Table 6-3), data obtained from the outdoor exposure condition are similar to those in xenon Condition [B] for most of the tested samples. The exceptions are SafeRoute (polyolefin) yellow color sample and Armor-Tile (epoxy) all three colors.

c) Material properties

Figures presented in Section 6.4.2 indicate that the changing trend and magnitude of ΔE with exposure time varies with products (i.e., polymer types) and color of the sample. Two general types of changing trends were observed and they are: 1) gradually increase to a maximum value and then leveling out, and 2) continuously increase with exposure time. Figure 6-57 shows the comparison of ΔE between 3,000 hours Condition [B] and 20 months outdoor exposure. The reason to choose 20 months outdoor exposure time is because it is the Florida equivalent time for 3,000 hours under Condition [B] (see Figure 5-19). The ΔE values between the two exposure conditions are relatively similarly, except for the black ADA Solutions, black Redimat, and red and yellow SafeRoute samples. The variability of ΔE is relatively small, except for the Armor-Tile samples. Based on Figure 6-57, the recommended ΔE values for most product samples are listed in Table 6-5. The values for red and yellow colors of SafeRoute samples were not included because the weatherometer cannot duplicate the outdoor degradation.

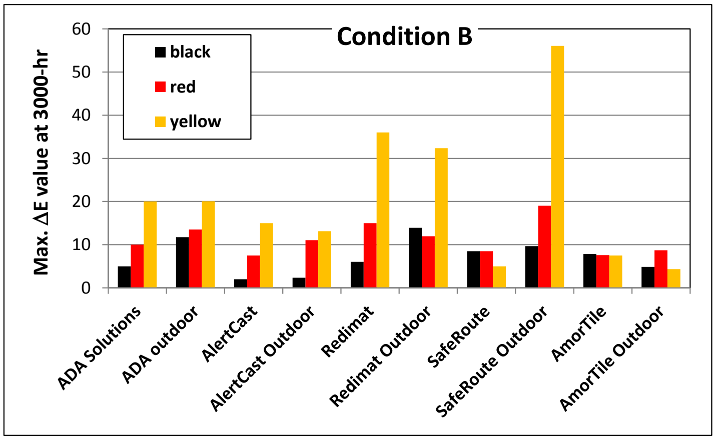


Figure 6-57 – Comparing the ΔE value between Condition [B] at 3,000 hours and outdoor exposure for 20 months

Table 6-5 – Recommended the ΔE Values for the Tested Samples

Product	Polymer Type	Color	ΔE
ADA Solutions	Polyester	Black	< 10
		Red	< 15
		Yellow	< 25
AlertCast	Polyester (NGP)	Black	< 5
		Red	< 15
		Yellow	< 15
Redimat	Polyurethane	Black	< 10
		Red	< 20
		Yellow	< 40
SafeRoute	Polyolefin	Black	< 15
		Red	NA
		Yellow	NA
Armor-Tile	Epoxy	Black	< 10
		Red	< 10
		Yellow	< 10

d) Recommended test protocol

The DWS products shall be tested for sunlight degradation resistance according to the following procedure:

- Test product according to ASTM D2565 "Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications". The test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C. The irradiance for the test standard is recommended to be *60 ± 2.5 W/m^2 from 300- to 400-nm*.
- Xenon lamp should be equipped with inner and outer borosilicate filters.
- Prepare test coupons from the product sample so that the test coupon can be securely fixed onto the sample rack inside the weatherometer, and with consistent surface texture pattern.
- Marked two spots on the test coupon's surface for color measurement.
- Measure color and take a digital photo at 30x magnification before placing the test coupon into the weatherometer.
- The exposure duration is 3,000 hr.
- Remove exposed coupons from the weatherometer, and measure color value at the two marked spots for each test coupon, and take a digital photo at 30x magnificent.
- Calculate the ΔE value of the exposed sample.
- The recommended ΔE value for each product is shown in Table 6-5. (It is not possible to specify a single maximum ΔE value for all 15 tested samples, not even appropriate for a single color.)

CHAPTER 7 – CONCLUSION

One structural plastic product and five DWS products were evaluated for their sunlight degradation behavior in this project. The exposure tests were performed in laboratory weatherometer and outdoor condition at Gainesville, Florida. An ATLAS Ci-4000 weatherometer equipped with a xenon lamp, and inner and outer borosilicate filters was used to simulate the outdoor sunlight in the laboratory. The xenon test procedure was set according to ASTM D2565 at irradiance of 41, 60 and 80 ± 2.5 W/m^2 for a duration of at least 3,000 hours. The outdoor exposure was setup according to ASTM D1435 without backing material. The duration of outdoor exposure was 24 months.

For the structural plastic product, which is made from recycled HDPE blended with 2.7% carbon black, four material properties were used to evaluate the effect of sunlight on the product throughout the exposure time. The surface morphology was examined using a digital light microscope. The stabilizer depletion was monitored using the OIT test (ASTM D 3895), the molecular weight change of the polymer was assessed using the MI test (ASTM D 1238), and the mechanical properties was evaluated by tensile test (ASTM D638, Type IV). In these four properties, the OIT test data provided the most meaningful information regarding the sunlight degradation of the tested HDPE structural plastic. The changes in OIT profiles across the thickness of the test coupons throughout the exposed period indicated that sunlight degradation mainly took place at the surface layer (0.015 ± 0.005 inch) of the test coupons under both xenon light and outdoor sunlight. As stabilizes depleted by the sunlight via the photo-degradation, surface cracking was observed subsequently leading to the decrease of tensile break strain. On the other hand, the surface degradation did not impact the overall molecular weight as indicated by the results of MI tests. Based on the OIT test data, the xenon irradiance at 60 ± 2.5 W/m^2 generated similar degradation as the outdoor exposure. Because the depletion of stabilizer is the precursor of the polymer degradation, the OIT test was recommended to be the test method to assess the sunlight resistance of HDPE structural plastics. However, the HDPE product tested in this project showed a poor service life; thus, it is inappropriate to set a specified value for the initial OIT value for all HDPE structural plastics. A test protocol was recommended as described in following test steps:

- Xenon weatherometer test condition – ASTM D 2565 with test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C and an irradiance of 60 ± 2.5 W/m^2. The xenon lamp should be equipped with inner and outer borosilicate filters.
- Test coupons should be machined to a constant thickness, recommended thickness to be 0.1 ± 0.5 inch.
- Perform OIT test (ASTM D 3895) on surface layer of unexposed coupon that will be exposed to the xenon lamp in the weatherometer.
  - A surface layer with thickness of 0.015 ± 0.005 inch should be cut from test coupons for the OIT test. The OIT specimen should weight 4 ± 0.5 mg. Two replicates should be tested.
- The exposure duration is 500 hours.
- Perform OIT test on the surface layer of exposed coupon that has been facing to the xenon lamp during the exposure duration.
  - A surface layer with thickness of 0.015 ± 0.005 inch should be cut from test coupons for the OIT test. The OIT specimen should weight 4 ± 0.5 mg. Two replicates should be tested.

For the five DWS products, three colors (black, red and yellow) were included, making total of 15 test samples. The DWS products are reinforced polymer composites. The polymer matrix is made from polyester, polyurethane, polyolefin or epoxy, and reinforced with glass fibers, inorganic fillers or aluminum particles. Three material properties were used to assess effect of sunlight on these products throughout the exposure time. The surface morphology was examined using a digital light microscope. The color was measured using a spectrocolorimeter (X-rite RM200QC), and the color change (ΔE) was calculated for each exposure time. A newly designed abrasion test was used to assess the surface degradation caused by sunlight. Based on the ΔE value and verified by the surface appearance, the xenon irradiance at 60 ± 2.5 W/m^2 generated a similar degradation as the outdoor exposure, except for the red and yellow SafeRoute product samples. Also, the ΔE value is commonly specified for DWS products by the manufacturers. The change of ΔE value can be explained by the fading of color and surface texture, and appearance of reinforcement (fibers or fillers). However, no correlation was found between ΔE and mass loss obtained from the abrasion test. Furthermore, the change of ΔE varies with the polymer type and color. It is inappropriate to set a single ΔE value for all of the tested DWS products. A test protocol was recommended as described in following test steps:

- Xenon weatherometer test condition – ASTM D 2565 with test cycle composes of 102 minutes of light followed by 18 minutes of light with water spray (102/18 cycle) at a temperature of 63 ± 2^{o}C and an irradiance of 60 ± 2.5 W/m^2. The xenon lamp should be equipped with inner and outer borosilicate filters.
- Cut test coupons from the product sample so that the dimensions of the test coupon can be securely fixed onto the sample rack inside the weatherometer, and all test coupons must have consistent surface texture pattern.
- Marked two spots on the test coupon's surface for color measurement.
- Measure color and take a digital photo at 30x magnification before placing the test coupon into the weatherometer.
- The exposure duration is 3,000 hr.
- Remove exposed coupons from the weatherometer, and measure color value at the two marked spots for each test coupon, and take a digital photo at 30x magnificent.
- Calculate the ΔE value of the exposed sample.

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APPENDICES:

Appendix-A

Polymer Used to Make
Structural Plastics and DWS Products

a) Structural Plastics (Bridge Fender Systems)

Table A-1 – Polymer Used to Make Structural Plastic Products

No.	Company	Product	Material
1	**Bedford Technology LLC** 148-1 Lenoir Drive Winchester, VA 56187 (540) 535-1710	BARFORCE	High Density Polyethylene
		FIBERFORCE	
		SeaTimber	Not Available
2	**Tangent Technologies** 1001 Sullivan Road Aurora, IL 60506 (603) 715-8739	PolyForce Plus	High Density Polyethylene, UV–inhibited pigments, anti-oxidant processing aids and foaming agents
		PolyForce	

b) Detectable Warning Surface Products

Table A-2 – Polymer Used to Make Detectable Warning Surface Products

No.	Company	Product	Material
1	**Flint Trading Inc** 115 Todd Court Thomasville, NC 27360 (336) 475-6600	TopMark	Not Available
2	**ADA Solutions** P. O. Box 3 N. Billerica, MA 01862 (800) 372-0519	ADA Tile Cast-In-Place ADA Replaceable Wet Set Composite ADAtile Surface Applied	Glass and carbon reinforced polyester based Sheet Molding Compound (SMC), Truncated domes must contain fiberglass
3	**Engineered Plastics** 300 International Drive, #100 Williamsville, NY 14221 (407) 803-2966	Armor-Tile Surface Applied Armor-Tile Replaceable Detectable Warning RCIP Armor-Tile Cast-In-Place	Vitrified Polymer Composite (VPC)
4	**Detectable Warning Systems** 9556 Historic Kings Road, Suite 315 Jacksonville, FL 32257 (866) 999-7452	Detectable Warning Mat EZ-Set Warning Tile	Not Available

Table A-2 – Continued

No.	Company	Product	Material
5	**Cape Fear Systems** 215 South Water Street, Suite 103 Wilmington, NC 28401 (910) 762-7220	Alertmat	Styrene Butadiene (SRB)
		AlertCast	Not Available
		AlertTile	
6	**Armorcast Products/Guardian Division** 13230 Saticoy Street North Hollywood, CA 910605 (818) 982-3600	Armorcast Detectable Warning Tile	Not Available
		Armorcast Detectable Warning Panel	
		Detectable Warning Wet Set Replaceable	
7	**Vanguard ADA Systems of America** 4726 North Lois Avenue Tampa, FL 33614 (813) 874-3600	Vanguard ADA Systems	Not Available
8	**EJ** 301 Spring Street East Jordan, MI 49727 (800) 899-0407	DURALAST	Iron Casting
9	**DetecTile, Inc.** 603 Mallard Lane Oak Brook, IL 60523 (630) 734-0277	DetecTile PFC Composite Detectable Warning Plate	Not Available
10	**Transpo Industries, Inc.** 20 Jones Street New Rochelle, NY 10801 (800) 321-7870	Step-Safe	Polymer concrete composed of specially blended polyester resins, promoters, initiators, and inert aggregate

Table A-2 – Continued

No.	Company	Product	Material
11	**Three D Traffic Works Inc** 430 North Varney St. Burbank, CA 91502 (877) 843-9757	The DWT-Detectable Warning Tile DWT Tough-RETRO Tile DWT-Tough-EZ Tile DWT Tough-REP Tile	UV-stabilized impact-modified polymer composite
12	**UltraTech International Inc.** 11542 Davis Creek Court Jacksonville, FL 32256 (800) 353-1611	Ultra ADA Pads (Surface Mount) Ultra ADA Pads (Wet Set)	Not Available
13	**Access Products Inc.** 241 Main Street, #100 Buffalo, NY 14203 (407) 803-2966	Access Tile Replaceable Cast-In-Place Detectable Warning Access Tile Surface Applied Detectable Warning	Vitrified Polymer Composite (VPC)
14	**StrongGo Industries** 3296 Hemisphere Loop Tucson, AZ 85706 (866) 439-3216	TekWay Dome Tiles	Not Available
15	**SafeRoute Products, LLC** 5649 2nd Street West #108 Lehigh Acres, FL 33971 (866) 929-4917	SafeRoute Tile Cast-In-Place SafeRoute Tile Surface Mount	Polyolefin
16	**Liquidomes LLC** 101 North US Highway 1, Suite 214 Fort Pierce, FL 34950 (772) 919-4949	Liquidomes	Not Available

Table A-2 – Continued

No.	Company	Product	Material
17	**Bailey Sigler Inc.** 1050 Freemont Street New Smyrna Beach, FL 32168 (386) 428-5566	ADA SadeDome Products	Polyester Resin, Styrene Monomer, Pigments, Methyl Methacrylate (Only in Black and Yellow colored products), Reflective glass beads (Only in Black and Yellow)
18	**Roadway Concepts, LLC** 4726 North Lois Avenue Tampa, FL 33614 (813) 874-3600	Top Guard Detectable Warning	Not Available

<u>Appendix-B</u>

Details of the Product Samples Received from the Manufacturers

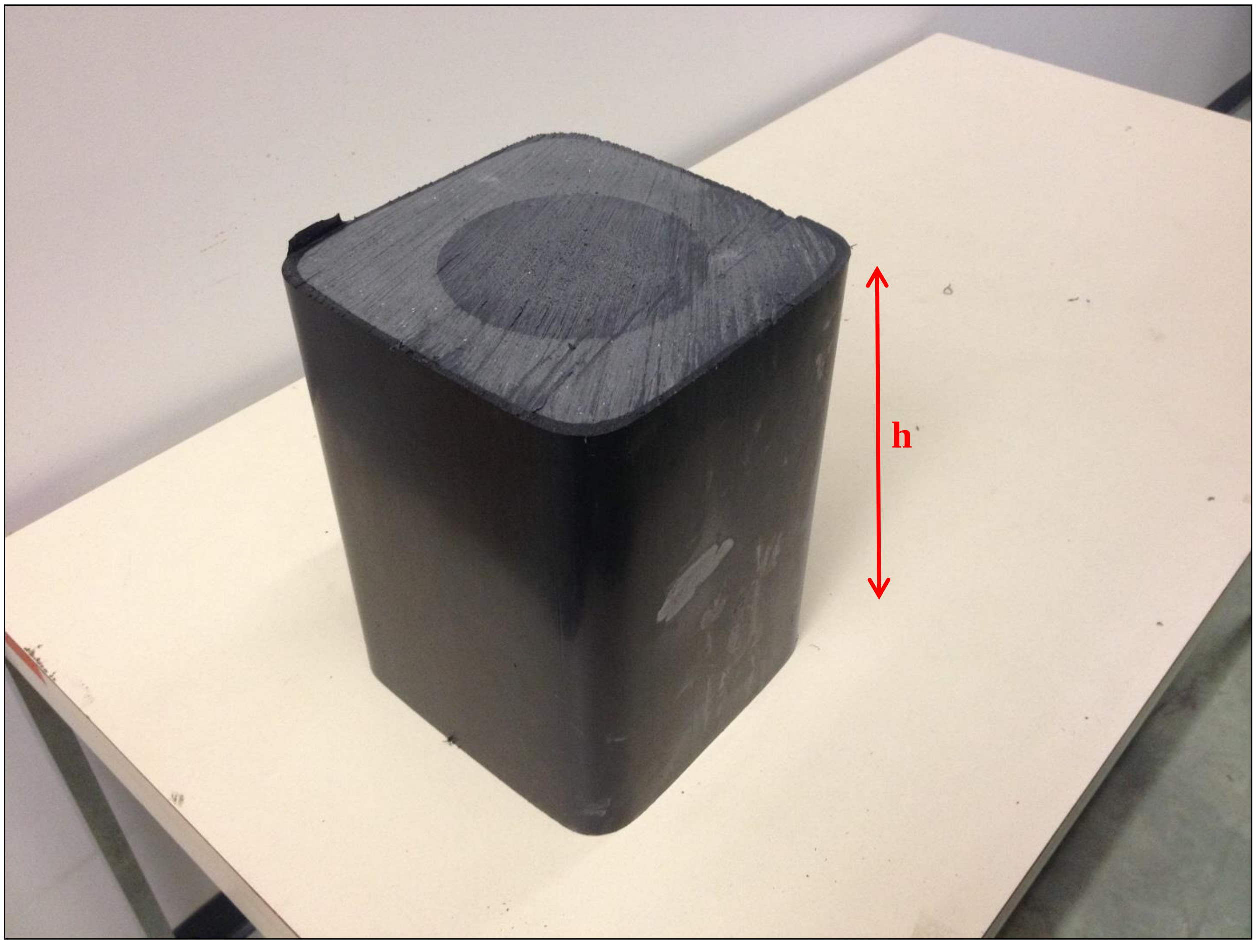
1- Bedford Technology – Structural Plastics

https://plasticboards.com/

Structural plastic samples were provided by Bedford Technology, LLC. These samples were cut in different sizes from a product called FIBERFORCE and had a UV resistant layer on the surface. According to the company's website, this product is made of recycled high density polyethylene (HDPE).

Samples were provided in three forms:

1) Two complete timber sections (Details provided on page 2)
2) Five 32cm × 24cm sheets cut from timber (Details provided on page 3)
3) Six 32cm × 19cm sheets cut from timber (Details provided on page 4)



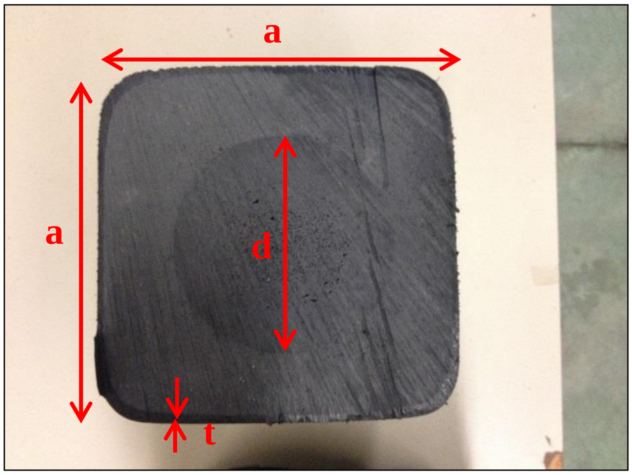


Figure B-1 – Photographs of HDPE samples obtained from Bedford Technology

Table B-2 – Dimensions for Timber Section of Bedford Technology Sample

a (in)	h (in)	d (in)	t (in)
9.5	12.5	6	0.15-0.3

Bedford Technology – Structural Plastics

Figure B-2(a) – Photograph of samples cut from large samples shown in Figure B-1

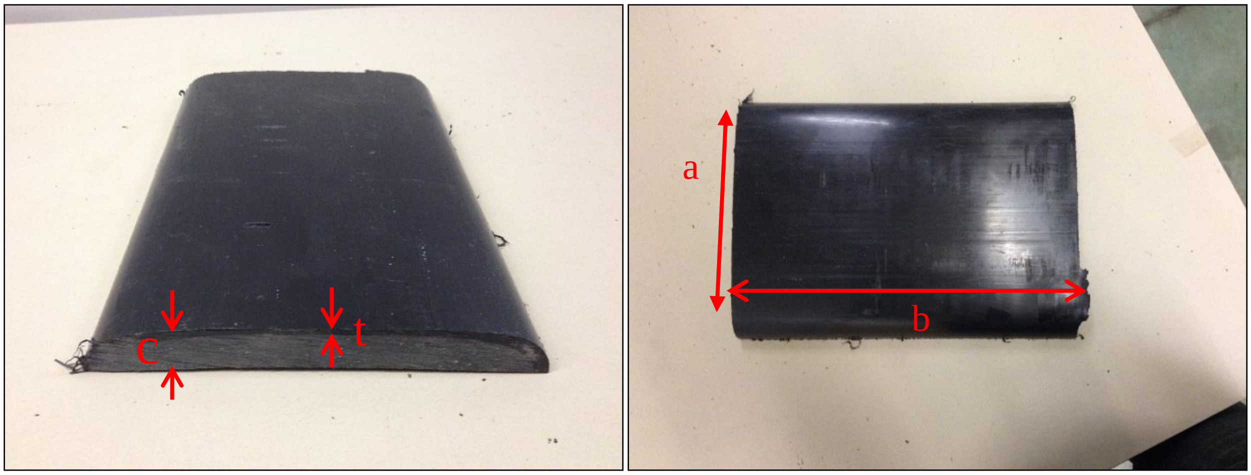


Figure B-2(b) – Photographs of samples cut from large samples shown in Figure B-1

Table B-2 – Dimensions for 32cm × 24cm Sheets Cut from Timber Sample

a (in)	b (in)	c (in)	t (in)
9.5	**12.5**	**1**	**0.15-0.3**

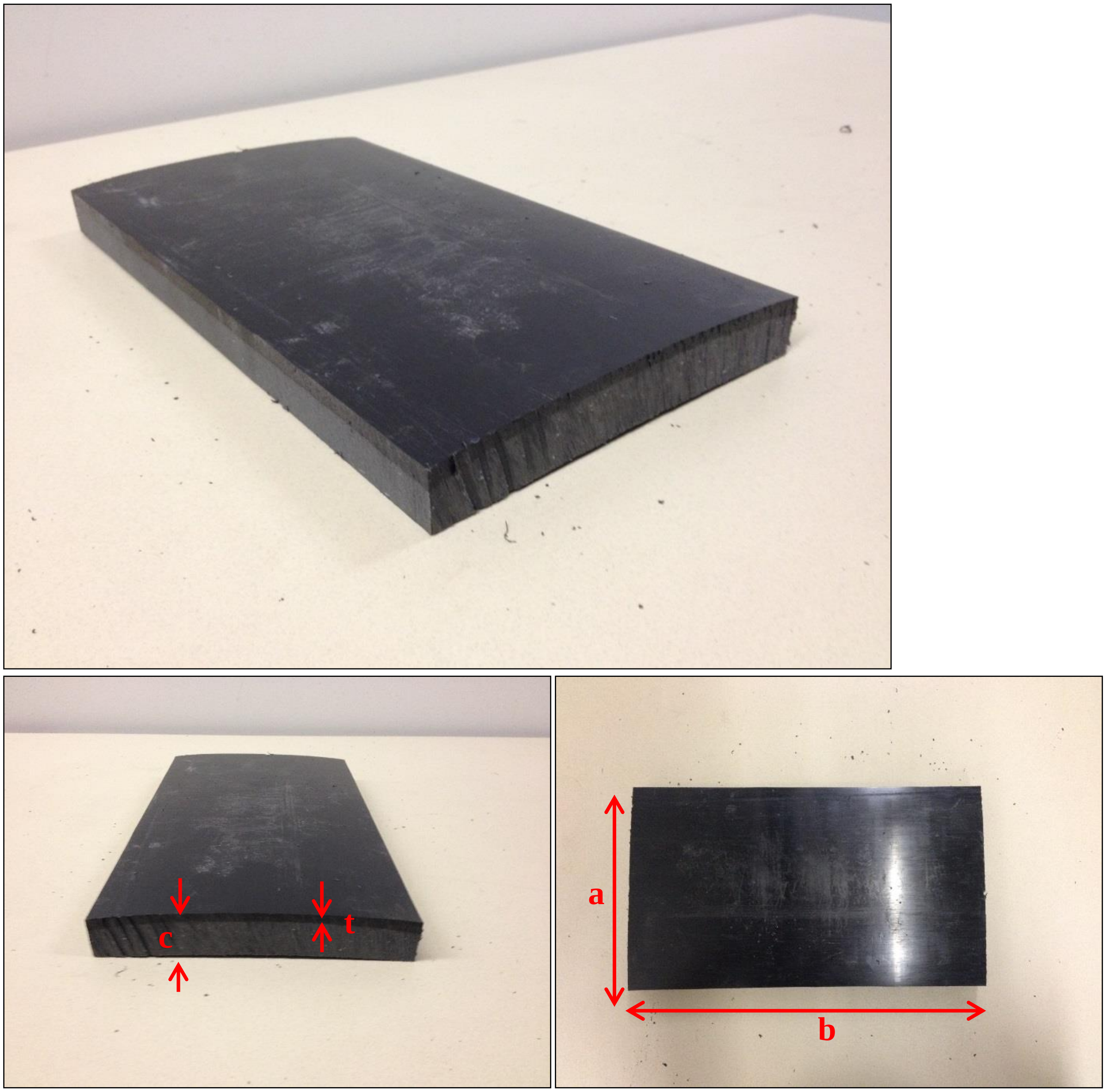


Figure B-3 – Details for 7.5 in × 12.5 in sheets cut from samples shown in Figure B-1

Table B-3 – Dimensions for 32cm × 19cm Sheets Cut from Timber Samples

a (in)	b (in)	c (in)	t (in)
7.5	12.5	1	0.15-0.3

ADA Solutions, Inc. – ADA Solutions

http://www.adatile.com/surfacemount.php

Specifications:
http://www.adatile.com/specs/SA-RAD.pdf

MATERIAL

A homogenous glass and carbon reinforced composite which is colorfast and UV stable. Truncated domes are fiberglass reinforced for enhanced durability. The Tactile Unit color is uniform throughout and does not rely on any type of paint coating to achieve color stability. Standard colors include: Federal Yellow, Brick Red, Clay Red, Safety Red, Blue, Dark Gray, and Black.

PHYSICAL CHARACTERISTICS:

Compressive Strength	28,900 psi	ASTM D 695
Flexural Strength	29,300 psi	ASTM D 790
Slip Resistance	1.18 Dry/1.05 Wet	ASTM C 1028
Chemical Stain Testing	No Deterioration	ASTM D 543
Abrasion Resistance	549	ASTM C 501
Accelerated Weathering	Delta E <5.0 (2,000 hours)	ASTM G 155
Tensile Strength	11,600 psi	ASTM D 638
Load Bearing at 16,000 #	No Damage	AASHTO-H20
Adhesion to Conc.(20-180 degrees)	No Delamination or Degradation	ASTM C 903
Freeze/Thaw/Heat	No Disintegration	ASTM C 1026

ADA Solutions, Inc – ADA Solutions

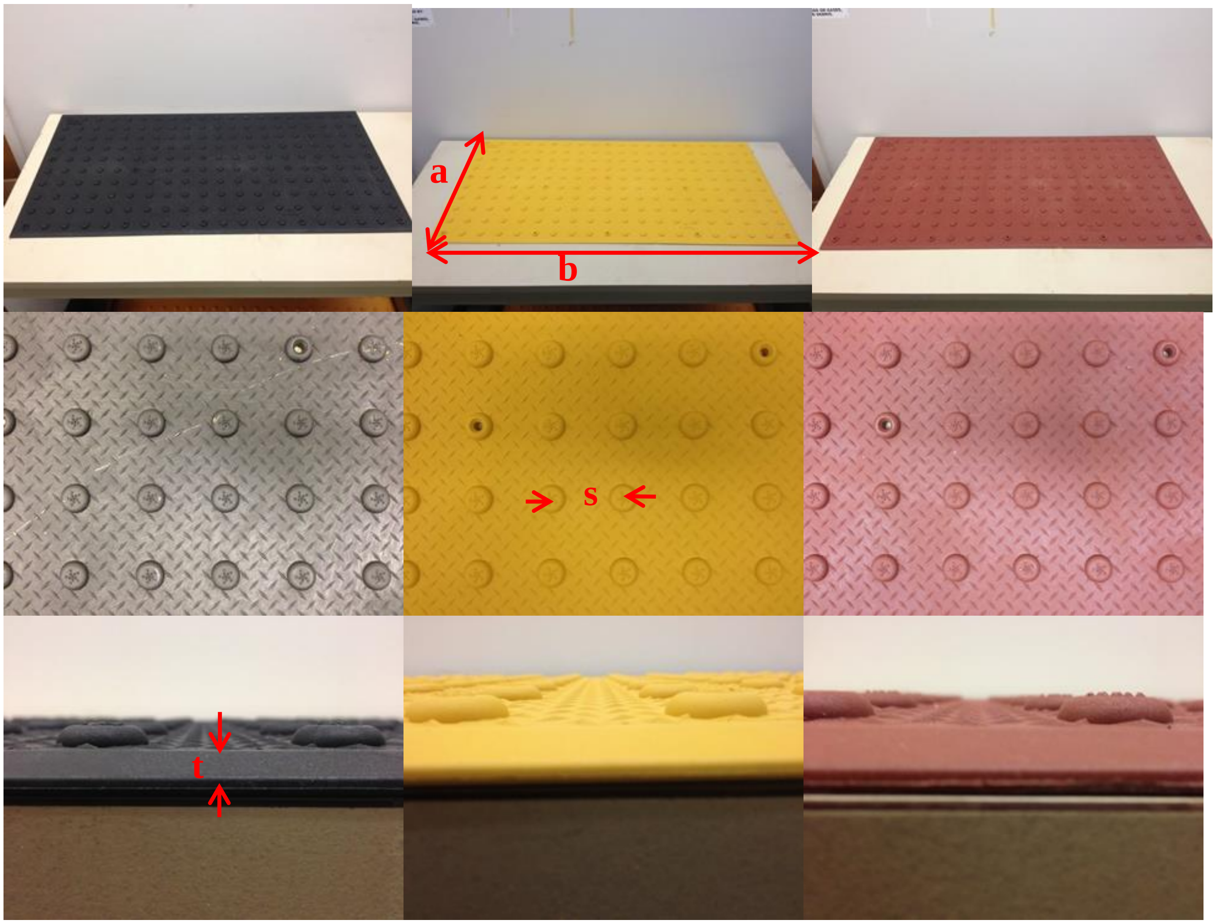


Figure B-4 – Photographs of ADA Solutions product samples

Table B-4 – Dimensions of ADA Solutions Samples

a (in)	b (in)	s (in)	t (in)	Number of Samples
24	**48**	**2.1 (1.3 clear)**	**0.1**	**4 of each color**

1- Alert Tile – AlertCast (Cape Fear Systems)

http://alerttile.com/

Alert Tile provided polymer samples from one of their products called AlertCast. Two sets of samples with different sizes were received in separately. The specifications for this product are shown in the table below:

alertcast® Detectable Warning Specification Sheet

Wear ResistanceASTM C 50183 grams or 0.0107"

PROPERTY	ASTM STANDARD	RESULT
Slip Resistance	C 1028	Dry 1.03 / Wet .83
Impact Resistance	D 256	8.0 Izod ft-ibs / in (notch)
Accelerated Weathering	ASTM G155-05	No Change
Water Absorption	C373	0.3 - 0.6%
Compresive Strength	D 695	30,000 psi
Flexural Strength	D 790	19,290 psi
Tensile Strength 1/8"	D 638	5,511 psi
Color	Integral Throughout Product	Yes
Color / Contrast	CAP-Y	Brick Red 5-15 Colonial Red 5-15 Federal Yellow 25-50
Dome Height	0.2"	Yes
Dome Base Width	0.9"	Yes
Dome Top Diameter	0.45"	Yes
Dome Spacing	2.35"	Center-to-Center
Salt Spray	B117	No Change
Wear Resistance	C 501	83 grams or 0.0107"
Penetrator® Concrete Anchor	Pullout Strength	729 pounds per anchor
Freeze-Thaw Durability	C 1262-08	Pass
Waste Classification	USEPA 40 CFR Part 261	Non-Hazardous

Alert Tile- AlertCast
Details for Alertcast Samples

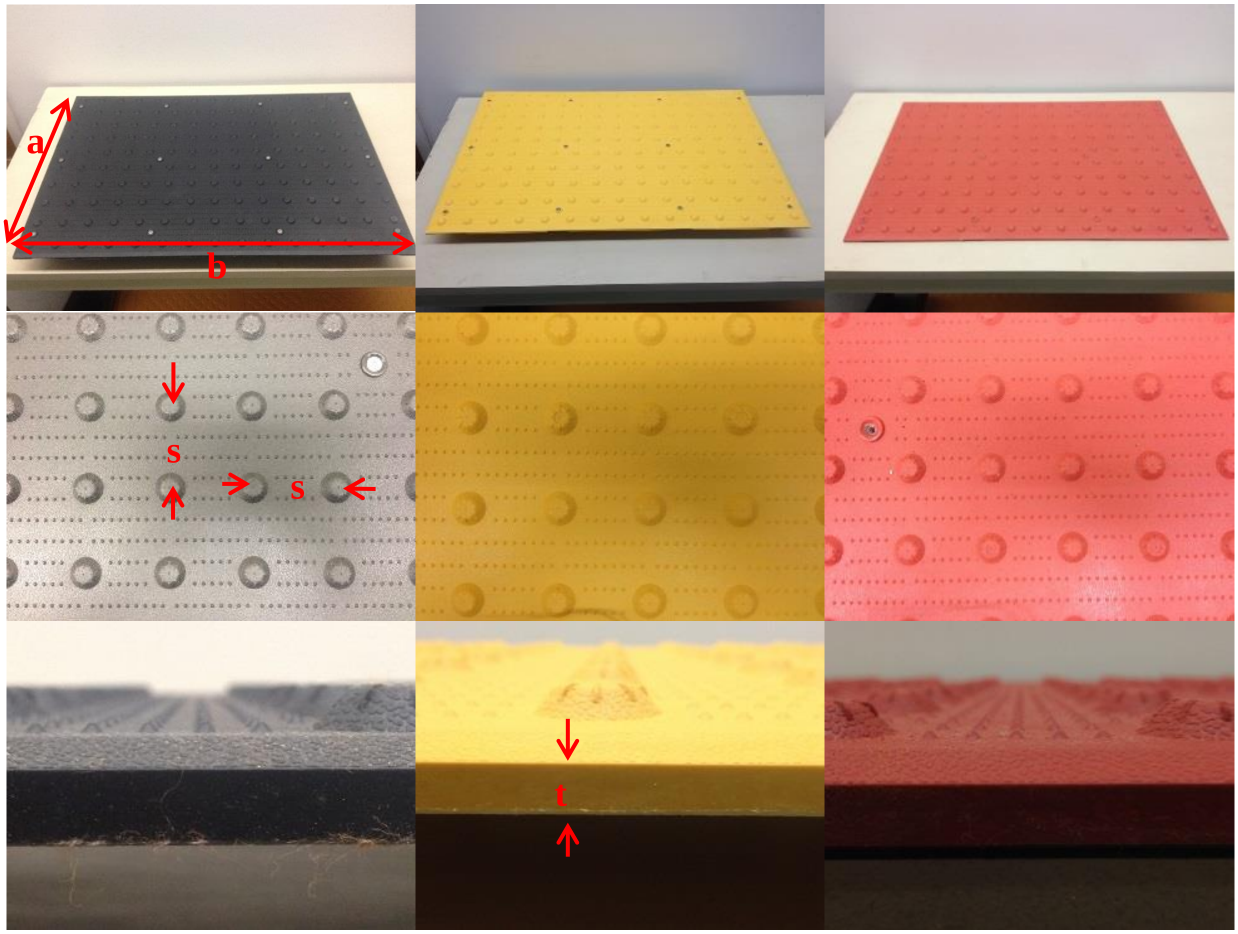


Figure B-5 – Photographs of AlertCast samples

Table B-5 – Dimensions of AlertCast Samples (2nd delivery)

a (in)	b (in)	s (in)	t (in)	Number of Samples
24	35	2.5 (1.7 clear)	0.1	Black and Yellow (5 each) Red (4 each)

Detectable Warning Systems - Redimat

http://www.detectable-warning.com/

Redimat samples were provided by detectable warning systems.

Details for RediMat

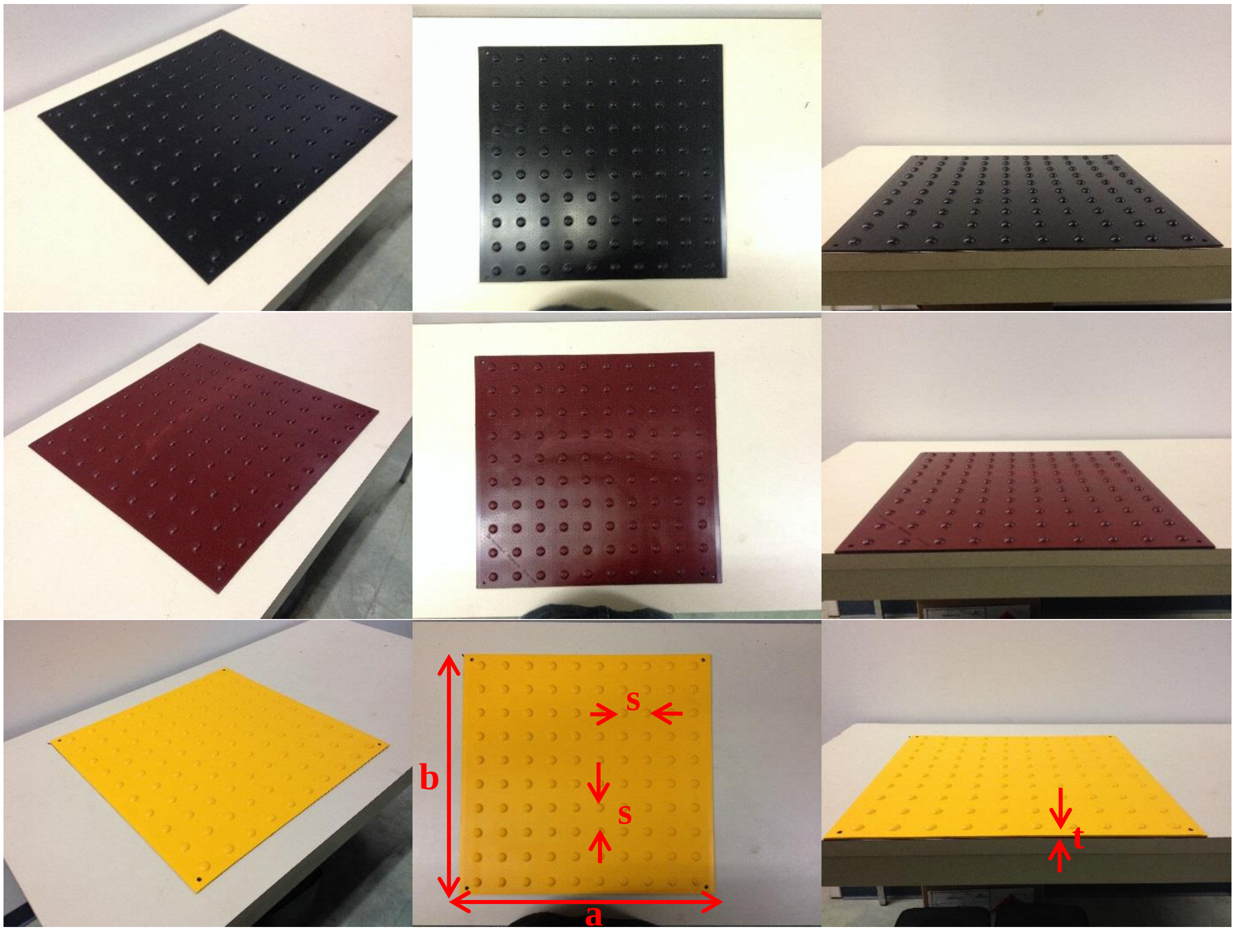


Figure B-6 – Photographs of Redimat samples

Table B-6 – Dimensions of Redimat Samples

a (in)	b (in)	s (in)	t (in)	Number of Samples
24	24	2.3 (1.4 clear)	0.1	1 of each color

*** The brick red sample has a sign of discoloration in the middle.**

SafeRoute Products – Saferoute

http://www.saferouteproducts.com/

Details for SafeRoute

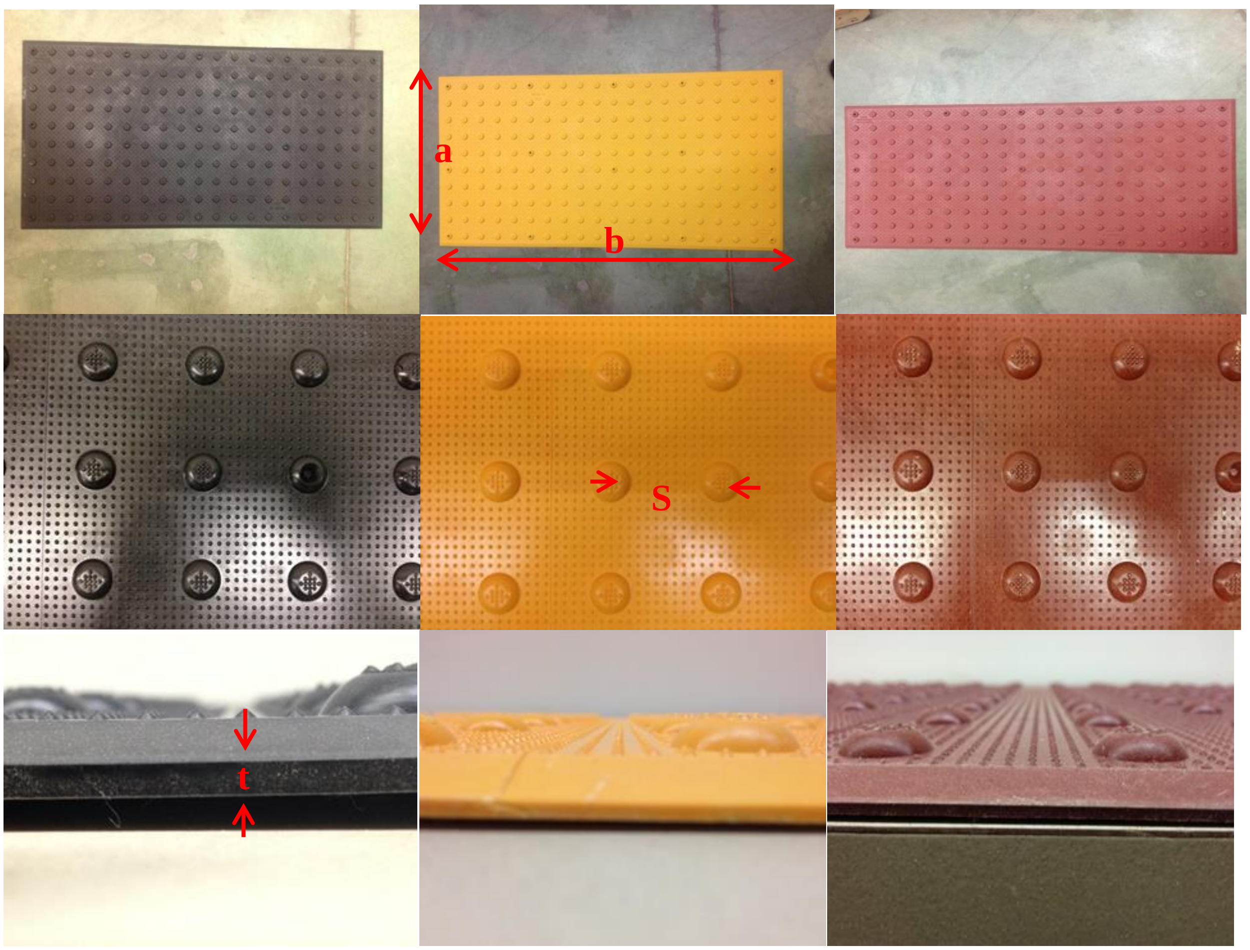


Figure B-7 – Photographs of SafeRoute samples

Table B-7 – Dimensions of SafeRoute Products Samples (2nd delivery)

a (in)	b (in)	s (in)	t (in)	Number of Samples
24	48	2.3 (1.4 clear)	0.1	2 of each color

Engineered plastics Inc. – Armor-Tile

www.armor-tile.com

Engineered Plastics Inc. provided polymer samples from one of their products called Armor Tile. Two sets of samples with different sizes were received in separately.

Details for Armor-Tile

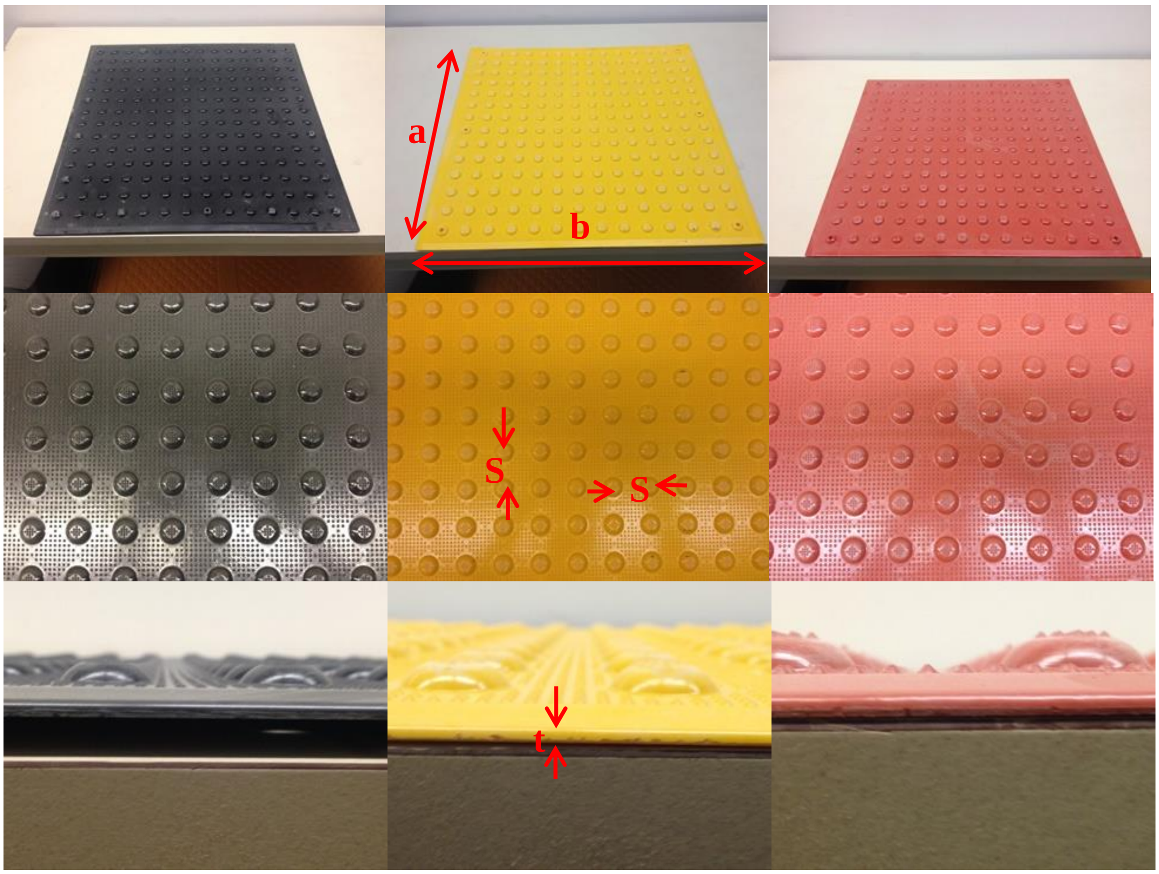


Figure B-8 – Photographs of Armor-Tile samples

Table B-8 –Dimensions of Armor-tile Samples (2nd delivery)

a (in)	b (in)	s (in)	t (in)	Number of Samples
24	24	1.7 (0.8)	0.1	2 of each color

Appendix-C

Florida Department of Transportation Specification
Section 973 - Structural Plastics

SECTION 973 STRUCTURAL PLASTICS

973-1 Description.
This work covers structural plastic components including fiberglass structurally reinforced composite lumber (SCL) and dimensional fiberglass fiber reinforced composite lumber (FFRCL).

973-2 Product Acceptance.
Use structural plastics listed on the Department's Qualified Products List (QPL). Manufacturers seeking evaluation of products for listing on the QPL must submit an application in accordance with Section 6 and include independently certified test reports, and manufacturer's certification that the material meets the requirements of this Section.

Structural plastic components used in Contractor-developed custom designs may be used in place of QPL listed products. For Contractor-developed custom designs, meet the product acceptance criteria in Section 471.

973-3 Materials.
Use polyethylene made from recycled post-consumer or post-industrial thermoplastics. Mix the plastic with appropriate colorants, UV inhibitors, hindered amine light stabilizers and antioxidants so that the resulting product meets the material property requirements specified in Tables 1 and 2. Structural plastic must not corrode, rot, warp, splinter or crack. The skin must be smooth and black in color unless otherwise specified in the Contract Documents. Skin is the surface material exposed to the atmosphere. Core is the material that surrounds and bonds to the fiberglass reinforcing rods. The use of separate materials for skin and core is at the discretion of each manufacturer; however, if a single material is used, that material must meet the requirements for both skin and core.

Manufacture structural plastic as one continuous piece with no joints or splices to the dimensions and tolerances in accordance with Table 3. Interior voids shall not exceed 3/4 inches in diameter. Structural plastic members shall be free of twist and curvature.

Reinforce square fiberglass structurally reinforced composite lumber with a minimum of four fiberglass reinforcing rods placed in the corners of the section.

Reinforcing rods must be continuous and offer a minimum flexural strength of 70.0 ksi when tested in accordance with ASTM D4476 and a minimum compressive strength of 40.0 ksi when tested in accordance with ASTM D695. Steel reinforcing rods are not permitted.

Reject any sections of structural plastic containing cracks or splits. Also, inspect the ends of the reinforcing rods and reject any sections containing reinforcing rods with voids or cracks.

Add a minimum of 15% (by weight) chopped fiberglass reinforcement to the polyethylene used for fiberglass structurally reinforced composite lumber and a minimum of 15% (by weight) chopped fiberglass reinforcement for smaller dimensional fiberglass fiber reinforced composite lumber. The fiberglass reinforcement may be reduced when other means of controlling cracking are specified with test results which show long term cracking is nonexistent.

Fiberglass structurally reinforced composite lumber must meet the minimum structural properties listed in Table 4.

Dimensional fiberglass fiber reinforced composite lumber must meet the minimum physical properties listed in Table 5.

Table C-1 Plastic Material Properties - SCL			
Density	ASTM D792	Skin	55-63 pcf
Density	ASTM D792	Core	48–63 pcf
Water Absorption	ASTM D570	Skin	2 hrs:<1.0% weight increase 24 hrs:<3.0% weight increase
Brittleness	ASTM D746	Skin	Brittleness temperature to be less than - 40°C
Impact Resistance	ASTM D256 Method A (Izod)	Skin	Greater than 0.55 ft-lbs/in
Hardness	ASTM D2240	Skin	44-75 (Shore D)
Ultraviolet	ASTM D4329 UVA	Skin	500 hours<10% change in Shore D Durometer Hardness
Abrasion	ASTM D 4060	Skin	Weight Loss: <0.02 oz Cycles=10,000 Wheel=CS17 Load=2.2 lb
Chemical Resistance	ASTM D543	Skin/Core Sea Water Gasoline No. 2 Diesel	 <1.5% weight increase < 9.5% weight increase <6.0% weight increase
Tensile Properties	ASTM D638	Core	2200 psi at break min.
Compressive Modulus	ASTM D695	Core	40 ksi min.
Static Coefficient of Friction	ASTM D1894	Skin	0.25, wet max.
Nail Withdrawal or Screw Withdrawal	ASTM D6117	Skin/Core	60 lb (nail) min. 400 lb (screw) min.

Table C-2 Plastic Material Properties - FFRCL		
Density	ASTM D792	50-65 pcf
Impact Resistance	ASTM D256 Method A (Izod)	Greater than 2.0 ft-lbs/in
Hardness	ASTM D2240	44-75 (Shore D)
Ultraviolet	ASTM D4329 (UVA)	500 hours <10% change in Shore D Durometer Hardness
Chemical Resistance	ASTM D756 or ASTM D543 Sea Water Gasoline No. 2 Diesel	 <1.5% weight increase <7.5% weight increase <6.0% weight increase
Tensile Properties	ASTM D638	3000 psi at break min.
Static Coeffecient of Friction	ASTM D2394	0.25, wet or dry min.
Nail Withdrawal or Screw Withdrawal	ASTM D6117	250 lb (nail) min. 400 lb (screw) min.

Table C-3 Dimensions and Tolerances		
Structural Plastic	Dimension	Tolerance
Length	Per order (80 ft Maximum)	0/+6 inch
Width – SCL Width – FFRCL	See Contract Plans	±1/2 inch ±1/4 inch
Height – SCL Width – FFRCL	See Contract Plans	±1/2 inch ±1/4 inch
Skin Thickness	3/16 inch minimum	n/a
Distance from outer surface to center rebar elements (SCL)	2 inches	±1/2 inch
Straightness (gap, bend or inside while lying on a flat surface)		<1-1/2 inches per 10 feet

Table C-4 Structural Properties for SCL		
Member Size		10 inches x 10 inches min.
Modulus of Elasticity Stiffness, E.I.	ASTM D6109 ASTM D6109	521 ksi min. 4.05E+08 lb-inch^2 min.
Yield Stress in Bending	ASTM D6109	5.3 ksi min.
Weight		30-37 lb/ft

Table C-5 Minimum Properties for FFRCL		
Modulus of Elasticity	ASTM D6109	300,000 psi
Flexural Strength	ASTM D6109	2,500 psi
Compressive Strength	ASTM D6108	2,200 psi
Compressive Strength Perpendicular to grain	ASTM D6108	700 psi

<u>Appendix-D</u>

Summarized Specified Sunlight Test Methods Obtained from DWS Manufacturers

Table D-1 – Specified Sunlight Test Methods Obtained from DWS Manufacturers

Company/ Product	Test Method	Light Source	Test Procedure	Criteria
ADA Solutions Inc./ ADA Solutions	ASTM G155	Test device is not specified	Test cycle is not specified	ΔE < 5.0 at 2000 hr.
Cape Fear System, LLC. / Alert Cast	ASTM G155	Xenon Arc Q-Sun weatherometer	Cycle 3: (daylight) 1.5 hr. light, 70% RH at 77°C/18 min light and water spray and 6 hr. dark at 95% RH at 24°C with irradiance 0.35 W/m^2-nm at 340 nm.	ΔE values after 2000 hr. and 3000 hr. are reported, but no specified critical value.
Detectable Warning Systems / Redimat	ASTM G154	QUV device UVB-313	3 cycles are designed for UVB-313 lamps: Following two cycles are likely used for the test: Cycle 2: (coatings) 4 hr. UV at 60°C and 4 hr. condensation at 50°C, at 0.71 W/m^2-nm irradiance using UVB-313 lamps. Cycle 5: (Roofing materials) 20 hr. UV at 80°C and 4 hr. condensation at 50°C, at 0.62 W/m^2-nm irradiance using UVB-313 lamps	No change after 200 hrs.
SafeRoute Products, LLC. / SafeRoute	ASTM G154	Not specified	Not available	Not available
Engineered Plastics / Armor-Tile	ASTM G155	Test device is not specified	Test cycle is not specified	ΔE < 5.0 at 2000 hr. minimum exposure

<u>Appendix-E</u>

Test Methods Used to Evaluate Structural Plastics Products and DWS Products

Table E-1 – Test Methods Used to Evaluate Structural Plastics Products

Information Source	Property	Standard
FDOT, Section 973	Density	ASTM D792
	Brittleness	ASTM D746
	Impact Resistance	ASTM D256, Method A
	Hardness	ASTM D2240
	Abrasion	ASTM D4060
	Chemical Resistance	ASTM D543
	Tensile Properties	ASTM D638
	Compressive Modulus	ASTM D695
	Static Coefficient of Friction	ASTM D1894

Table E-2 – Test Methods Used to Evaluate DWS Products

Information Source	Property	Standard
Physical Properties		
(1), (2), (3), (4), (5)	Water Absorption	ASTM D570
(1), (2), (3), (4)	Flame Spread	ASTM DE84
(3)	Specific Gravity	ASTM D792
(3)	Flammability	ASTM E648
(3)	Smoke Density	ASTM E662
(3)	Hardness Test	ASTM D2240 (Shore A)
(4)	Flame/Smoke Resistance	FMVSS 302
(4)	Water Absorption	ASTM C373
Mechanical Properties		
(1), (2), (4)	Compressive Strength	ASTM D695
(1), (3), (4)	Flexural Strength	ASTM D790
(1), (2), (4), (5)	Slip Resistance	ASTM C1028
(1), (2), (4), (5)	Wear Resistance	ASTM C501
(2), (3)	Abrasion Wear of Tile	ASTM D2486
(3)	Abrasion/Wear Test	ASTM D4060
(1), (2), (3), (4)	Tensile Strength	ASTM D638
(4)	Tensile Strength	ASTM D412
(1)	Load Bearing Test	AASHTO H20
(2)	Impact Test, Gardner Impact	ASTM D5420
(4)	Impact Test	ASTM D256
(2)	Single wheel Test	AASHTO HB-17
(3)	Tear Strength	ASTM D624
Endurance Properties		
(1), (2), (4), (5)	Salt and Spray Performance	ASTM B117
(1), (2)	Chemical Stain Resistance	ASTM D543
(3)	Chemical Stain Resistance (household chemicals)	ASTM D1308
(1), (2), (4)	Accelerated Weathering	ASTM G155/151
(3)	Accelerated Weathering	QUV exposure, UVB lamps
(1), (3)	Freeze/thaw/Heat	ASTM C1026
(2), (3), (4)	Accelerated Aging and Freeze Thaw test	ASTM D1037
(4), (5)	Freeze-Thaw Durability with Concrete	ASTM C1262

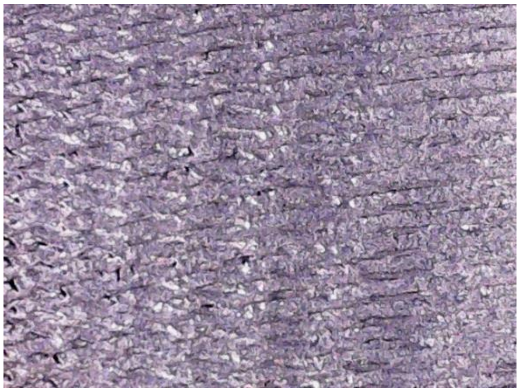
Note: ADA Solutions(1), Engineered Plastics(2), Detectable Warning Systems(3), Cape Fear Systems(4), SafeRoute Products, LLC(5)

APPENDIX-F

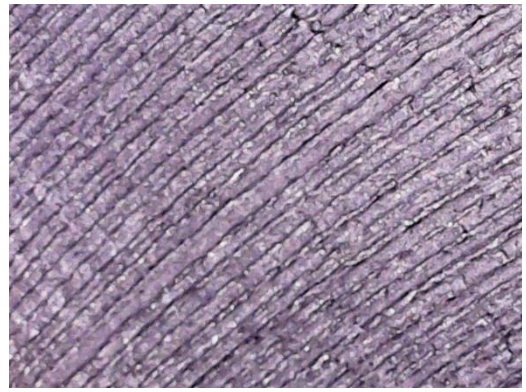
Test Data of HDPE Structural Plastic Product
After Exposed to Xenon Weatherometer

Appendix-F(a)

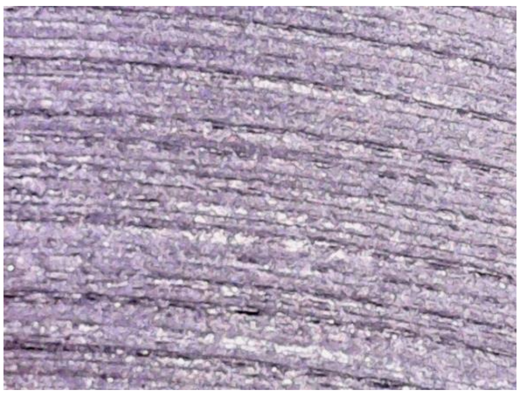
Surface Morphology



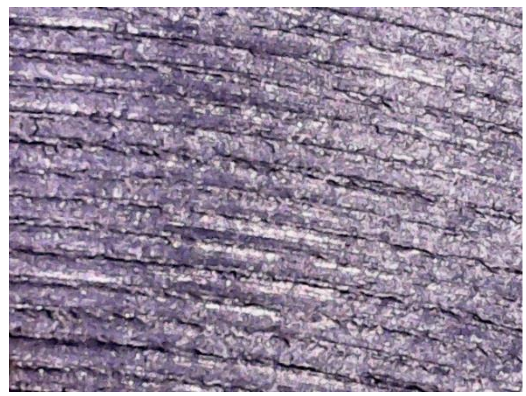
Condition A – 0 hr (30x)



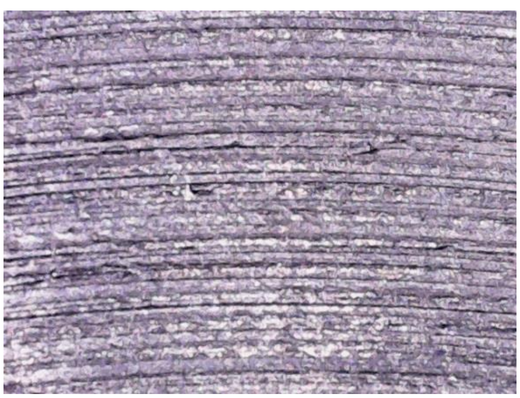
Condition A – 500 hr (30x)



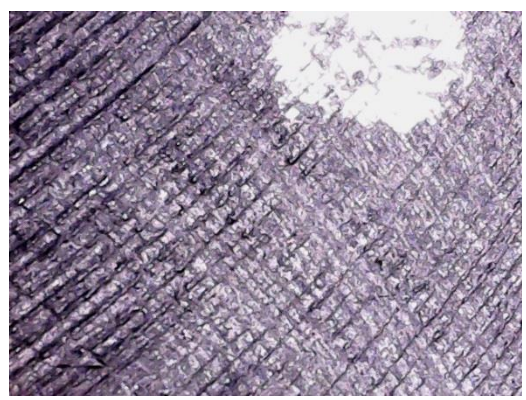
Condition A – 1,000 hr (30x)



Condition A – 1,500 hr (30x)

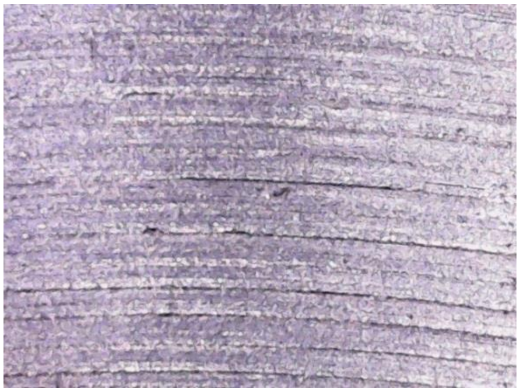


Condition A – 2,000 hr (30x)

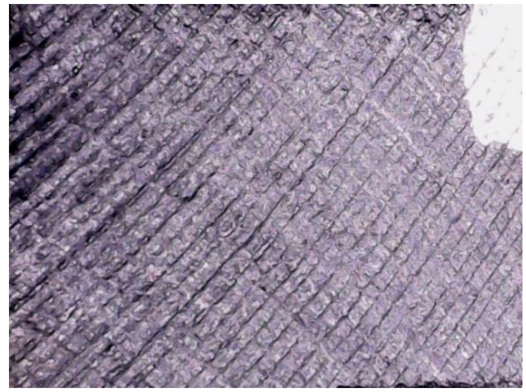


Condition A – 2,500 hr (30x)

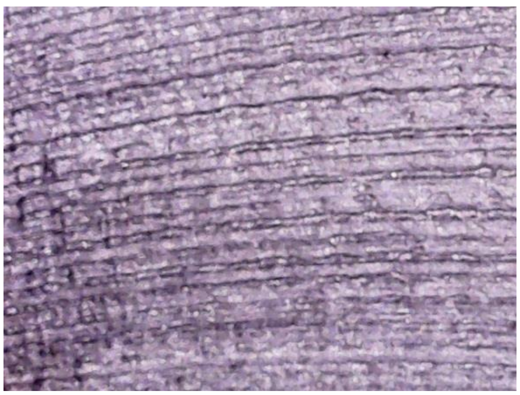
Figure F-1 – Surface morphology of HDPE coupons after exposed in xenon weatherometer under Condition [A]



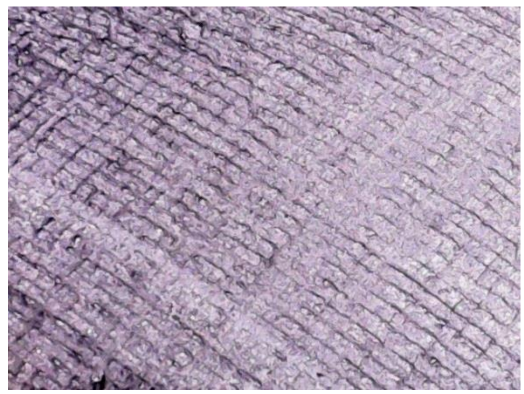
Condition A – 3,000 hr (30x)



Condition A – 3,500 hr (30x)

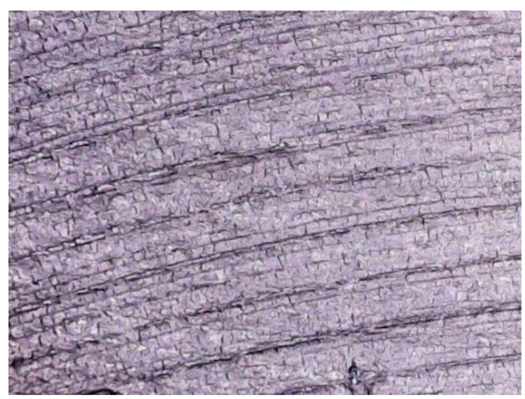


Condition A – 4,000 hr (30x)



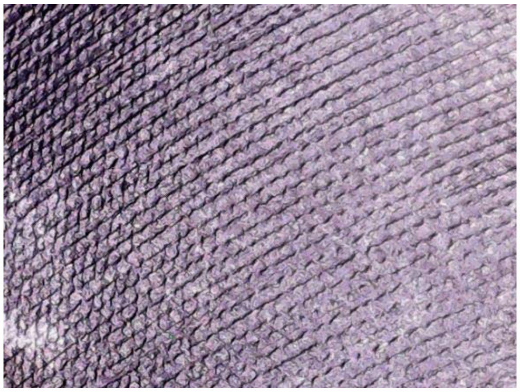
Condition A – 4,500 hr (30x)

Condition A – 4,500 hr (160x)

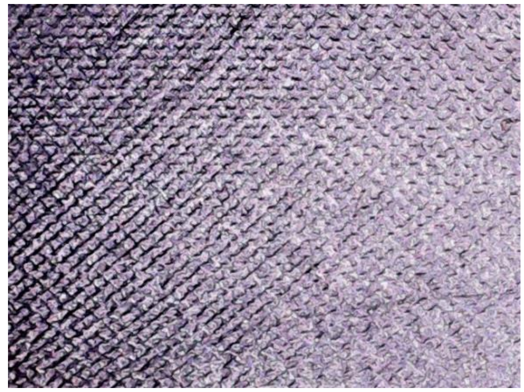


Condition A – 5,000 hr (30x)

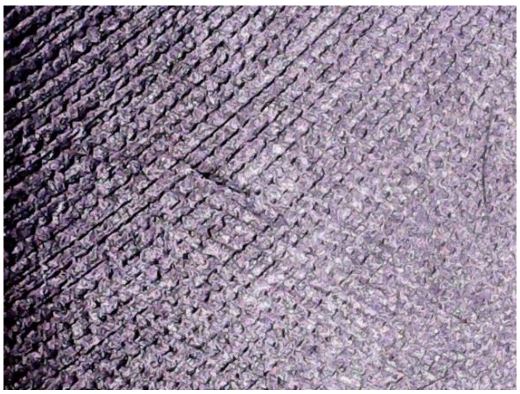
Figure F-1 – Continued



Condition B – 500 hr (30x)

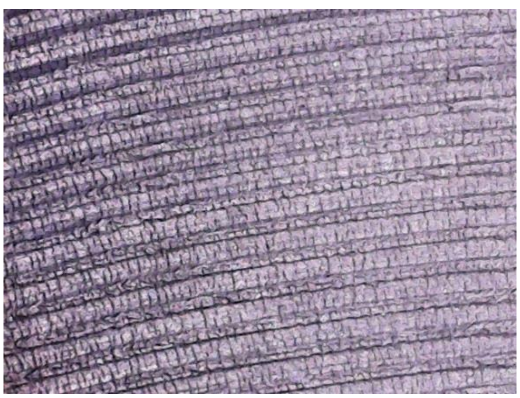


Condition B – 1,000 hr (30x)

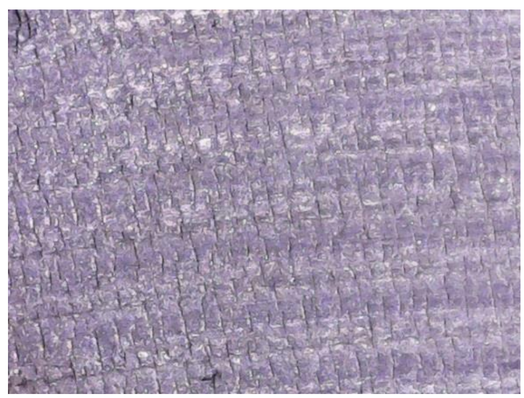


Condition B – 2,000 hr (30x)

Condition B – 3,000 hr (30x)

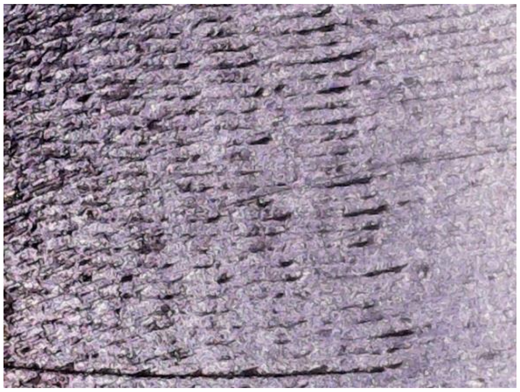


Condition B – 4,000 hr (30x)

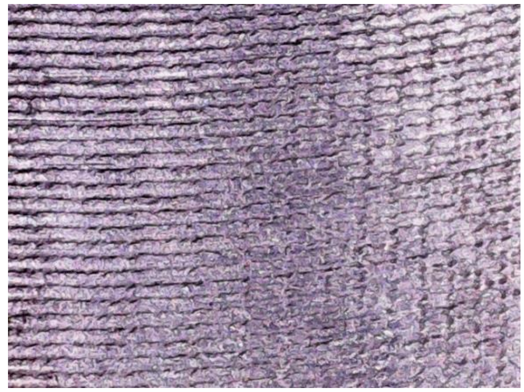


Condition B – 4,000 hr (160x)

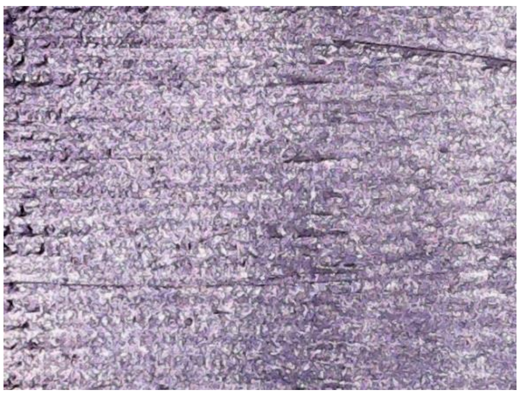
Figure F-2 – Surface morphology of HDPE coupons after exposed in xenon weatherometer under Condition [B]



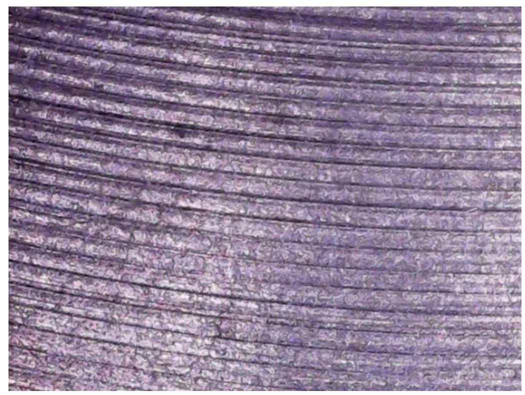
Condition C – 500 hr (30x)



Condition C – 1,000 hr (30x)

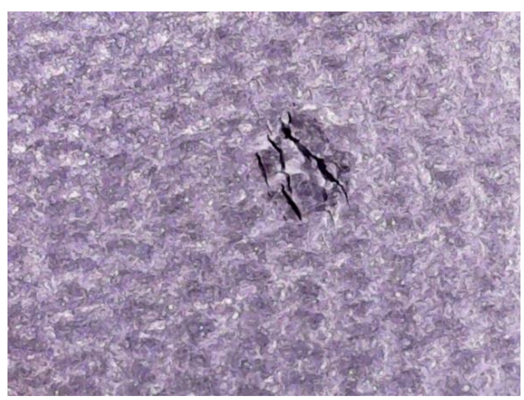


Condition C – 2,000 hr (30x)



Condition C – 2,500 hr (30x)

Condition C – 3,000 hr (30x)



Condition C – 3,000 hr (160x)

Figure F-3 – Surface morphology of HDPE coupons after exposed in xenon weatherometer under Condition [C]

Appendix-F(b)

Oxidative Induction Time Test Data

Table F-1 – Oxidative Induction Time Test Data (percentage retained)

Condition A											
Hours	**0**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**4500**	**5000**
Layer 1	100	37.3	31.8	17.4	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Layer 2	100	79.3	92.8	83.7	75.3	56.3	61.1	87.5	82.5	93.9	45.7
Layer 3	100	76.8	101.4	87.5	75.2	120.4	63.9	102.6	88.3	114.2	100.6
Layer 4	100	83.0	104.9	89.7	79.7	128.1	74.0	111.9	92.1	127.3	113.9
Layer 5	100	59.4	84.1	84.4	59.6	103.2	74.7	100.1	62.7	67.9	88.9
average	100	67.2	83.0	72.5	59.0	82.6	55.8	81.4	66.1	81.7	70.8
stdev.p	0	17.0	26.6	27.7	27.8	46.1	25.9	39.0	32.2	43.2	40.0
Condition B											
Hours	**0**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**		**4000**		
Layer 1	100	20.5	5.1	5.1	5.1	5.1	5.1		5.1		
Layer 2	100	91.4	84.3	76.1	93.6	76.9	65.2		48.0		
Layer 3	100	93.8	107.8	73.0	97.6	77.4	71.1		56.2		
Layer 4	100	95.7	107.3	70.9	109.4	56.1	63.8		52.1		
Layer 5	100	55.2	80.8	59.1	94.7	44.8	36.0		40.3		
average	100	71.3	77.0	56.9	80.1	52.0	48.2		40.3		
stdev.p	0	29.5	37.7	26.5	37.9	26.6	24.8		18.4		
Condition C											
Hours	**0**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**				
Layer 1	100	18.6	10.5	13.8	5.1	5.1	5.1				
Layer 2	100	62.2	39.5	73.0	49.5	40.8	49.3				
Layer 3	100	41.5	43.7	68.0	45.3	52.4	49.2				
Layer 4	100	58.8	42.2	67.9	52.6	45.6	23.0				
Layer 5	100	15.5	15.6	38.7	47.4	34.2	16.0				
average	100	39.3	30.3	52.3	40.0	35.6	28.5				
stdev.p	0	19.5	14.3	22.7	17.6	16.4	17.9				

Appendix-F(c)

Melt Index Test Data

Table F-2 – Melt Index Value under Test Condition of 2.19g/190^{o}C

Exposure Time (hr.)	Condition [A] (g/10-min.)	Condition [B] (g/10-min.)	Condition [C] (g/10-min.)
0	0.71	0.71	0.71
458	0.71	NA	NA
1,000	0.65	0.69	0.68
1,500	0.65	NA	NA
2,000	0.73	0.74	0.70
3,000	0.71	0.71	0.70
4,000	0.70	0.71	NA
5,000	0.72	NA	NA

NA = Not available (no test coupon)

Appendix-F(d)

Tensile Test Data

Table F-3 – Tensile Test Data based on ASTM D638 Type IV

Condition A					
Exposure Time (hr)	yield stress (psi)	yield strain (%)	ultimate stress (psi)	ultimate strain (%)	break strain (%)
0	3250	18	1772	258	282
	3303	18	1883	201	214
	3326	18	2258	456	460
500	3253	16	1824	232	330
1000	3554	15	2037	98	112
	3298	15	1744	203	229
1500	3125	18	2002	443	454
	3066	18	1848	427	436
2000	3207	17	1910	411	425
	3248	17	1706	206	246
3000	3449	15	1861	158	180
	3517	15	1658	33	48
4000	3422	17	1825	94	199
	3494	15	1606	34	58
5000	3651	14	1722	25	32
	3582	16	1218	19	21
Condition B					
Exposure Time (hr)	**yield stress (psi)**	**yield strain (%)**	**ultimate stress (psi)**	**ultimate strain (%)**	**break strain (%)**
0	3250	18	1772	258	282
	3303	18	1883	201	214
	3326	18	2258	456	460
500	3581	15	1891	26	32
	3678	15	1995	50	67
1000	3913	15	2098	69	79
	3847	15	N/A	N/A	38
2000	3571	13	1880	22	30
	3598	13	1398	27	29
3000	3609	12	N/A	N/A	32
	3953	15	2108	32	48
4000	3784	14	2218	76	91
	3673	15	2135	84	104
Condition C					
Exposure Time (hr)	**yield stress (psi)**	**yield strain (%)**	**ultimate stress (psi)**	**ultimate strain (%)**	**break strain (%)**
0	3250	18	1772	258	282
	3303	18	1883	201	214
	3326	18	2258	456	460
500	3838	15	N/A	N/A	32
	3749	14	2050	32	45
1000	3620	14	N/A	N/A	40
	3668	14	N/A	N/A	191
2000	3557	15	1985	72	123
	3546	15	1966	206	228
3000	3644	14	N/A	N/A	27
	3682	14	1843	21	27

Appendix-G

Oxidative Induction Time Test Data from Oven-Aged Coupons

Table G-1 – OIT Value in Percentage Retained Across the Thickness

65°C							
Time (hr.)	**0**	**500**	**1000**	**1500**	**2000**	**4000**	
Layer 1	100	78.8	89.4	100.5	79.2	86.9	
Layer 2	100	75.9	78.5	104.1	85.6	88.0	
Layer 3	100	92.9	81.2	104.3	83.3	84.1	
Layer 4	100	105.4	89.1	111.9	81.7	92.6	
Layer 5	100	117.7	96.6	114.5	85.5	100.0	
average	**100**	**94.2**	**87.0**	**107.0**	**83.1**	**90.3**	
stdev.	**0**	**15.8**	**6.5**	**5.3**	**2.4**	**5.6**	
75°C							
Time (hr.)	**0**	**500**	**1000**	**2000**		**4000**	
Layer 1	100	84.5	106.4	76.2		72.7	
Layer 2	100	90.0	103.7	77.9		76.0	
Layer 3	100	90.0	111.6	78.8		83.0	
Layer 4	100	88.5	108.2	76.7		85.8	
Layer 5	100	85.3	110.7	82.1		74.8	
average	**100**	**87.7**	**108.1**	**78.4**		**78.5**	
stdev.	**0**	**2.3**	**2.9**	**2.1**		**5.1**	
85°C							
Time (hr.)	**0**	**500**	**1000**	**2000**	**3000**	**4000**	**5000**
Layer 1	100	75.2	54.9	61.6	44.4	61.3	46.0
Layer 2	100	77.6	62.4	51.0	55.8	47.0	51.4
Layer 3	100	78.4	73.5	67.0	62.9	60.2	53.3
Layer 4	100	68.6	70.9	72.6	63.7	54.4	52.7
Layer 5	100	53.3	69.5	55.4	39.4	54.3	50.5
average	100.0	70.6	66.2	61.5	53.2	55.4	50.8
stdev.	0.0	9.3	6.7	7.7	9.8	5.1	2.6

Table G-2 – Average OIT Value in Percentage Retained

65°C															
Time (hr.)	**0**	**500**	**1000**	**1500**	**2000**	**4000**	**6000**	**8000**	**10000**	**14000**	**18700**				
Average	100	94.2	87.0	107.0	83.1	90.3	78.6	76.6	69.7	41.3	28.5				
75°C															
Time (hr.)	**0**	**500**	**1000**		**2000**	**4000**	**6000**	**8000**	**10000**	**14000**	**18000**				
average	100	87.7	108.1		78.4	78.5	84.3	61.0	53.4	24.0	23.8				
85°C															
Time (hr.)	**0**	**500**	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**7000**	**8000**	**9000**	**10000**	**11000**	**14000**	**18000**
average	100	70.6	66.2	61.5	53.2	55.4	50.8	48.0	33.6	45.1	32.8	32.7	28.6	13.8	11.3

Appendix-H

Test Data of HDPE Structural Plastic Product after Outdoor Exposure at Gainesville, Florida

Appendix-H(a)

Oxidative Induction Time Test Data

Table H-1 – Oxidative Induction Time Test Data for Outdoor-Exposed Samples

4 Months						
Location	Thickness (in)	Weight (mg)	Total Thickness (in)	Normalized Depth	OIT (min)	OIT Retained (%)
First Set						
Surface (1)	0.020	4.2	0.09	0.12	2.29	23.30
2nd	0.017	4		0.24	6.36	61.75
3rd	0.023	6.7		0.59	8.33	86.68
4th	0.014	5.6		0.82	7.78	87.42
5th (bottom)	0.016	7.1		1.00	3.51	44.15
Second Set						
Surface (1)	0.014	3.3	0.106	0.08	2.27	23.09
2nd	0.020	5.4		0.16	4.5	43.69
3rd	0.016	5.1		0.48	7.71	80.23
4th	0.019	5.6		0.68	7.89	88.65
5th (bottom)	0.037	6.4		1.00	5.13	64.47

4 Months						
Location	Avg Depth (in)	Avg OIT (min)	STDEV Depth (in)	STDEV OIT (min)	Avg OIT Retained (%)	STDEV OIT Retained (%)
Average						
Surface (1)	0.101	2.28	0.0297	0.01	23.19	0.14
2nd	0.202	5.43	0.0593	1.32	52.72	12.77
3rd	0.536	8.02	0.0788	0.44	83.45	4.56
4th	0.749	7.84	0.0969	0.08	88.03	0.87
5th (bottom)	1.000	4.32	0.0000	1.14	54.31	14.36

8 Months						
Location	Thickness (in)	Weight (mg)	Total Thickness (in)	Normalized Depth	OIT (min)	OIT Retained (%)
First Set						
Surface (1)	0.024	2.7	0.1	0.13	1.92	19.53
2nd	0.03	3.2		0.26	5.64	54.76
3rd	0.019	5.1		0.68	7.43	77.32
4th	0.014	7.1		0.86	7.19	80.79
5th (bottom)	0.013	5.4		1.00	4.14	52.08
Second Set						
Surface (1)	0.023	2.2	0.098	0.12	1.39	14.14
2nd	0.025	3.6		0.25	5.41	52.52
3rd	0.021	4.2		0.63	6.86	71.38
4th	0.019	4.9		0.84	4.17	46.85
5th (bottom)	0.01	5		1.00	1.75	22.01

8 Months						
Location	Avg Depth (in)	Avg OIT (min)	STDEV Depth (in)	STDEV OIT (min)	Avg OIT Retained (%)	STDEV OIT Retained (%)
Average						
Surface (1)	0.126	1.66	0.0033	0.37	16.84	3.81
2nd	0.252	5.53	0.0066	0.16	53.64	1.58
3rd	0.654	7.15	0.0354	0.40	74.35	4.19
4th	0.850	5.68	0.0082	2.14	63.82	23.99
5th (bottom)	1.000	2.95	0.0000	1.69	37.04	21.26

Table H-1 – Continued

12 Months						
Location	Thickness (in)	Weight (mg)	Total Thickness (in)	Normalized Depth	OIT (min)	OIT Retained (%)
First Set						
Surface (1)	0.014	4	0.102	0.074	1.90	19.33
2nd	0.023	3.5		0.148	5.18	50.29
3rd	0.036	100		0.582	4.50	46.83
4th	0.014	5.8		0.847	5.50	61.80
5th (bottom)	0.015	3.4		1.000	3.74	47.04
Second Set						
Surface (1)	0.015	3.9	0.103	0.081	1.99	20.24
2nd	0.011	3.2		0.162	3.74	36.31
3rd	0.028	8.2		0.432	3.75	39.02
4th	0.028	8.5		0.735	2.97	33.37
5th (bottom)	0.021	6.3		1.000	2.75	34.59

12 Months						
Location	Avg Depth (in)	Avg OIT (min)	STDEV Depth (in)	STDEV OIT (min)	Avg OIT Retained (%)	STDEV OIT Retained (%)
Average						
Surface (1)	0.0776	1.95	0.0050	0.06	19.79	0.65
2nd	0.1552	4.46	0.0099	1.02	43.30	9.89
3rd	0.5072	4.13	0.1058	0.53	42.92	5.52
4th	0.7908	4.24	0.0788	1.79	47.58	20.10
5th (bottom)	1.0000	3.25	0.0000	0.70	40.82	8.81

16 Months						
Location	Thickness (in)	Weight (mg)	Total Thickness (in)	Normalized Depth	OIT (min)	OIT Retained (%)
First Set						
Surface (1)	0.014	3.4	0.084	0.090	0.93	9.46
2nd	0.020	2.7		0.179	6.14	59.61
3rd	0.030	7.6		0.628	4.83	50.26
4th	0.008	5.1		0.872	6.63	74.49
5th (bottom)	0.012	4.2		1.000	3.38	42.52
Second Set						
Surface (1)	0.016	5.2	0.095	0.092	1.4	14.24
2nd	0.029	4.5		0.185	7.6	73.79
3rd	0.019	5.7		0.630	7.3	75.96
4th	0.014	8		0.821	5.95	66.85
5th (bottom)	0.017	3.8		1.000	3.84	48.30
Third Set						
Surface (1)	0.012	3.1	0.093	0.069	1.19	12.11
2nd	0.028	3.9		0.139	5.43	52.72
3rd	0.024	8		0.601	4.42	45.99
4th	0.016	7.8		0.832	2.79	31.35
5th (bottom)	0.013	4.2		1.000	2.29	28.81

16 Months						
Location	Avg Depth (in)	Avg OIT (min)	STDEV Depth (in)	STDEV OIT (min)	Avg OIT Retained (%)	STDEV OIT Retained (%)
Average						
Surface (1)	0.084	1.17	0.013	0.24	11.94	2.40
2nd	0.168	6.39	0.025	1.11	62.04	10.74
3rd	0.620	5.52	0.016	1.56	57.41	16.21
4th	0.842	5.12	0.027	2.05	57.57	23.02
5th (bottom)	1.000	3.17	0.000	0.80	39.87	10.01

Table H-1 – Continued

20 Months						
Location	Thickness (in)	Weight (mg)	Total Thickness (in)	Normalized Depth	OIT (min)	OIT Retained (%)
First Set						
Surface (1)	0.016	3.7	0.102	0.088	2.16	21.97
2nd	0.018	4.9		0.177	3.53	34.27
3rd	0.022	4.6		0.497	4.55	47.35
4th	0.023	4.9		0.746	1.78	20.00
5th (bottom)	0.023	4.7		1.000	6.35	79.87
Second Set						
Surface (1)	0.017	4	0.104	0.087	0.77	7.83
2nd	0.012	4.8		0.174	6.97	67.67
3rd	0.021	4.4		0.405	3.91	40.69
4th	0.041	3.6		0.723	3.38	37.98
5th (bottom)	0.013	4.9		1.000	3.99	50.19

20 Months						
Location	Avg Depth (in)	Avg OIT (min)	STDEV Depth (in)	STDEV OIT (min)	Avg OIT Retained (%)	STDEV OIT Retained (%)
Average						
Surface (1)	0.088	1.465	0.001	0.98	14.90	10.00
2nd	0.176	5.25	0.002	2.43	50.97	23.62
3rd	0.451	4.23	0.065	0.45	44.02	4.71
4th	0.734	2.58	0.016	1.13	28.99	12.71
5th (bottom)	1.000	5.17	0.000	1.67	65.03	20.99

24 Months						
Location	Thickness (in)	Weight (mg)	Total Thickness (in)	Normalized Depth	OIT (min)	OIT Retained (%)
First Set						
Surface (1)	0.019	2.7	0.077	0.13	1.02	10.38
2nd	0.024	3.2		0.27	5.43	52.72
3rd	0.014	5.1		0.70	5.39	56.09
4th	0.009	7.1		0.86	5.42	60.90
5th (bottom)	0.011	5.4		1.00	3.1	38.99
Second Set						
Surface (1)	0.014	2.2	0.067	0.11	0.93	9.46
2nd	0.024	3.6		0.23	5.07	49.22
3rd	0.010	4.2		0.69	5.62	58.48
4th	0.009	4.9		0.85	5.94	66.74
5th (bottom)	0.010	5		1.00	3.3	41.51

24 Months						
Location	Avg Depth (in)	Avg OIT (min)	STDEV Depth (in)	STDEV OIT (min)	Avg OIT Retained (%)	STDEV OIT Retained (%)
Average						
Surface (1)	0.123	0.98	0.0141	0.064	9.92	0.65
2nd	0.246	5.25	0.0282	0.255	50.97	2.47
3rd	0.696	5.51	0.0041	0.163	57.28	1.69
4th	0.853	5.68	0.0095	0.368	63.82	4.13
5th (bottom)	1.000	3.20	0.0000	0.141	40.25	1.78

Appendix H(b)

Tensile Test Data

Table H-2 – Tensile Test Data of Outdoor-Exposed Samples

Test	Yield Stress (psi)		Yield Strain (%)		Break Stress (psi)		Break Strain (%)	
0 (2)	3250.0		17.7		1772.5		282.0	
0 (3)	3303.2		17.7		1883.2		213.6	
0 (4)	3326.1		17.7		2257.7		460.0	
4 mon (1)	3528.2		8.9		2175.2		432.3	
4 mon (2)	3430.2		16.5		1830.0		340.4	
4 mon (3)	3238.3		12.7		1869.1		107.4	
4 mon(4)	3167.3		17.7		1359.7		68.3	
8 mon (1)	3761.2		13.9		1710.0		53.0	
8 mon (2)	3593.7		13.0		1901.6		106.2	
8 mon (3)	3136.5		11.4		1717.3		42.4	
8 mon (4)	3199.3		17.3		1744.8		90.9	
12 mon (1)	3337.3		11.2		1799.0		55.3	
12 mon (2)	3223.6		13.3		2781.9		25.3	
12 mon (3)	3368.4		11.8		2021.0		193.2	
12 mon (4)	3444.4		16.3		1548.1		79.5	
16 mon (1)	3093.4		11.1		1452.1		42.4	
16 mon (2)	2791.5		13.1		1680.8		64.0	
16 mon (3)	3119.4		10.8		2072.9		433.7	
16 mon (4)	3236.3		22.4		1562.2		164.9	
20 mon (1)	3372.8		10.1		2860.0		28.3	
20 mon (2)	3323.3		14.7		2542.8		48.7	
20 mon (3)	3577.9		13.6		2138.3		484.4	
20 mon (4)	3388.3		16.9		1972.3		112.9	
24 mon (1)	3542.0		13.5		1753.5		50.6	
24 mon (2)	3253.3		16.7		1616.3		66.9	
24 mon (3)	2767.0		14.0		0.0		27.2	
24mon (4)	3141.6		15.7		1618.2		74.3	

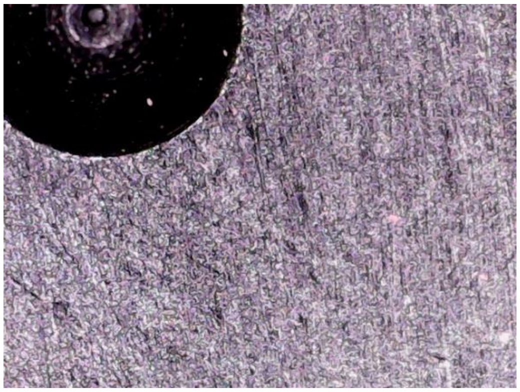
Time (mon)	Yield Stress (psi)	STDEV	Yield Strain (%)	STDEV	Break Stress (psi)	STDEV	Break Strain (%)	STDEV
0	3293.1	39.0	17.7	0.0	1971.2	254.3	318.5	127.2
4	3341.0	167.1	14.0	4.0	1808.5	336.7	237.1	177.1
8	3422.7	303.1	13.9	2.5	1768.4	90.0	73.1	30.3
12	3343.4	91.7	13.1	2.3	2037.5	532.5	88.3	73.3
16	3060.2	189.6	14.3	5.5	1692.0	270.5	176.2	179.8
20	3348.1	35.0	12.4	3.3	2701.4	224.3	168.6	213.6
24	3176.0	320.6	15.0	1.5	1247.0	833.8	54.8	20.9

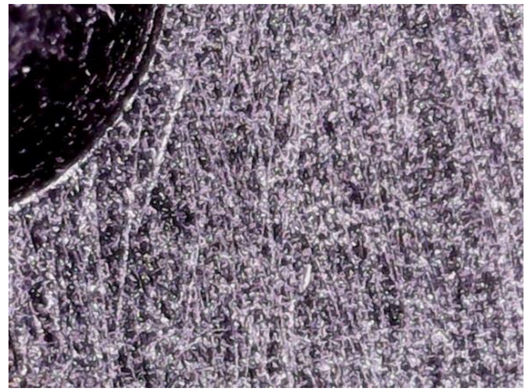
Appendix-I

Surface Appearance Photographs of DWS Samples After Exposure in Xenon Weatherometer

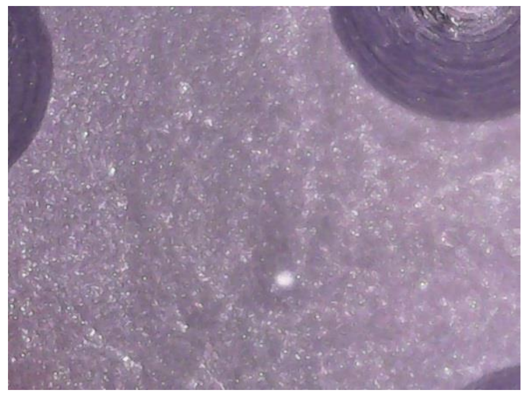
<u>Appendix-I(a)</u>

ADA Solutions (Polyester) Coupons

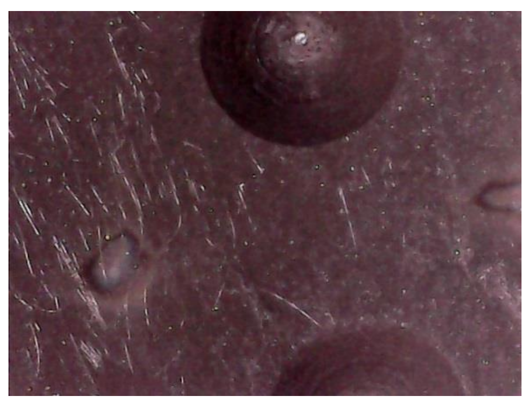




ADA Solution, Black – Condition [A], 0 hr. ADA Solution, Black – Condition [A], 500 hr.

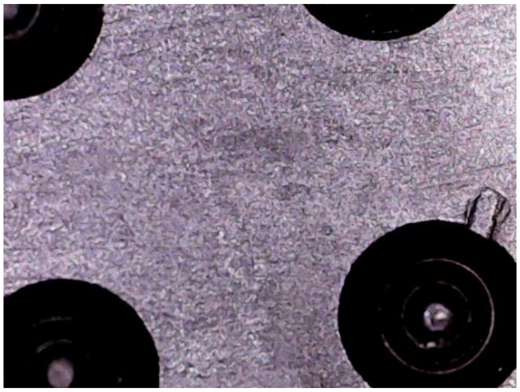


ADA Solution, Black-Condition [A], 1500 hr. ADA Solution, Black – Condition [A], 2000 hr.

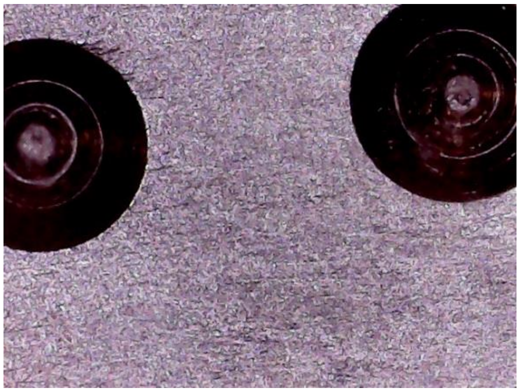


ADA Solution, Black – Condition [A], 2500 hr. ADA Solution, Black – Condition [A], 3000 hr.

Figure I-1 – Surface morphology of ADA Solutions black coupons exposed to xenon weatherometer under Condition [A]



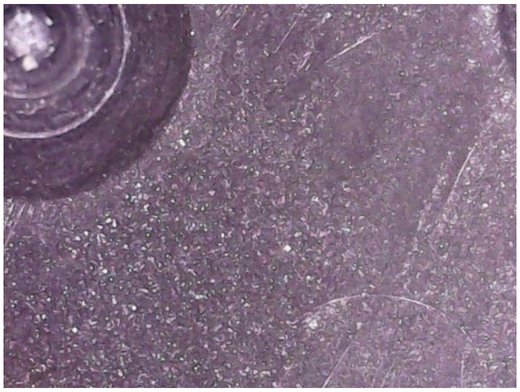
ADA Solution, Black – Condition [B], 0 hr.



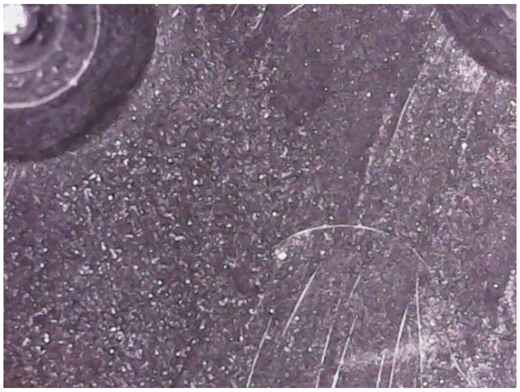
ADA Solution, Black – Condition [B], 500 hr.

ADA Solution, Black – Condition [B], 1500 hr.

ADA Solution, Black – Condition [B], 2000 hr.



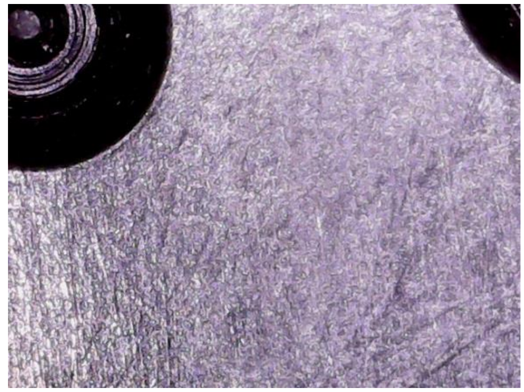
ADA Solution, Black – Condition [B], 2500 hr.



ADA Solution, Black – Condition [B], 3000 hr.

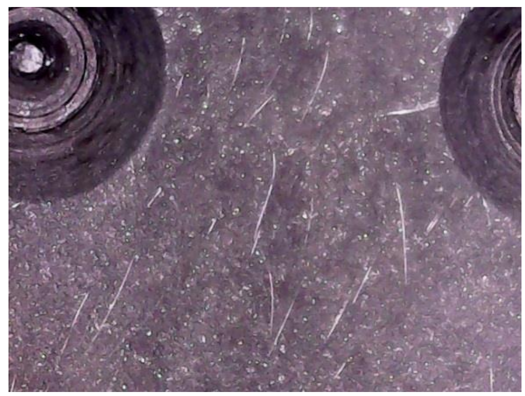
Figure I-2 – Surface morphology of ADA Solutions black coupons exposed to xenon weatherometer under Condition [B]

ADA Solution, Black – Condition [C], 0 hr.

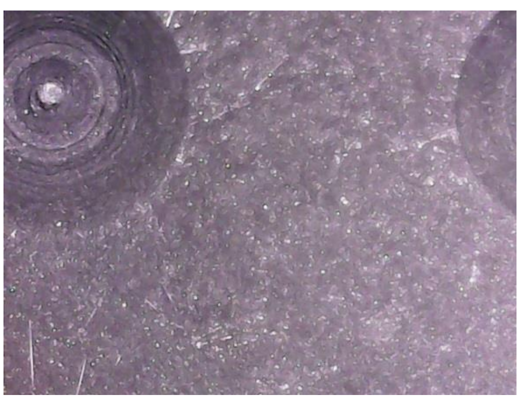


ADA Solution, Black – Condition [C], 500 hr.

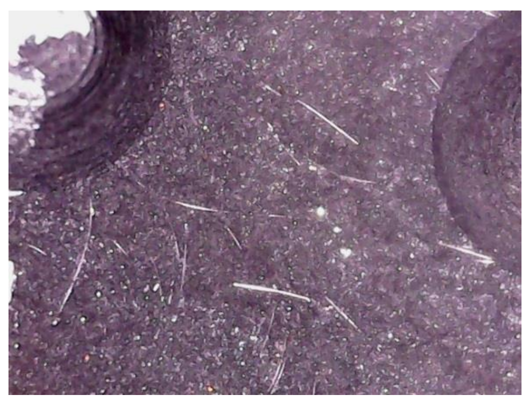
ADA Solution, Black – Condition [C], 1500 hr.



ADA Solution, Black – Condition [C], 2000 hr.

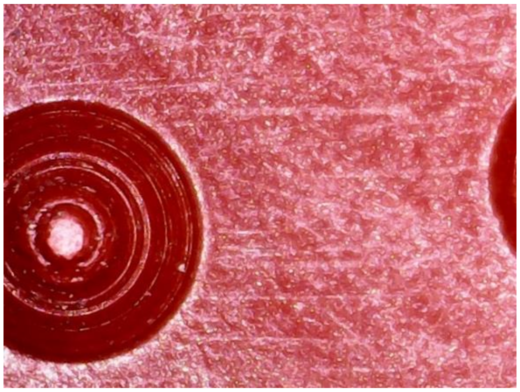


ADA Solution, Black – Condition [C], 2500 hr.

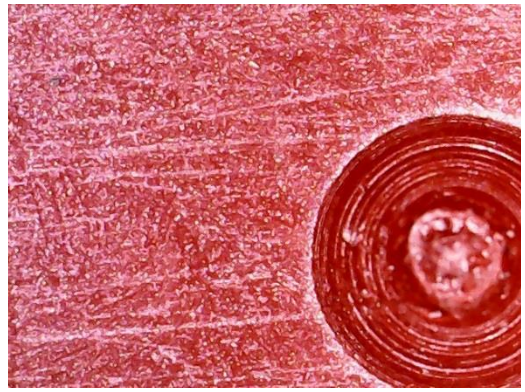


ADA Solution, Black – Condition [C], 3000 hr.

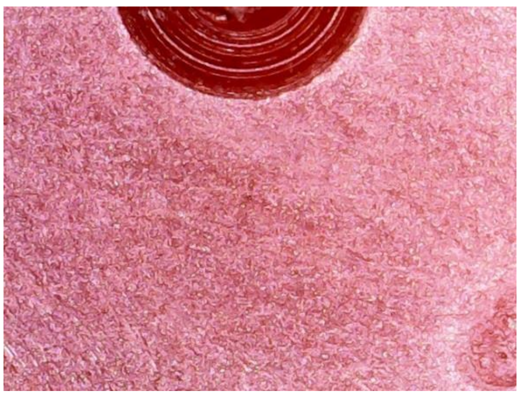
Figure I-3 – Surface morphology of ADA Solutions black coupons exposed to xenon weatherometer under Condition [C]



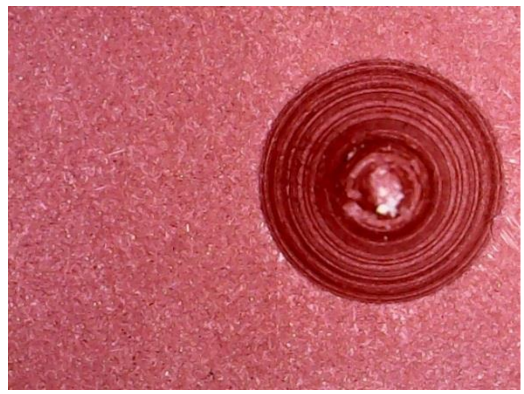
ADA Solution, Red-Condition [A], 0 hr.



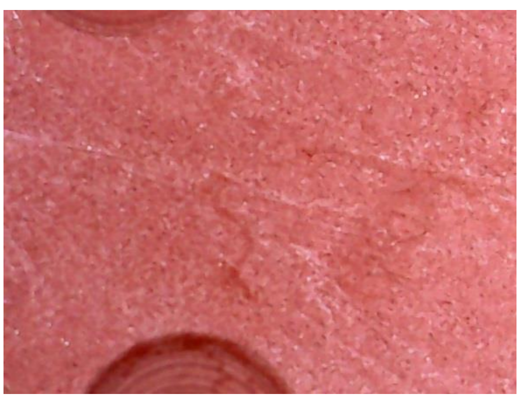
ADA Solution, Red – Condition [A], 500 hr.



ADA Solution, Red-Condition [A], 1500 hr.



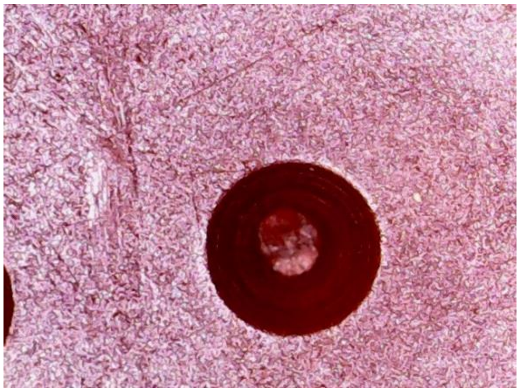
ADA Solution, Red – Condition [A], 2000 hr.



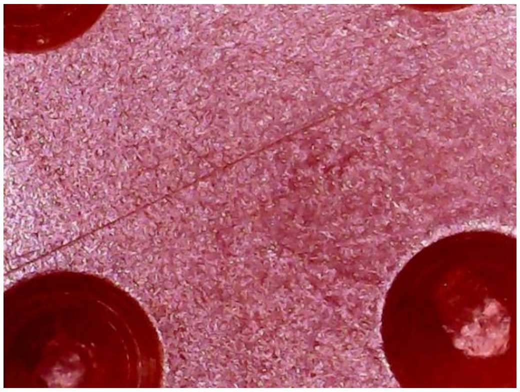
ADA Solution, Red-Condition [A], 2500 hr.

ADA Solution, Red – Condition [A], 3000 hr.

Figure I-4 – Surface morphology of ADA Solutions red coupons exposed to xenon weatherometer under Condition [A]

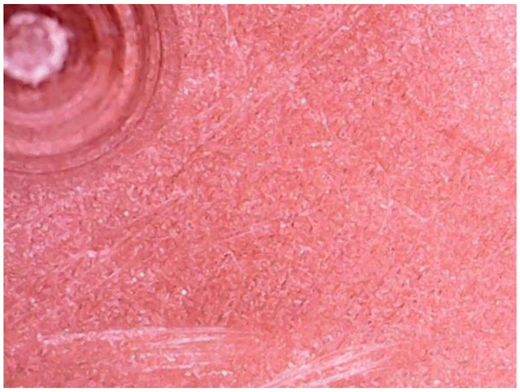


ADA Solution, Red-Condition [B], 0 hr.



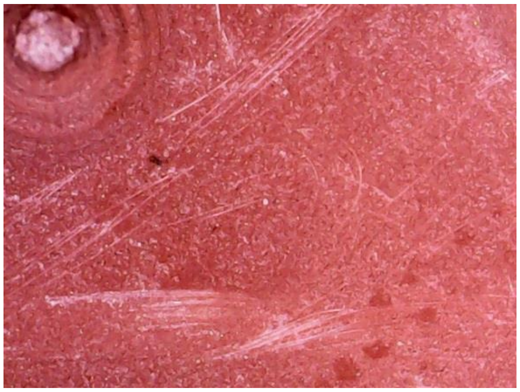
ADA Solution, Red – Condition [B], 500 hr.

ADA Solution, Red-Condition [B], 1500 hr.



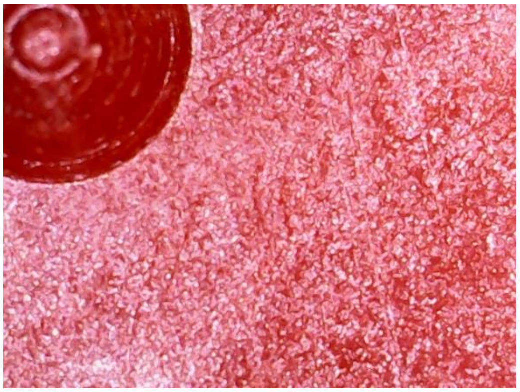
ADA Solution, Red – Condition [B], 2000 hr.

ADA Solution, Red-Condition [B], 2500 hr.

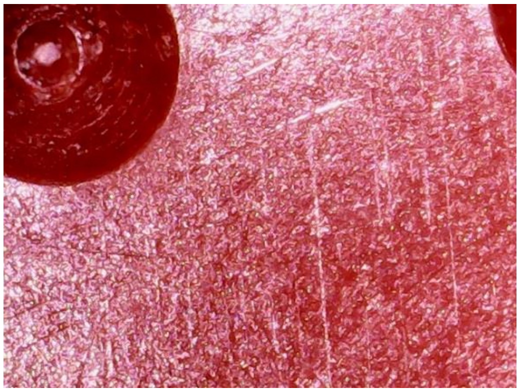


ADA Solution, Red – Condition [B], 3000 hr.

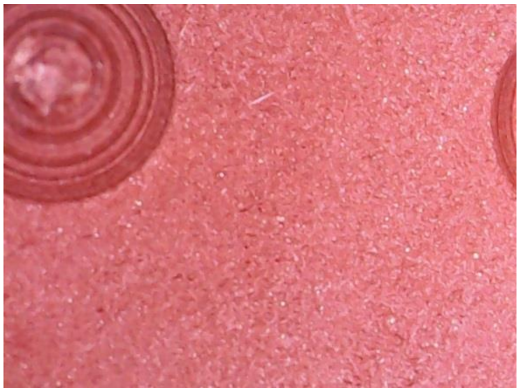
Figure I-5 – Surface morphology of ADA Solutions red coupons exposed to xenon weatherometer under Condition [B]



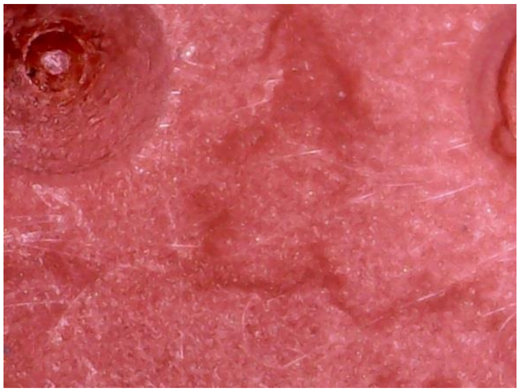
ADA Solution, Red-Condition [C], 0 hr.



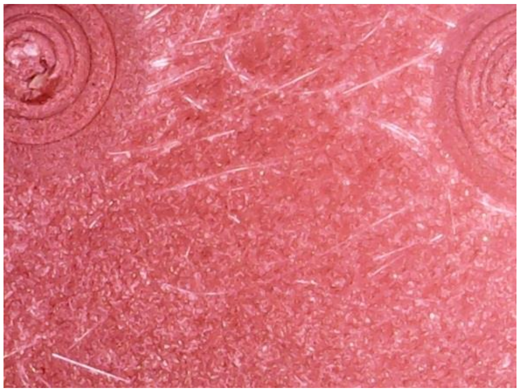
ADA Solution, Red – Condition [C], 500 hr.



ADA Solution, Red-Condition [C], 1500 hr.



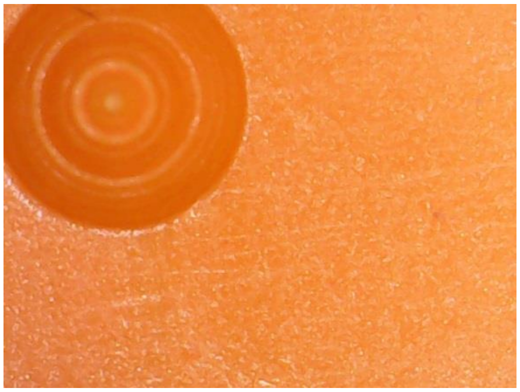
ADA Solution, Red – Condition [C], 2000 hr.



ADA Solution, Red-Condition [C], 2500 hr.

ADA Solution, Red – Condition [C], 3000 hr.

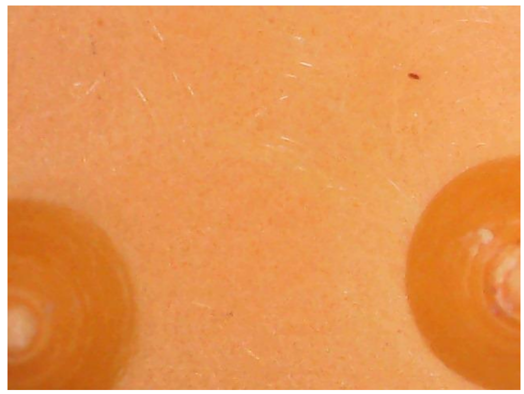
Figure I-6 – Surface morphology of ADA Solutions red coupons exposed to xenon weatherometer under Condition [C]



ADA Solution, Yellow – Condition [A], 0 hr.

ADA Solution, Yellow – Condition [A], 500 hr.

ADA Solution, Yellow – Condition [A], 1500 hr.

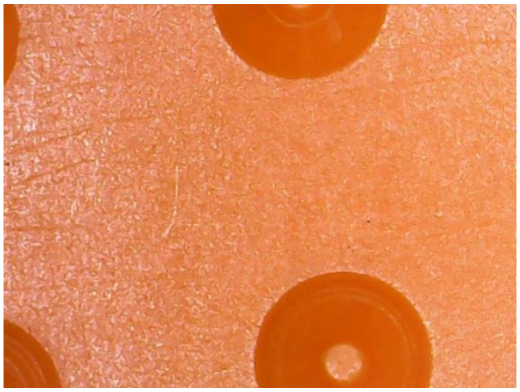


ADA Solution, Yellow – Condition [A], 2000 hr.

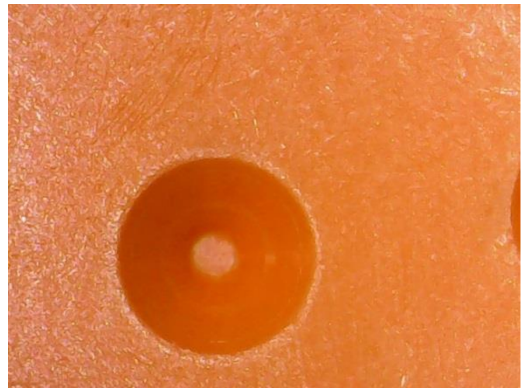
ADA Solution, Yellow – Condition [A],. 1500 hr.

ADA Solution, Yellow – Condition [A], 2000 hr.

Figure I-7 – Surface morphology of ADA Solutions yellow coupons exposed to xenon weatherometer under Condition [A]



ADA Solution, Yellow – Condition [B], 0 hr.



ADA Solution, Yellow – Condition [B], 500 hr.

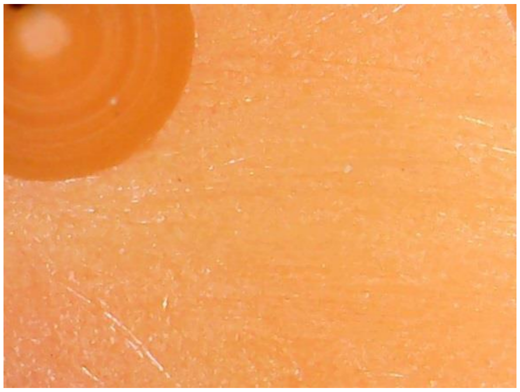
ADA Solution, Yellow – Condition [B], 1500 hr.

ADA Solution, Yellow – Condition [B], 2000 hr.

ADA Solution, Yellow – Condition [B], 2500 hr.

ADA Solution, Yellow – Condition [B], 3000 hr.

Figure I-8 – Surface morphology of ADA Solutions yellow coupons exposed to xenon weatherometer under Condition [B]



ADA Solution, Yellow – Condition [C], 0 hr.

ADA Solution, Yellow – Condition [C], 500 hr

ADA Solution, Yellow – Condition [C], 1500 hr.

ADA Solution, Yellow – Condition [C], 2000 hr.

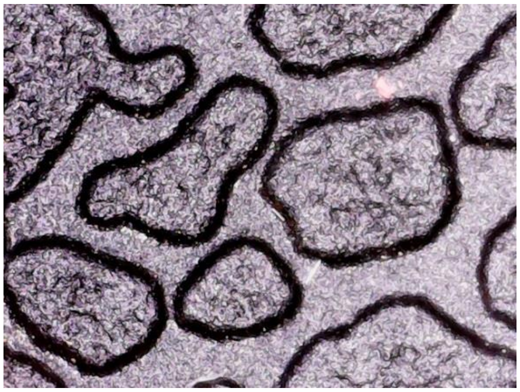
ADA Solution, Yellow – Condition [C], 2500 hr.

ADA Solution, Yellow – Condition [C], 3000 hr.

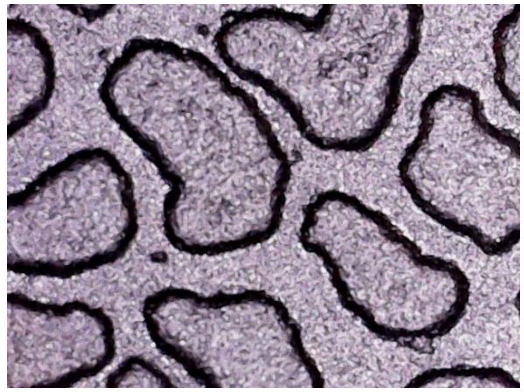
Figure I-9 – Surface morphology of ADA Solutions yellow coupons exposed to xenon weatherometer under Condition [C]

Appendix-I(b)

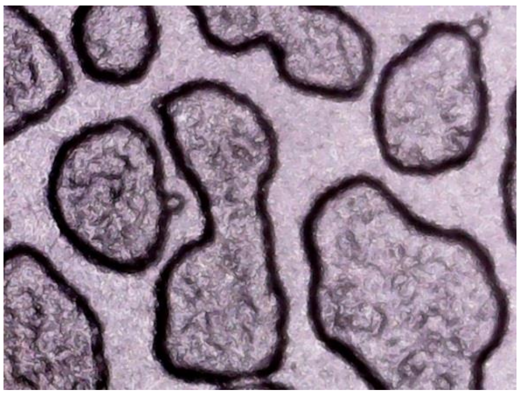
AlertCast (Polyester NPG) Coupons



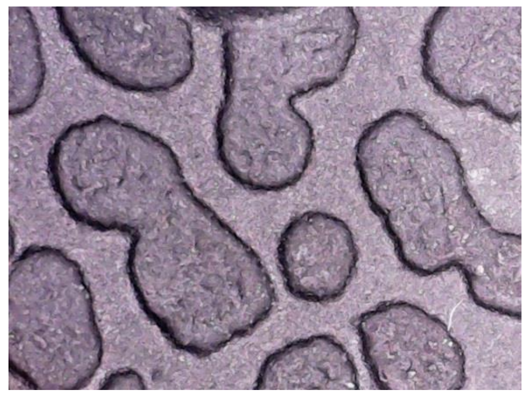
AlertCast, Black – Condition [A], 0 hr.



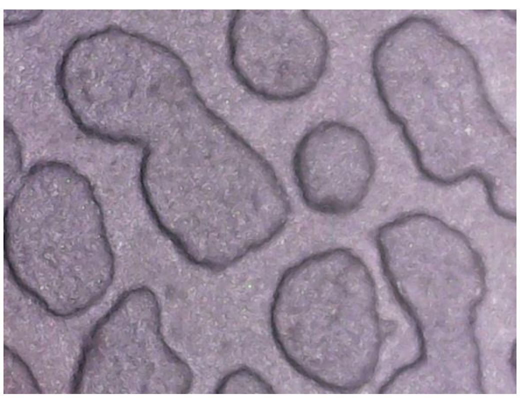
AlertCast, Black – Condition [A], 500 hr.



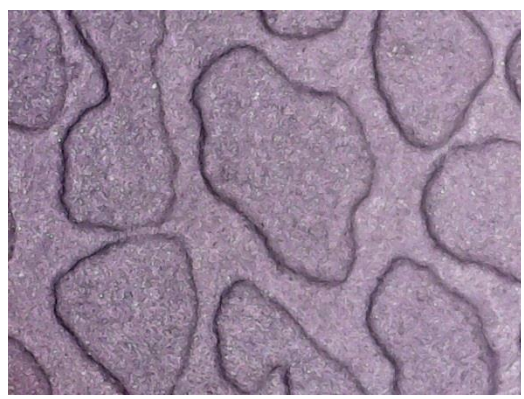
AlertCast, Black – Condition [A], 1500 hr.



AlertCast, Black – Condition [A], 2000 hr.

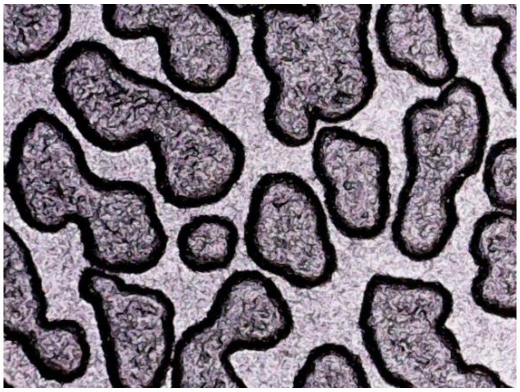


AlertCast, Black – Condition [A], 2500 hr.

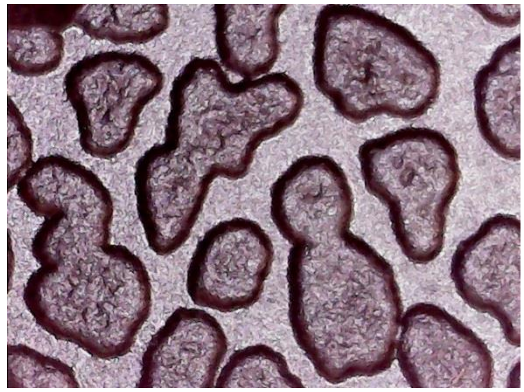


AlertCast, Black – Condition [A], 3000 hr.

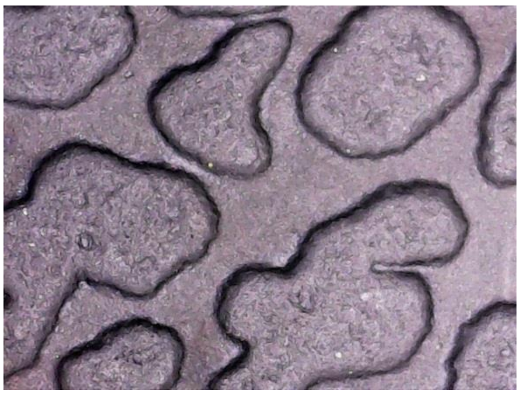
Figure I-9 – Surface morphology of AlertCast black coupons exposed to xenon weatherometer under Condition [A]



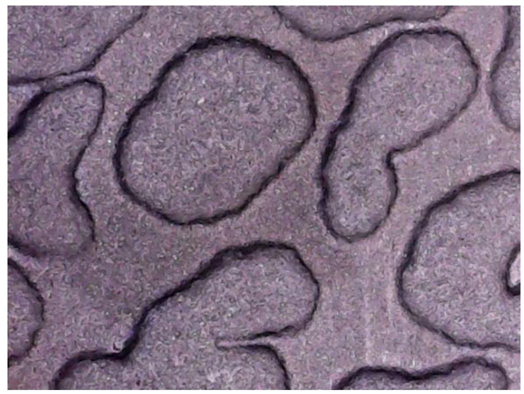
AlertCast, Black – Condition [B], 0 hr.



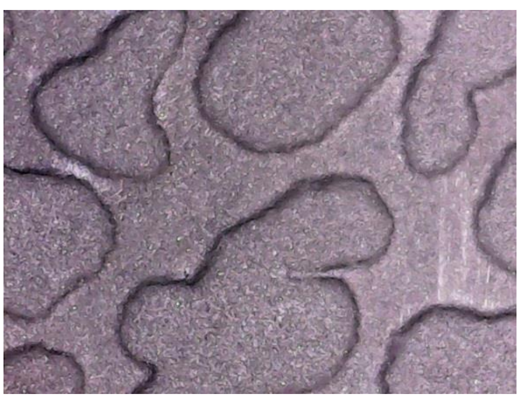
AlertCast, Black – Condition [B], 500 hr.



AlertCast, Black – Condition [B], 1500 hr.



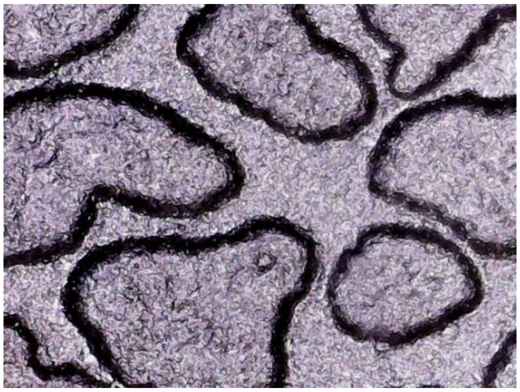
AlertCast, Black – Condition [B], 2000 hr.



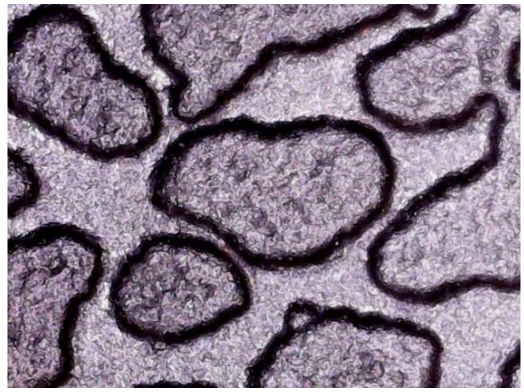
AlertCast, Black – Condition [B], 2500 hr.

AlertCast, Black – Condition [B], 3000 hr.

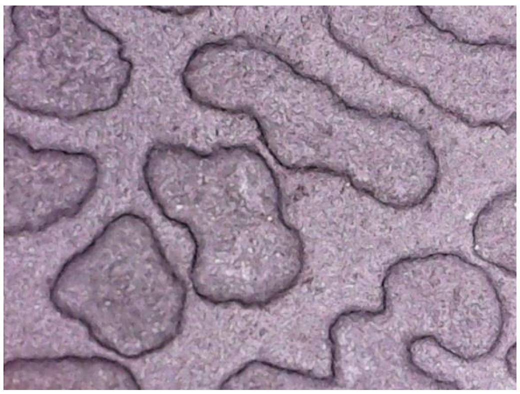
Figure I-11 – Surface morphology of AlertCast black coupons exposed to xenon weatherometer under Condition [B]



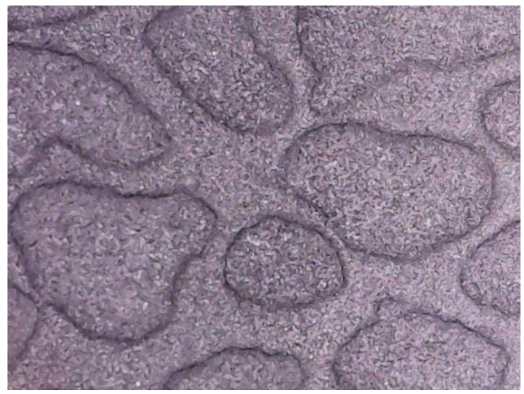
AlertCast, Black – Condition [C], 0 hr.



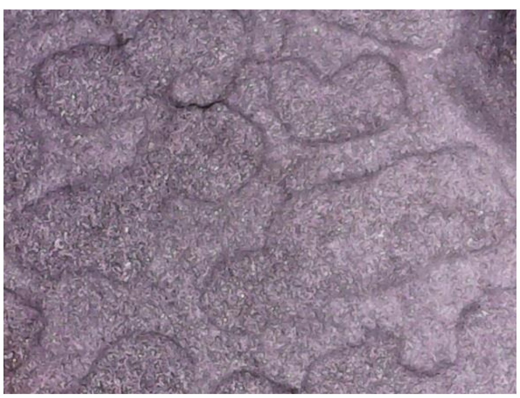
AlertCast, Black – Condition [C], 500 hr.



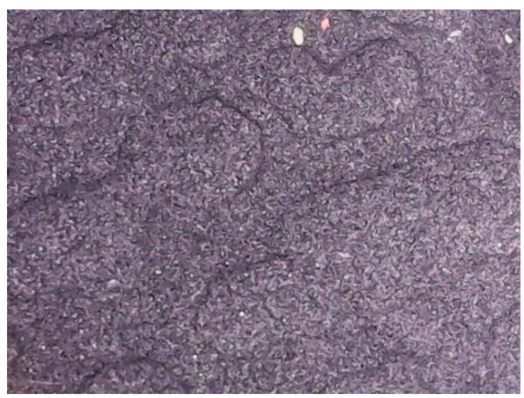
AlertCast, Black – Condition [C], 1500 hr.



AlertCast, Black – Condition [C], 2000 hr.



AlertCast, Black – Condition [C], 2500 hr.



AlertCast, Black – Condition [C], 3000 hr.

Figure I-12 – Surface morphology of AlertCast black coupons exposed to xenon weatherometer under Condition [C]

AlertCast, Red – Condition [A], 0 hr.

AlertCast, Red – Condition [A], 500 hr.

AlertCast, Red – Condition [A], 1500 hr.

AlertCast, Red – Condition [A], 2000 hr.

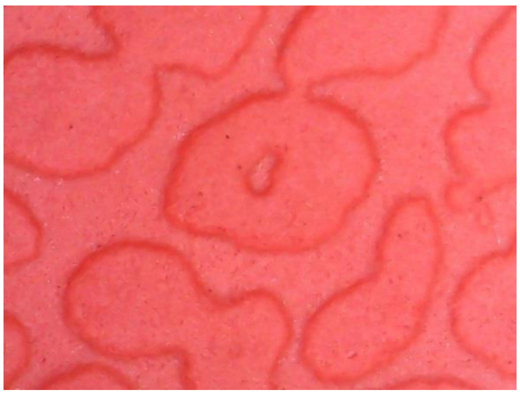
AlertCast, Red – Condition [A], 2500 hr.

AlertCast, Red – Condition [A], 3000 hr.

Figure I-13 – Surface morphology of AlertCast red coupons exposed to xenon weatherometer under Condition [A]

AlertCast, Red – Condition [B], 0 hr.

AlertCast, Red – Condition [B], 500 hr.



AlertCast, Red – Condition [B], 1500 hr.

AlertCast, Red – Condition [B], 2000 hr.

AlertCast, Red – Condition [B], 3000 hr.

AlertCast, Red – Condition [B], 2500 hr.

Figure I-14 – Surface morphology of AlertCast red coupons exposed
to xenon weatherometer under Condition [B]

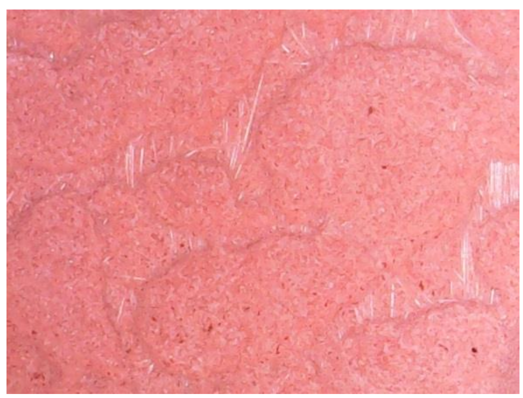
AlertCast, Red – Condition [C], 0 hr.

AlertCast, Red – Condition [C], 500 hr.

AlertCast, Red – Condition [C], 1500 hr.

AlertCast, Red – Condition [C], 2000 hr.

AlertCast, Red – Condition [C], 2500 hr.



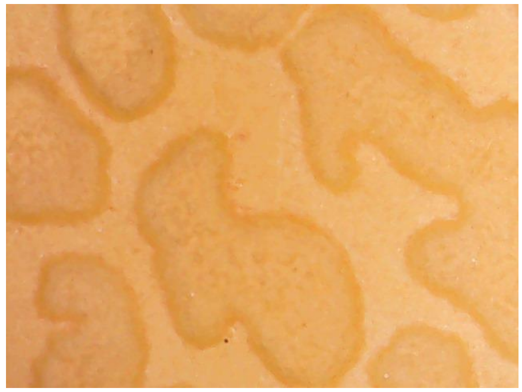
AlertCast, Red – Condition [C], 3000 hr.

Figure I-15 – Surface morphology of AlertCast red coupons exposed to xenon weatherometer under Condition [C]

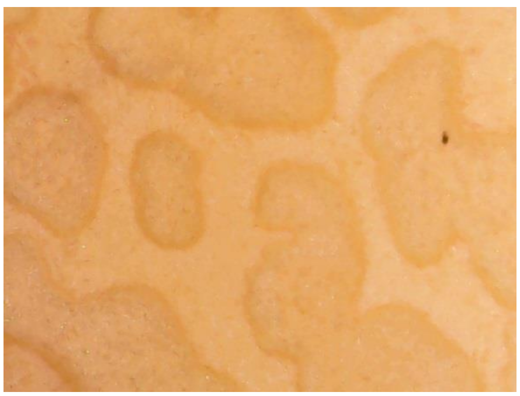
AlertCast, Yellow – Condition [A], 0 hr.

AlertCast, Yellow – Condition [A], 500 hr.

AlertCast, Yellow – Condition [A], 1500 hr.



AlertCast, Yellow – Condition [A], 2000 hr.



AlertCast, Yellow – Condition [A], 2500 hr.

AlertCast, Yellow – Condition [A], 3000 hr.

Figure I-16 – Surface morphology of AlertCast yellow coupons exposed to xenon weatherometer under Condition [A]

AlertCast, Yellow – Condition [B], 0 hr. AlertCast, Yellow – Condition [B], 500 hr.

AlertCast, Yellow – Condition [B], 1500 hr.
AlertCast, Yellow – Condition [B], 2000 hr.

AlertCast, Yellow – Condition [B], 2500 hr.
AlertCast, Yellow – Condition [B], 3000 hr.

Figure I-17 – Surface morphology of AlertCast yellow coupons exposed to xenon weatherometer under Condition [B]

AlertCast, Yellow – Condition [C], 0 hr.

AlertCast, Yellow – Condition [C], 500 hr.

AlertCast, Yellow – Condition [C], 1500 hr.

AlertCast, Yellow – Condition [C], 2000 hr.

AlertCast, Yellow – Condition [C], 2500 hr.

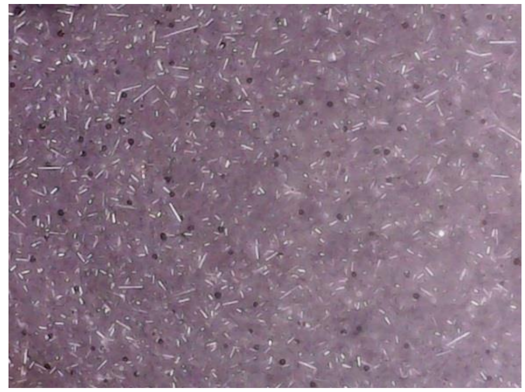
AlertCast, Yellow – Condition [C], 3000 hr.

Figure I-18 – Surface morphology of AlertCast yellow coupons exposed to xenon weatherometer under Condition [C]

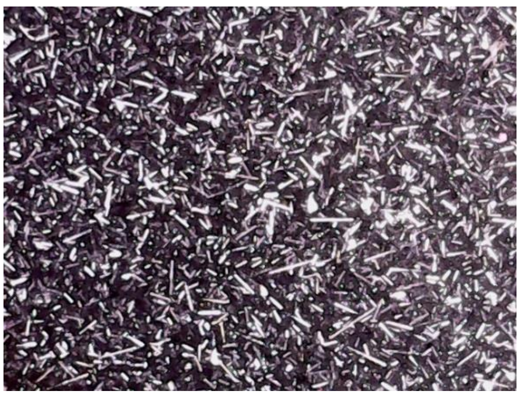
Appendix-I(c)

Redimat (Polyurethane) Coupons

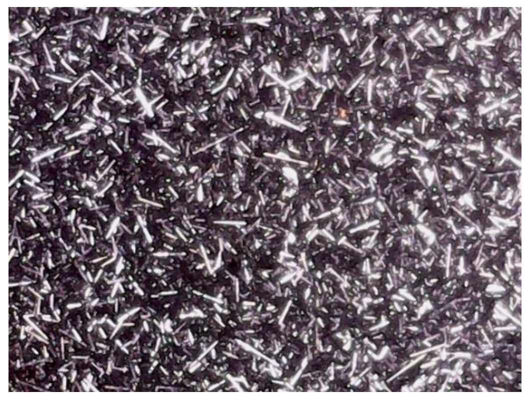
Redimat, Black – Condition [A], 0 hr.



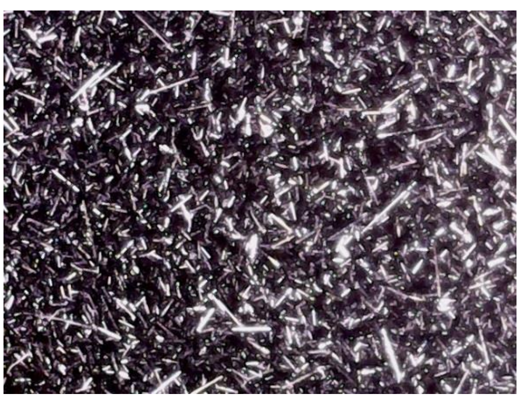
Redimat, Black – Condition [A], 500 hr.



Redimat, Black – Condition [A], 1500 hr.



Redimat, Black – Condition [A], 2000 hr.

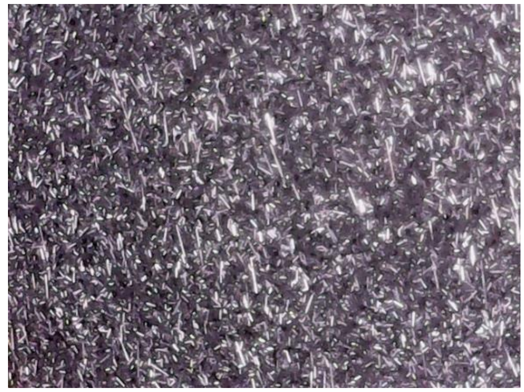


Redimat, Black – Condition [A], 2500 hr.

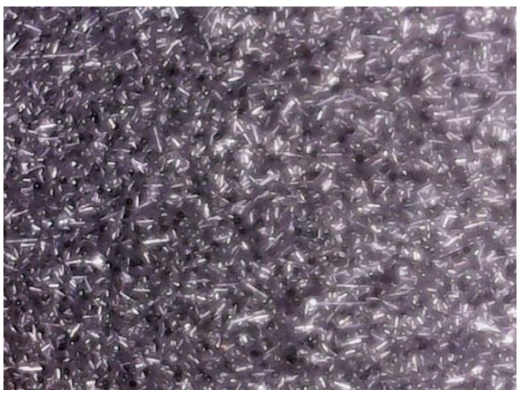
Redimat, Black – Condition [A], 3000 hr.

Figure I-19 – Surface morphology of Redimat black coupons exposed to xenon weatherometer under Condition [A]

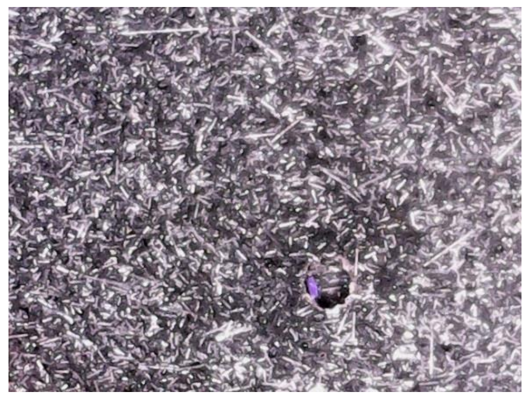
Redimat, Black – Condition [B], 0 hr.



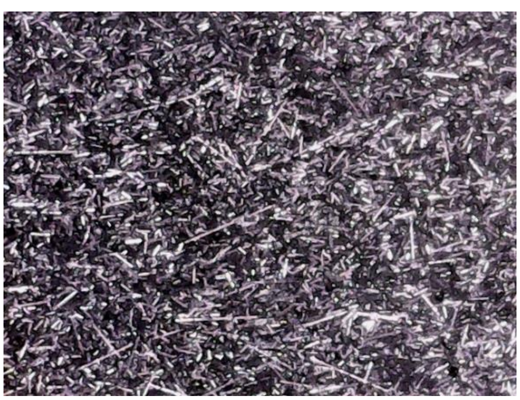
Redimat, Black – Condition [B], 1000 hr.



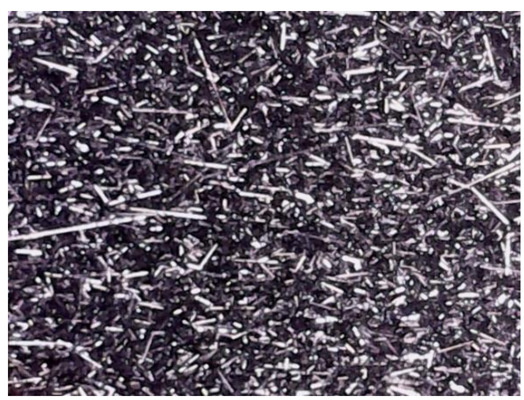
Redimat, Black – Condition [B], 2000 hr.



Redimat, Black – Condition [B], 1500 hr.

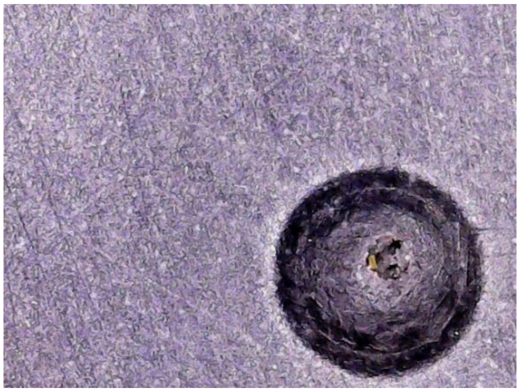


Redimat, Black – Condition [B], 2500 hr.

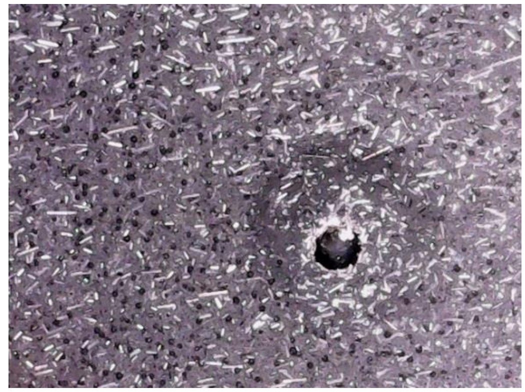


Redimat, Black – Condition [B], 3000 hr.

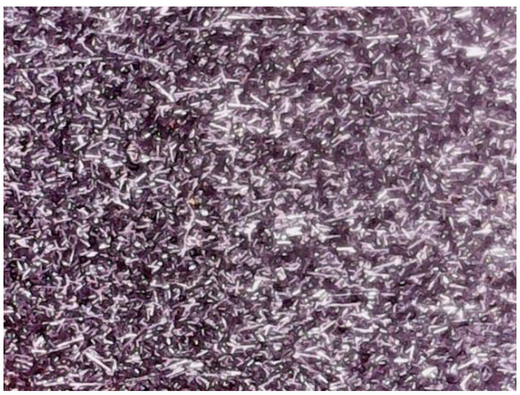
Figure I-20 – Surface morphology of Redimat black coupons exposed to xenon weatherometer under Condition [B]



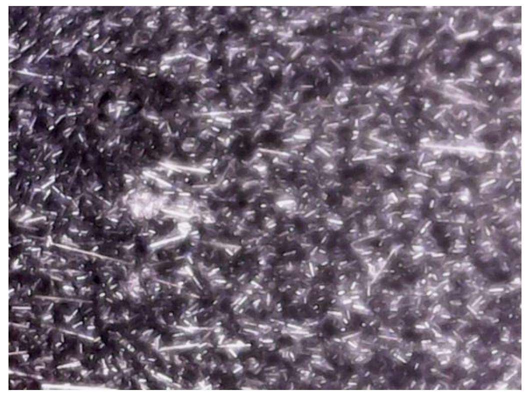
Redimat, Black – Condition [C], 0 hr.



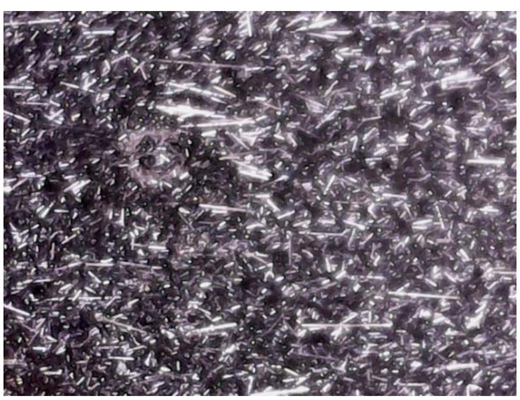
Redimat, Black – Condition [C], 500 hr.



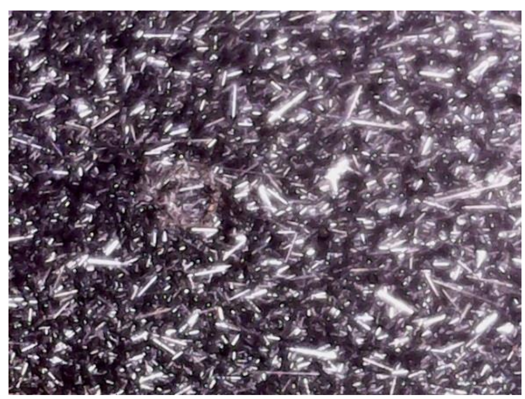
Redimat, Black – Condition [C], 1500 hr.



Redimat, Black – Condition [C], 2000 hr.

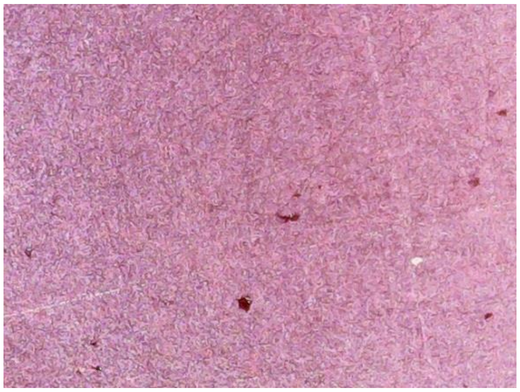


Redimat, Black – Condition [C], 2000 hr.



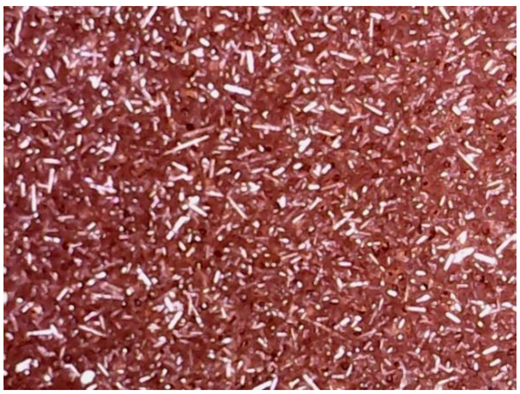
Redimat, Black – Condition [C], 3000 hr.

Figure I-21 – Surface morphology of Redimat black coupons exposed to xenon weatherometer under Condition [C]

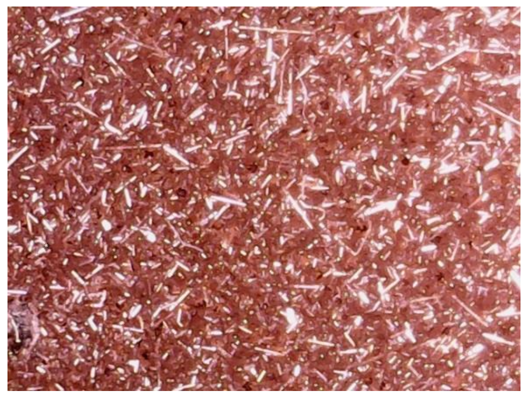


Redimat, Red – Condition [A], 0 hr.

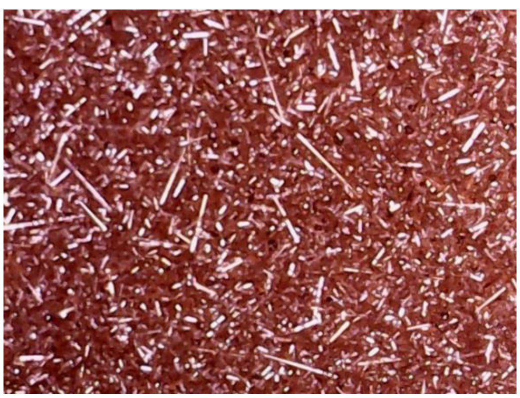
Redimat, Red – Condition [A], 500 hr.



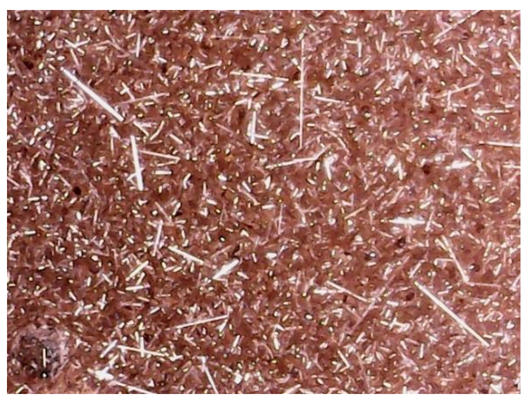
Redimat, Red – Condition [A], 1500 hr.



Redimat, Red – Condition [A], 2000 hr.

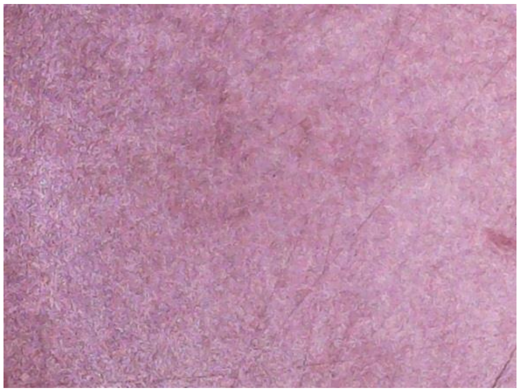


Redimat, Red – Condition [A], 2500 hr.

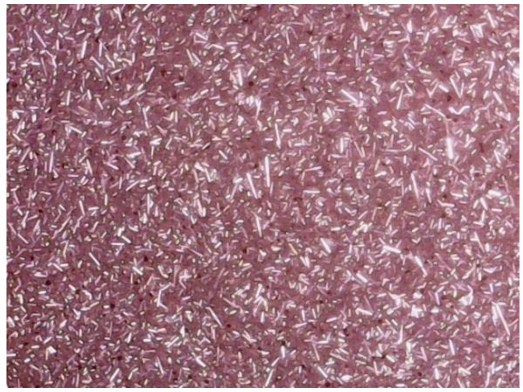


Redimat, Red – Condition [A], 3000 hr.

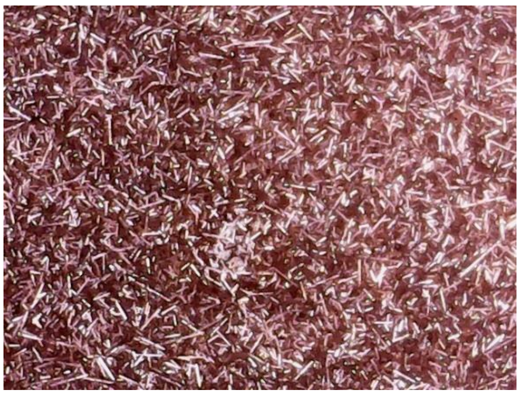
Figure I-22 – Surface morphology of Redimat red coupons exposed to xenon weatherometer under Condition [A]



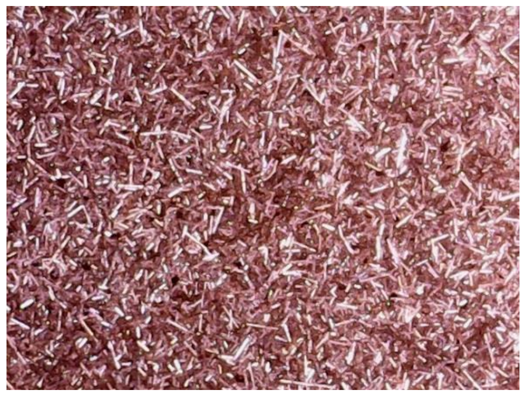
Redimat, Red – Condition [B], 0 hr.



Redimat, Red – Condition [B], 500 hr.

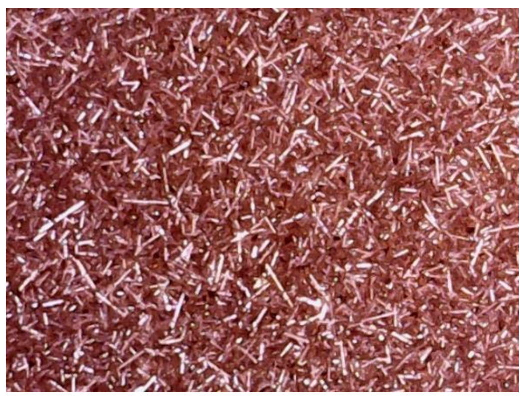


Redimat, Red – Condition [B], 1500 hr.



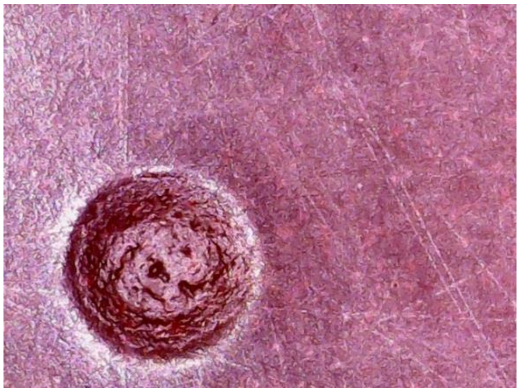
Redimat, Red – Condition [B], 2000 hr.

Redimat, Red – Condition [B], 2500 hr.

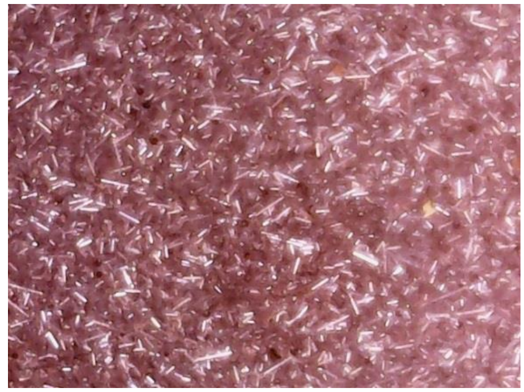


Redimat, Red – Condition [B], 3000 hr.

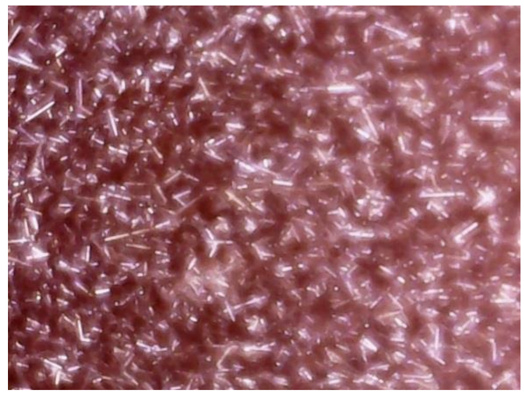
Figure I-23 – Surface morphology of Redimat red coupons exposed to xenon weatherometer under Condition [B]



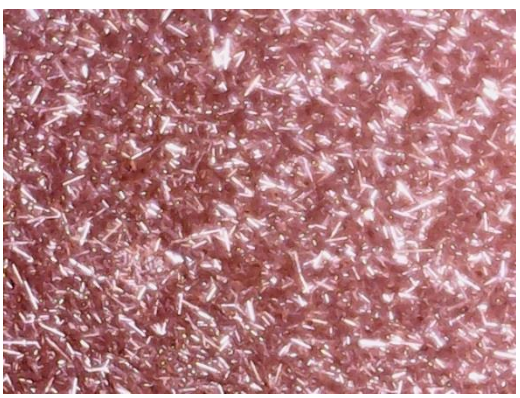
Redimat, Red – Condition [C], 0 hr.



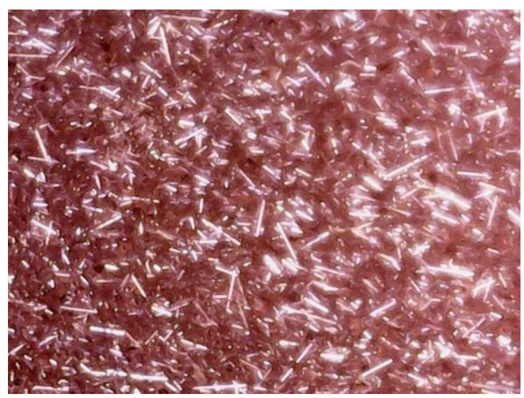
Redimat, Red – Condition [C], 500 hr.



Redimat, Red – Condition [C], 1500 hr. Redimat, Red
– Condition [C], 2000 hr.

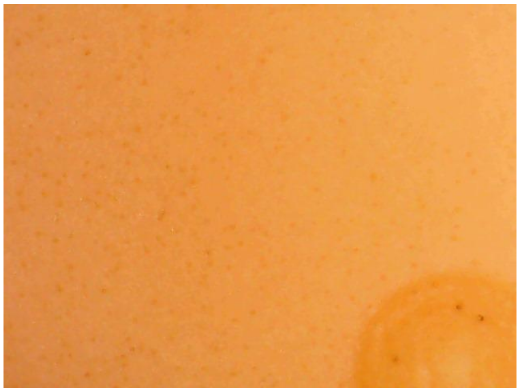


Redimat, Red – Condition [C], 2500 hr.



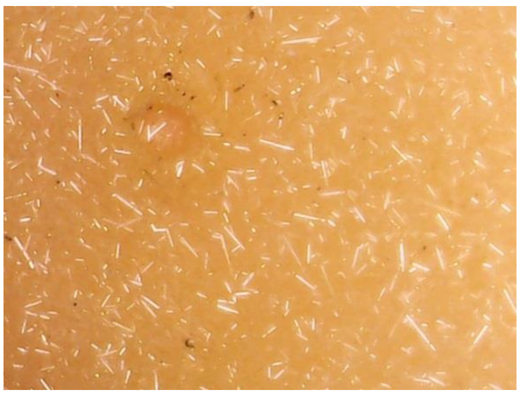
Redimat, Red – Condition [C], 3000 hr.

Figure I-24 – Surface morphology of Redimat red coupons exposed to xenon weatherometer under Condition [C]



Redimat, Yellow – Condition [A], 0 hr.

Redimat, Yellow – Condition [A], 500 hr.



Redimat, Yellow – Condition [A], 1500 hr.

Redimat, Yellow – Condition [A], 2000 hr.

Redimat, Yellow – Condition [A], 2500 hr.

Redimat, Yellow – Condition [A], 3000 hr.

Figure I-25 – Surface morphology of Redimat yellow coupons exposed to xenon weatherometer under Condition [A]

Redimat, Yellow – Condition [B], 0 hr.

Redimat, Yellow – Condition [B], 500 hr.

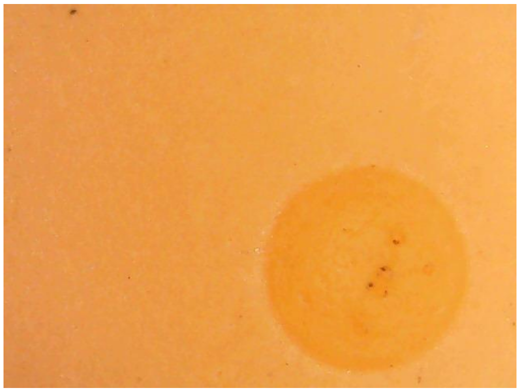
Redimat, Yellow – Condition [B], 1500 hr.

Redimat, Yellow – Condition [B], 2000 hr.

Redimat, Yellow – Condition [B], 2500 hr.

Redimat, Yellow – Condition [B], 3000 hr.

Figure I-26 – Surface morphology of Redimat yellow coupons exposed to xenon weatherometer under Condition [B]



Redimat, Yellow – Condition [C], 0 hr.

Redimat, Yellow – Condition [C], 500 hr.

Redimat, Yellow – Condition [C], 1500 hr.

Redimat, Yellow – Condition [C], 2000 hr.

Redimat, Yellow – Condition [C], 2500 hr.

Redimat, Yellow – Condition [C], 3000 hr.

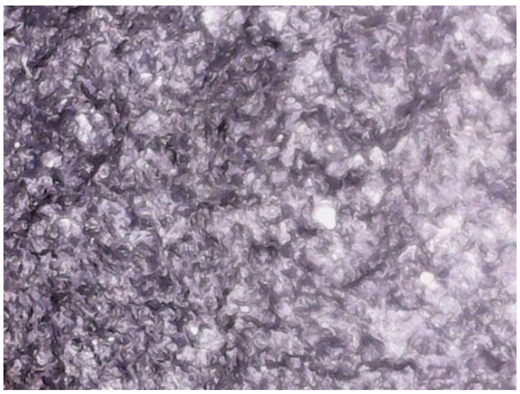
Figure I-27 – Surface morphology of Redimat yellow coupons exposed to xenon weatherometer under Condition [C]

Appendix-I(d)

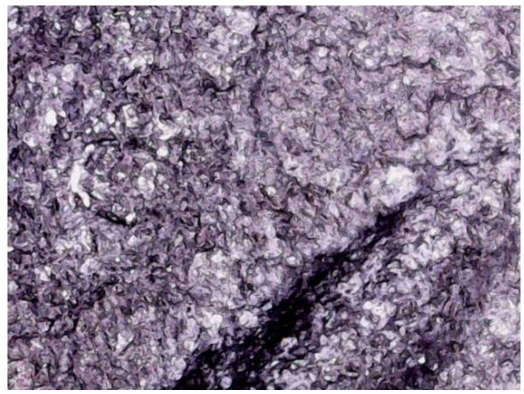
SafeRoute (Polyolefin) Coupons

SafeRoute, Black – Condition [A], 0 hr.

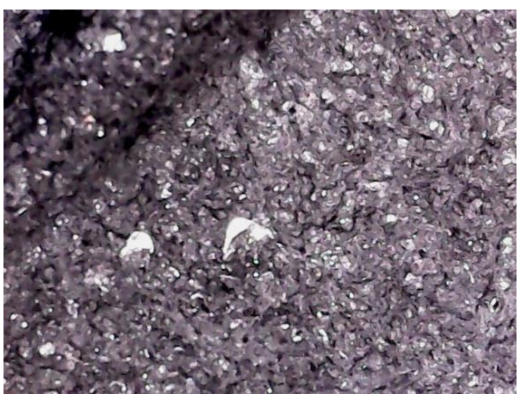
SafeRoute, Black – Condition [A], 500 hr.



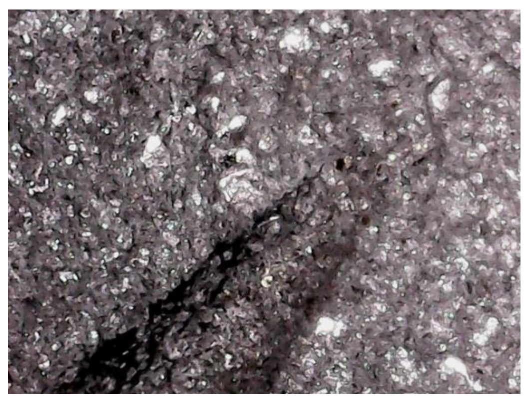
SafeRoute, Black – Condition [A], 1500 hr.



SafeRoute, Black – Condition [A], 2000 hr.



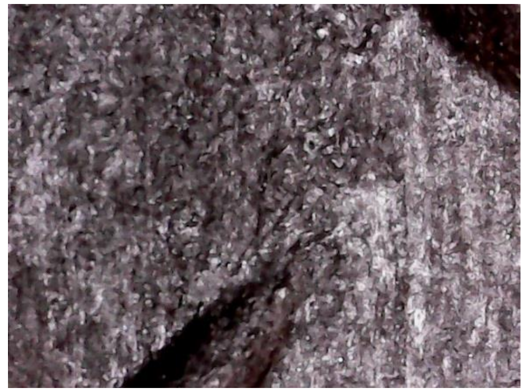
SafeRoute, Black – Condition [A], 2500 hr.



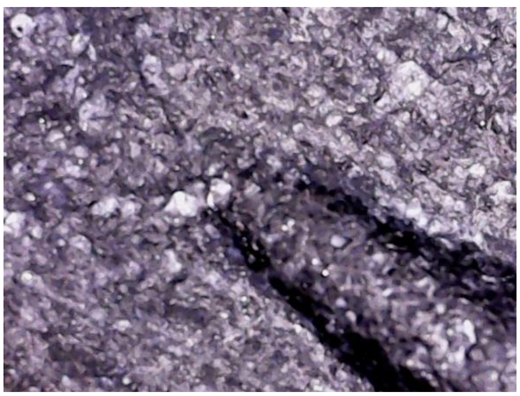
SafeRoute, Black – Condition [A], 3000 hr.

Figure I-28 – Surface morphology of SafeRoute black coupons exposed to xenon weatherometer under Condition [A]

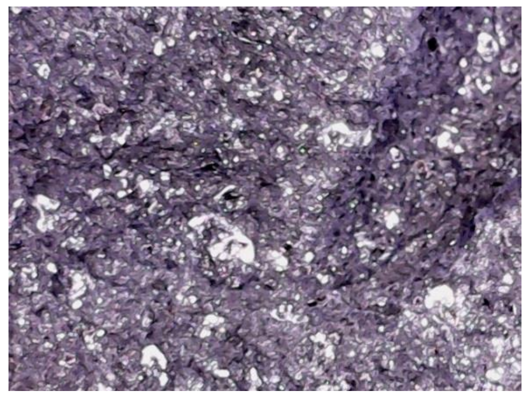
SafeRoute, Black – Condition [B], 0 hr.



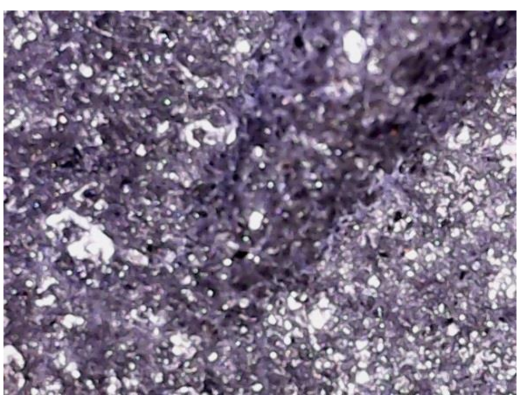
SafeRoute, Black – Condition [B], 500 hr.



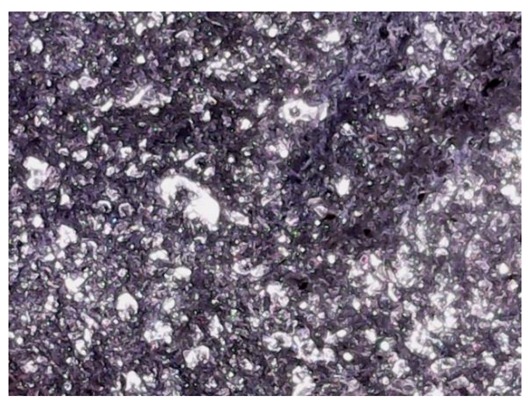
SafeRoute, Black – Condition [B], 1500 hr.



SafeRoute, Black – Condition [B], 2000 hr.

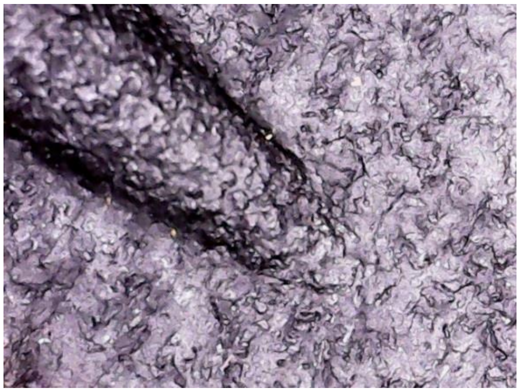


SafeRoute, Black – Condition [B], 2500 hr.

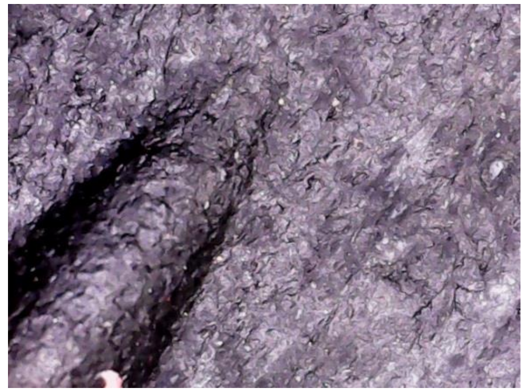


SafeRoute, Black – Condition [B], 3000 hr.

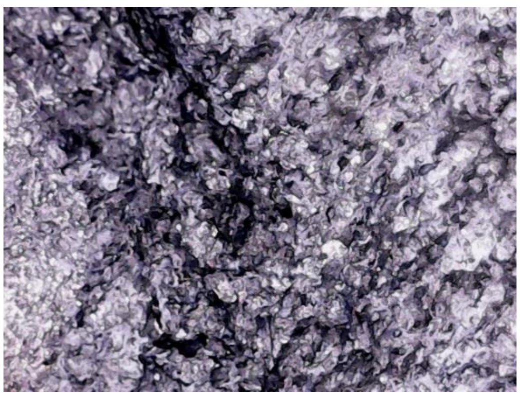
Figure I-29 – Surface morphology of SafeRoute black coupons exposed to xenon weatherometer under Condition [B]



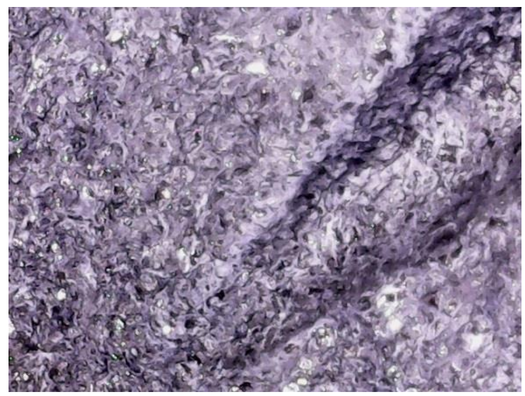
SafeRoute, Black – Condition [C], 0 hr.



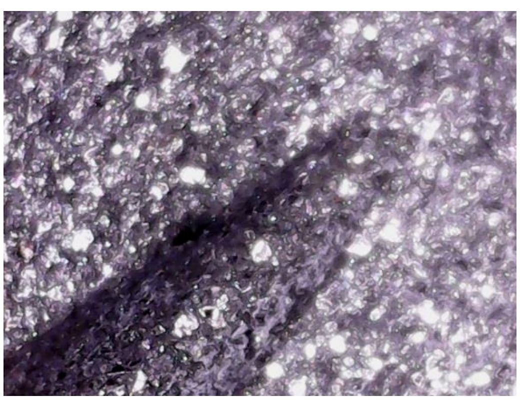
SafeRoute, Black – Condition [C], 500 hr.



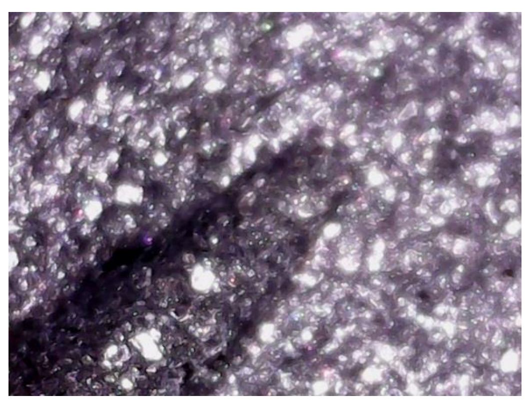
SafeRoute, Black – Condition [C], 1500 hr.



SafeRoute, Black – Condition [C], 2000 hr.

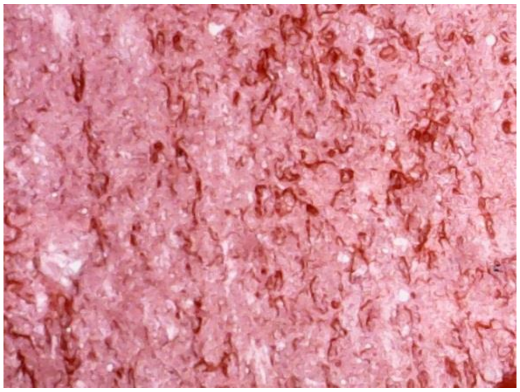


SafeRoute, Black – Condition [C], 2500 hr.

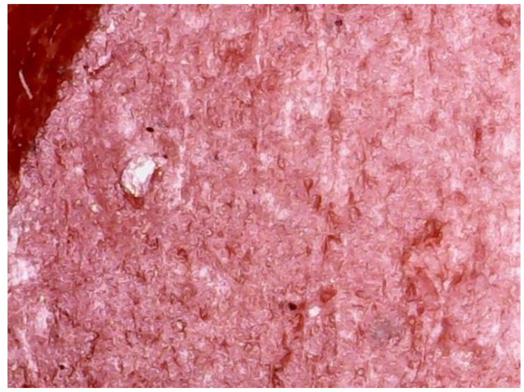


SafeRoute, Black – Condition [C], 3000 hr.

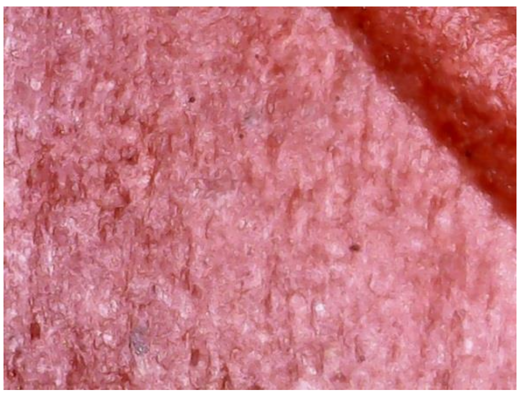
Figure I-30 – Surface morphology of SafeRoute black coupons exposed to xenon weatherometer under Condition [C]



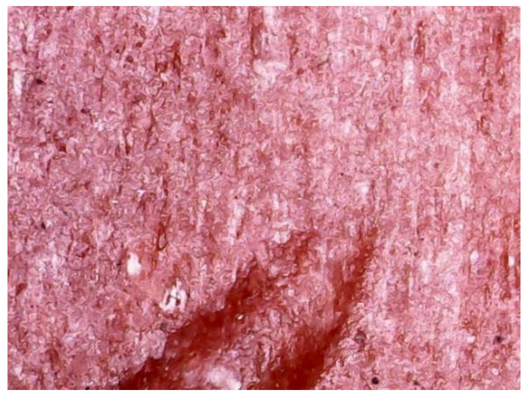
SafeRoute, Red – Condition [A], 0 hr.



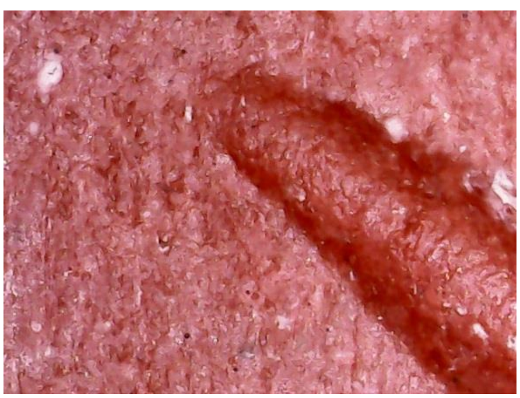
SafeRoute, Red – Condition [A], 500 hr.



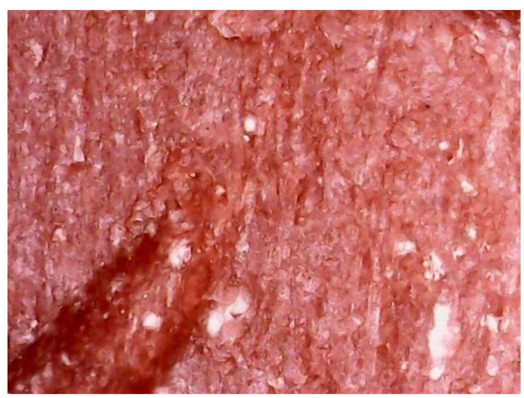
SafeRoute, Red – Condition [A], 1500 hr.



SafeRoute, Red – Condition [A], 2000 hr.

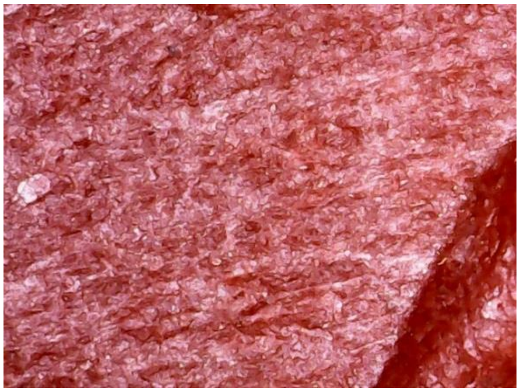


SafeRoute, Red – Condition [A], 2500 hr.

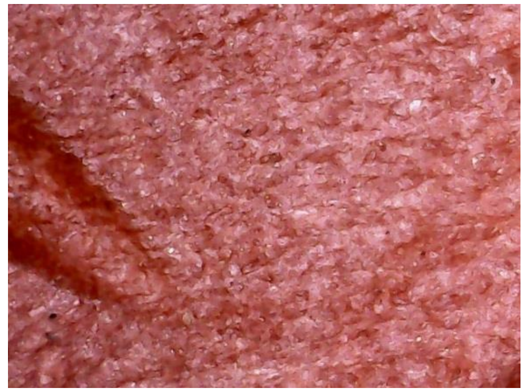


SafeRoute, Red – Condition [A], 3000 hr.

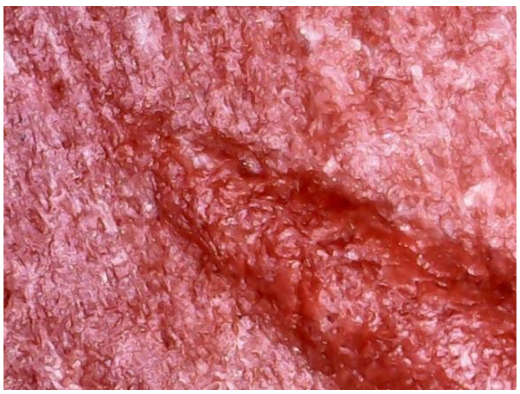
Figure I-31 – Surface morphology of SafeRoute red coupons exposed
to xenon weatherometer under Condition [A]



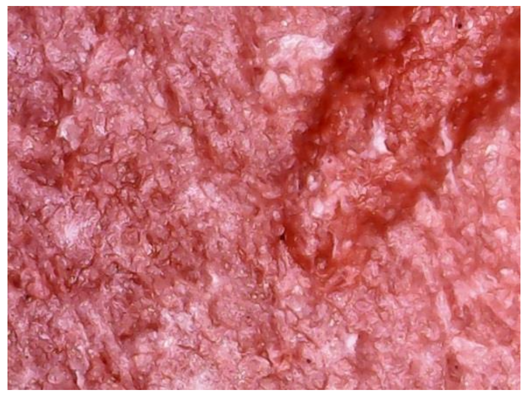
SafeRoute, Red – Condition [B], 0 hr.



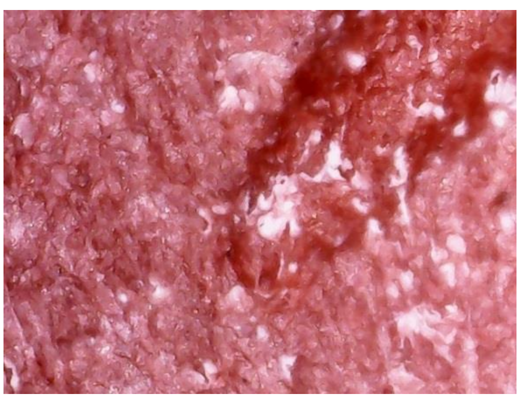
SafeRoute, Red – Condition [B], 500 hr.



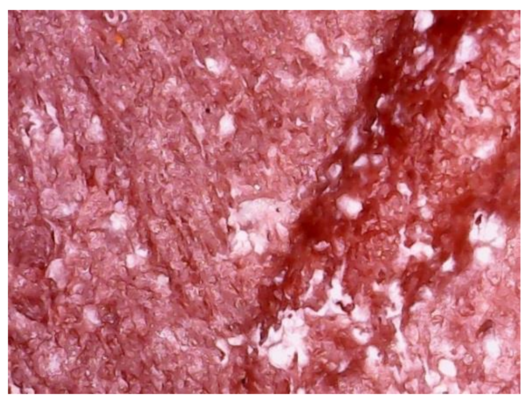
SafeRoute, Red – Condition [B], 1500 hr.



SafeRoute, Red – Condition [B], 2000 hr.

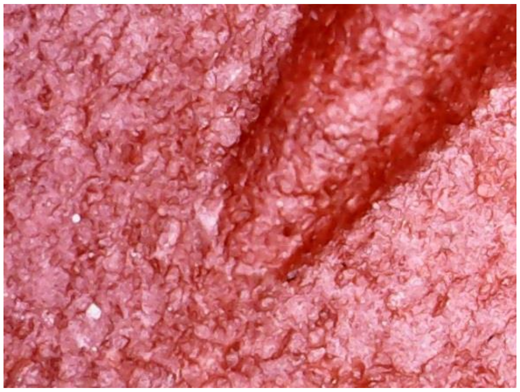


SafeRoute, Red – Condition [B], 2500 hr.



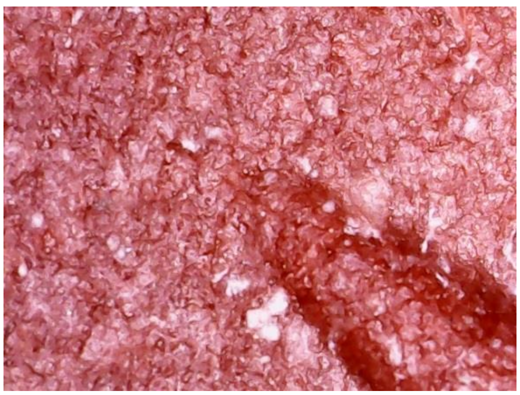
SafeRoute, Red – Condition [B], 3000 hr.

Figure I-32 – Surface morphology of SafeRoute red coupons exposed
to xenon weatherometer under Condition [B]

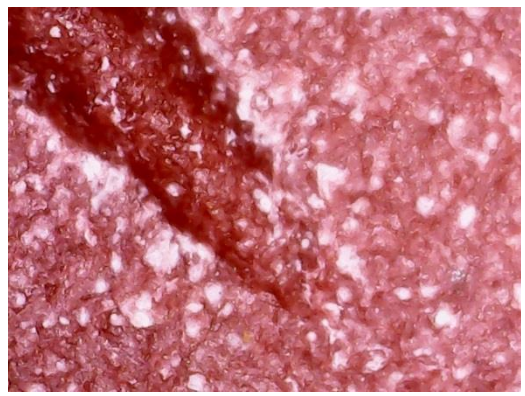


SafeRoute, Red – Condition [C], 0 hr.

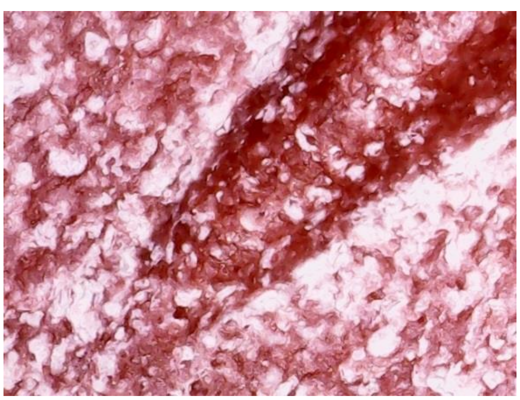
SafeRoute, Red – Condition [C], 500 hr.



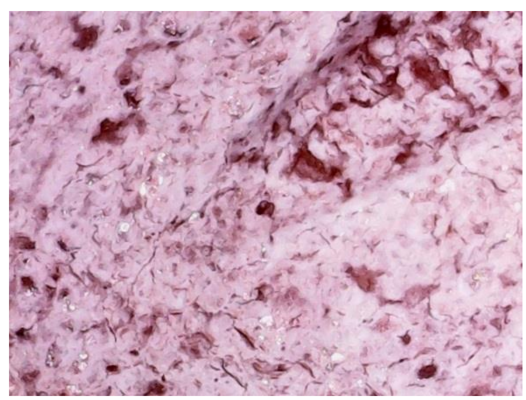
SafeRoute, Red – Condition [C], 1500 hr.



SafeRoute, Red – Condition [C], 2000 hr.



SafeRoute, Red – Condition [C], 2500 hr.



SafeRoute, Red – Condition [C], 3000 hr.

Figure I-33 – Surface morphology of SafeRoute red coupons exposed
to xenon weatherometer under Condition [C]

SafeRoute, Yellow – Condition [A], 0 hr.

SafeRoute, Yellow – Condition [A], 500 hr.

SafeRoute, Yellow – Condition [A], 1500 hr.

SafeRoute, Yellow – Condition [A], 2000 hr.

SafeRoute, Yellow – Condition [A], 2500 hr.

SafeRoute, Yellow – Condition [A], 3000 hr.

Figure I-34 – Surface morphology of SafeRoute yellow coupons exposed to xenon weatherometer under Condition [A]

SafeRoute, Yellow – Condition [B], 0 hr.

SafeRoute, Yellow – Condition [B], 500 hr.

SafeRoute, Yellow – Condition [B], 1500 hr.

SafeRoute, Yellow – Condition [B], 2000 hr.

SafeRoute, Yellow – Condition [B], 2500 hr.

SafeRoute, Yellow – Condition [B], 3000 hr.

Figure I-35 – Surface morphology of SafeRoute yellow coupons exposed to xenon weatherometer under Condition [B]

SafeRoute, Yellow – Condition [C], 0 hr.

SafeRoute, Yellow – Condition [C], 500 hr.

SafeRoute, Yellow – Condition [C], 1500 hr.

SafeRoute, Yellow – Condition [C], 2000 hr.

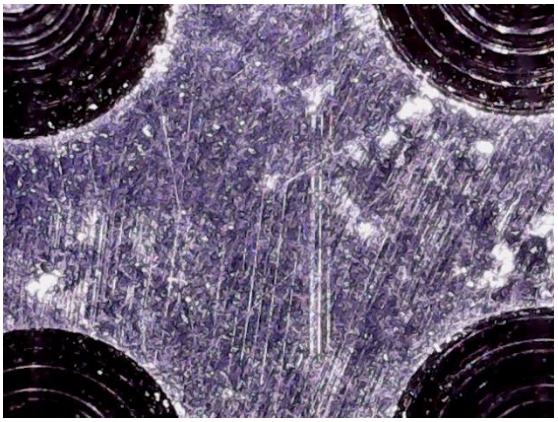
SafeRoute, Yellow – Condition [C], 2500 hr.

SafeRoute, Yellow – Condition [C], 3000 hr.

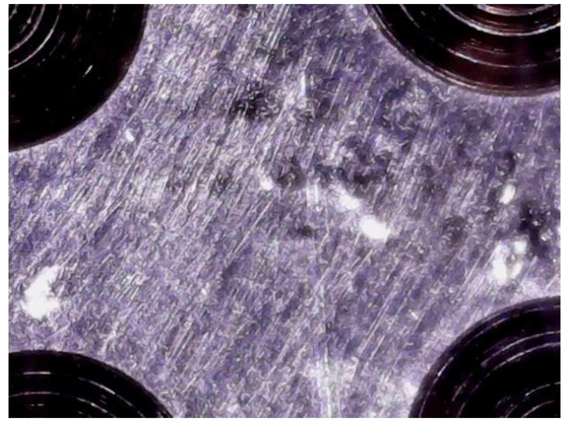
Figure I-36 – Surface morphology of SafeRoute yellow coupons exposed to xenon weatherometer under Condition [C]

Appendix-I(e)

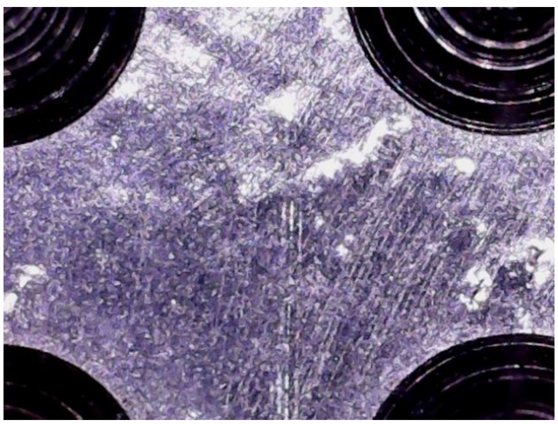
Armor-Tile (Epoxy) Coupons



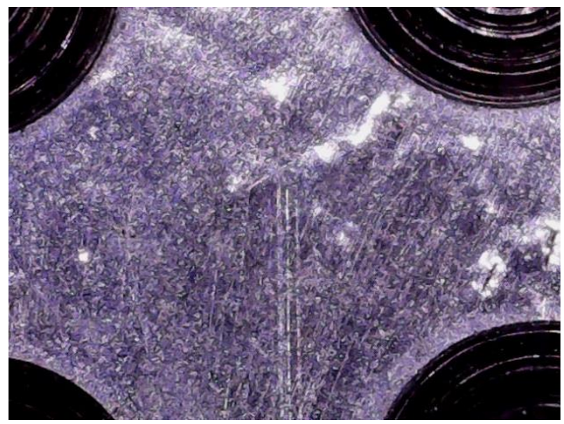
Armor-Tile, Black – Condition [A], 0 hr.



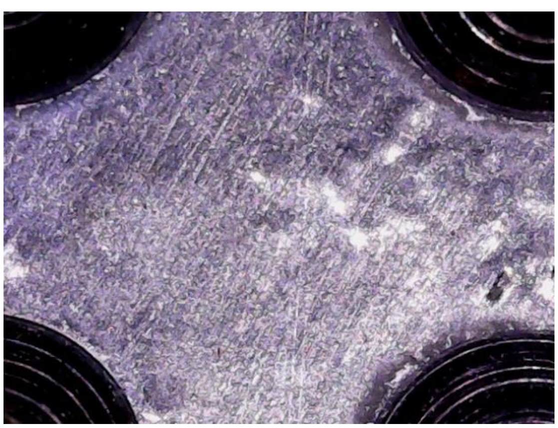
Armor-Tile, Black – Condition [A], 500 hr.



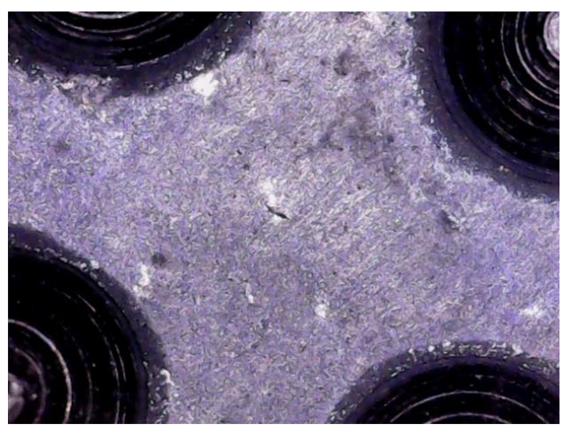
Armor-Tile, Black – Condition [A], 1000 hr.



Armor-Tile, Black – Condition [A], 1500 hr.

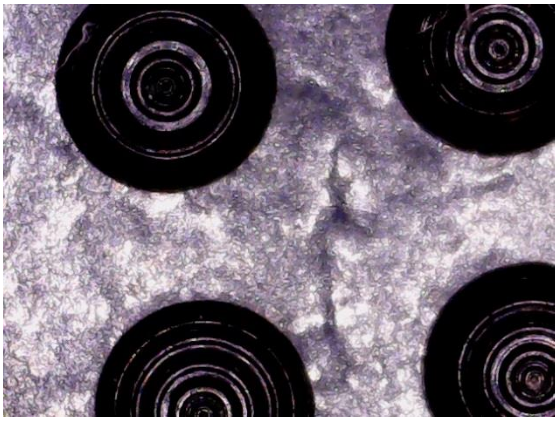


Armor-Tile, Black – Condition [A], 2000 hr.

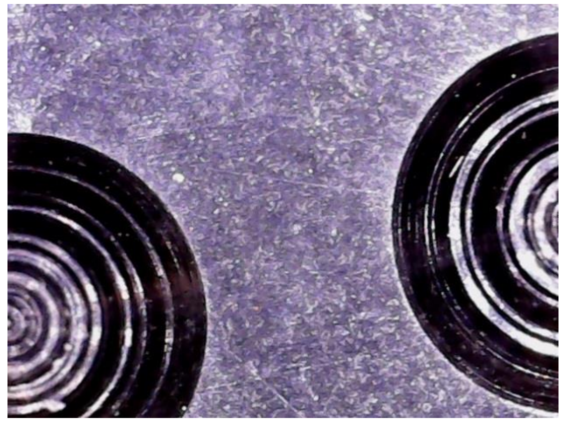


Armor-Tile, Black – Condition [A], 3000 hr.

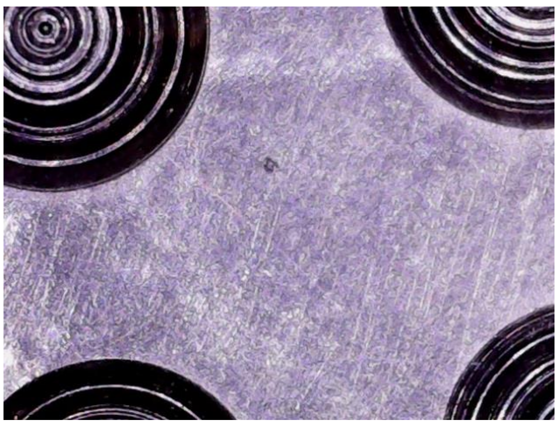
Figure I-37 – Surface morphology of Armor-Tile black coupons exposed to xenon weatherometer under Condition [A]



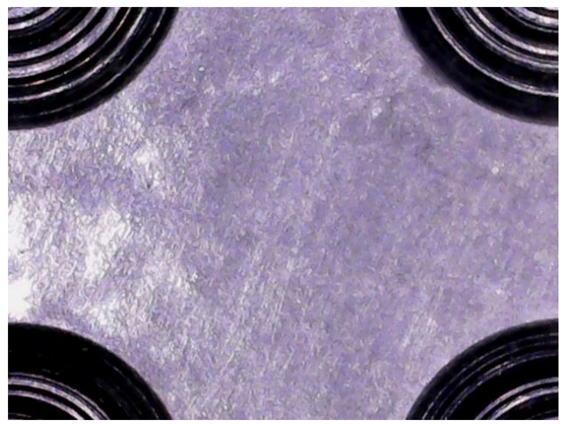
Armor-Tile, Black – Condition [B], 0 hr.



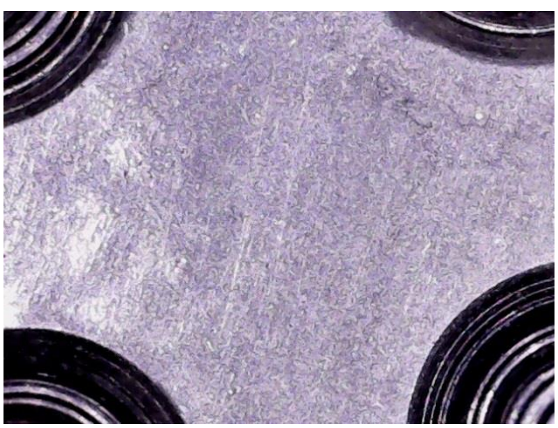
Armor-Tile, Black – Condition [B], 1000 hr.



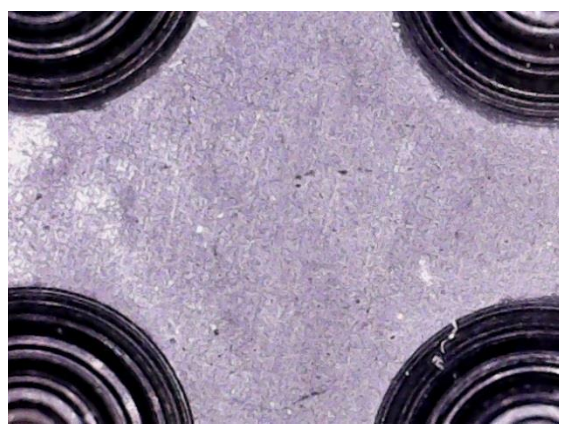
Armor-Tile, Black – Condition [B], 1500 hr.



Armor-Tile, Black – Condition [B], 2000 hr.

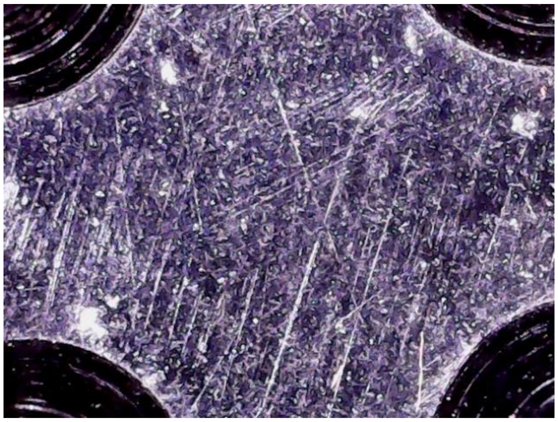


Armor-Tile, Black – Condition [B], 2500 hr.

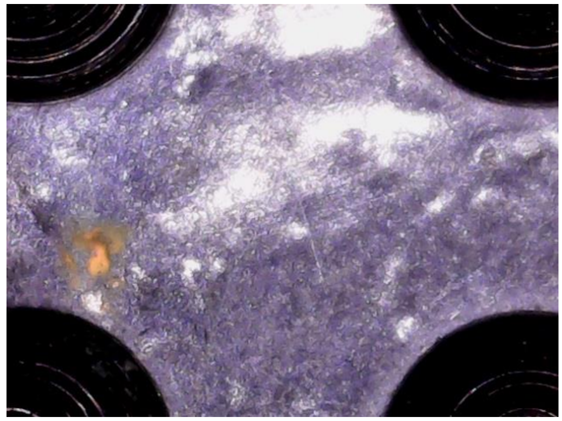


Armor-Tile, Black – Condition [B], 3000 hr.

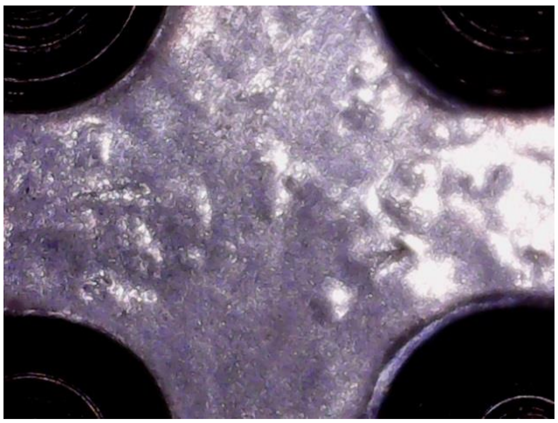
Figure I-38 – Surface morphology of Armor-Tile black coupons exposed to xenon weatherometer under Condition [B]



Armor-Tile, Black – Condition [C], 0 hr.

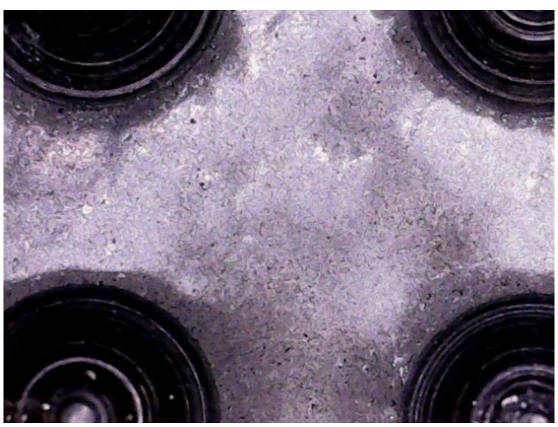


Armor-Tile, Black – Condition [C], 1000 hr.

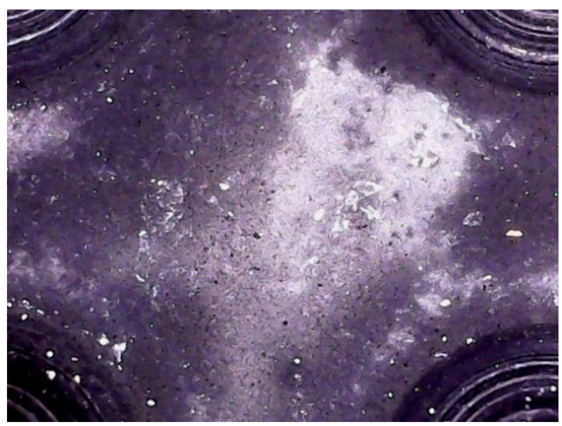


Armor-Tile, Black – Condition [C], 1500 hr.

Armor-Tile, Black – Condition [C], 2000 hr.



Armor-Tile, Black – Condition [C], 2500 hr.



Armor-Tile, Black – Condition [C], 3000 hr.

Figure I-39 – Surface morphology of Armor-Tile black coupons exposed to xenon weatherometer under Condition [C]

Armor-Tile, Red – Condition [A], 0 hr.

Armor-Tile, Red – Condition [A], 500 hr.

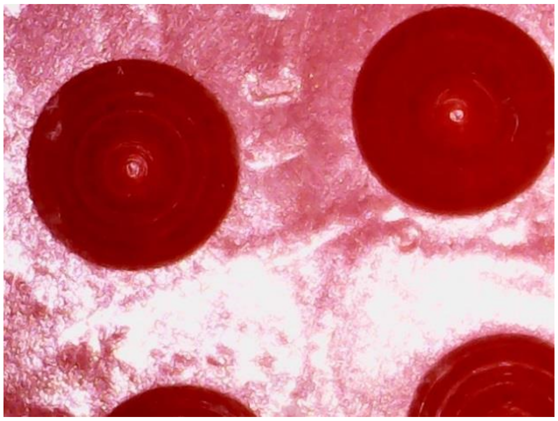
Armor-Tile, Red – Condition [A], 1000 hr.

Armor-Tile, Red – Condition [A], 1500 hr.

Armor-Tile, Red – Condition [A], 2000 hr.

Armor-Tile, Red – Condition [A], 3000 hr.

Figure I-40 – Surface morphology of Armor-Tile red coupons exposed to xenon weatherometer under Condition [A]



Armor-Tile, Red – Condition [B], 0 hr.

Armor-Tile, Red – Condition [B], 1000 hr.

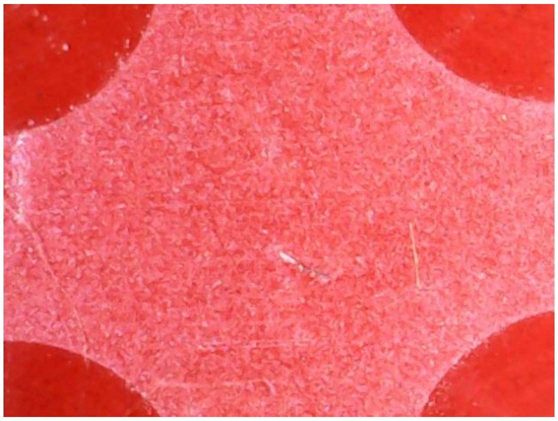
Armor-Tile, Red – Condition [B], 1500 hr.

Armor-Tile, Red – Condition [B], 2000 hr.

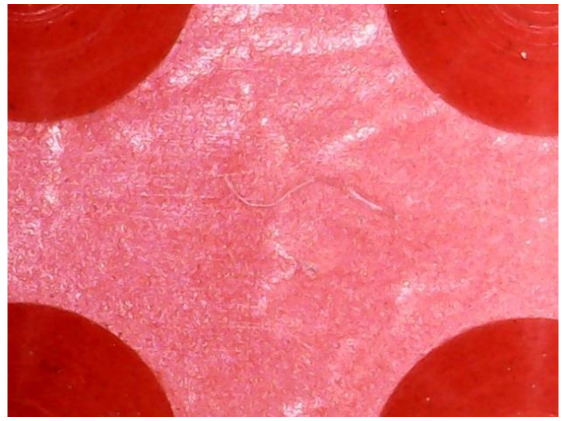
Armor-Tile, Red – Condition [B], 2500 hr.

Armor-Tile, Red – Condition [B], 3000 hr.

Figure I-41 – Surface morphology of Armor-Tile red coupons exposed to xenon weatherometer under Condition [B]

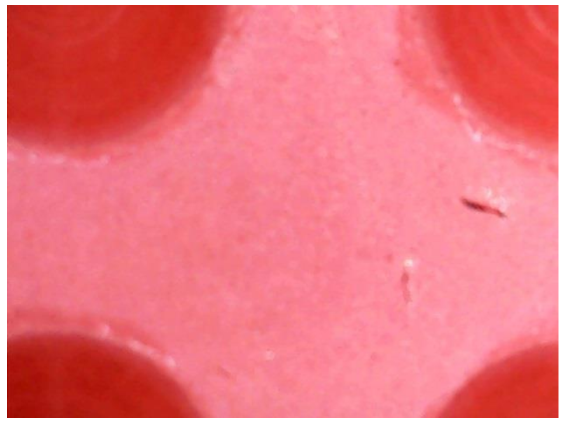


Armor-Tile, Red – Condition [C], 0 hr.



Armor-Tile, Red – Condition [C], 1000 hr.

Armor-Tile, Red – Condition [C], 1500 hr.



Armor-Tile, Red – Condition [C], 2000 hr.

Armor-Tile, Red – Condition [C], 2500 hr.

Armor-Tile, Red – Condition [C], 3000 hr.

Figure I-42 – Surface morphology of Armor-Tile red coupons exposed to xenon weatherometer under Condition [C]

Armor-Tile, Yellow – Condition [A], 0 hr.

Armor-Tile, Yellow – Condition [A], 500 hr.

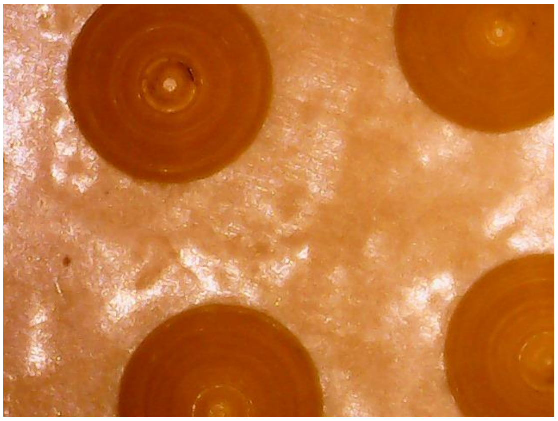
Armor-Tile, Yellow – Condition [A], 1000 hr.

Armor-Tile, Yellow – Condition [A], 1500 hr.

Armor-Tile, Yellow – Condition [A], 2000 hr.

Armor-Tile, Yellow – Condition [A], 3000 hr.

Figure I-43 – Surface morphology of Armor-Tile yellow coupons exposed to xenon weatherometer under Condition [A]



Armor-Tile, Yellow – Condition [B], 0 hr.

Armor-Tile, Yellow – Condition [B], 1000 hr.

Armor-Tile, Yellow – Condition [B], 1500 hr.

Armor-Tile, Yellow – Condition [B], 2000 hr.

Armor-Tile, Yellow – Condition [B], 2500 hr.

Armor-Tile, Yellow – Condition [B], 3000 hr.

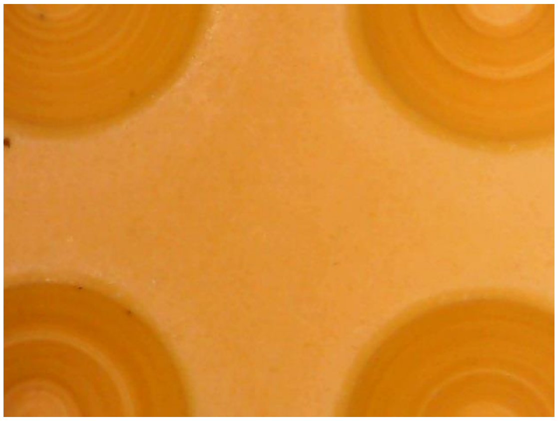
Figure I-44 – Surface morphology of Armor-Tile yellow coupons exposed to xenon weatherometer under Condition [B]

Armor-Tile, Yellow – Condition [C], 0 hr.

Armor-Tile, Yellow – Condition [C], 1000 hr.

Armor-Tile, Yellow – Condition [C], 1500 hr.

Armor-Tile, Yellow – Condition [C], 2000 hr.



Armor-Tile, Yellow – Condition [C], 2500 hr.

Armor-Tile, Yellow – Condition [C], 3000 hr.

Figure I-45 – Surface morphology of Armor-Tile yellow coupons exposed to xenon weatherometer under Condition [C]

Appendix-J

Test Data of Color Measurement of DWS Products after Exposed in the Xenon Weatherometer

Appendix-J(a)

ADA Solutions (Polyester) Products

Table J-1 – Color Measurement of ADA Solutions Coupons Condition A

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	15.5	0.5	-1.2	15.9	-0.1	-0.7	0.877		16.9	0.2	-1.1	1.44		21.6	0.1	-0.5	6.15		20.1	0.1	0	4.77		20.4	0.3	0.3	5.13		20.4	0.4	0.3	5.13	
		Middle	14.4	0.8	-1.2	15.4	0.5	-0.5	1.257	1.231	16	0.8	-2.2	1.89	1.804	21.9	0.2	-0.3	7.58	6.612	20.8	0.2	0.1	6.56	5.243	20.7	0.4	0.2	6.47	5.345	20.7	0.4	0.1	6.45	5.258
		Bottom	16	-1.4	0	16.3	0.1	-0.3	1.559		17.8	-0.7	-0.8	2.09		21.9	0	-0.7	6.10		20.1	0.2	0	4.40		20.1	0.3	0.1	4.44		19.8	0.4	0	4.20	
	Red	Top	26.8	23.7	18	27.2	23.8	17.2	0.900		27.4	23.5	17.4	0.87		30.1	20.4	14.4	5.89		37.8	17.3	12.4	13.90		38.9	18.1	13.6	14.04		37.6	18.5	13.7	12.73	
		Middle	26.4	23.7	17.6	27.4	23.3	17.6	1.077	0.832	28	23.6	17.9	1.63	1.164	30.4	20.2	14.7	6.05	5.302	38.1	17.2	12.4	14.36	13.818	38.2	18.4	14	13.43	13.853	36.6	18.4	13.4	12.24	12.879
		Bottom	26.8	22.7	17.5	27.1	22.4	17.8	0.520		27.6	23	17	0.99		29.4	20.8	15.2	3.96		37.4	17.1	12	13.19		39.4	17.9	13.4	14.09		38.7	17.9	12.8	13.67	
	Yellow	Top	70.6	26.3	74.6	72	23.5	72.6	3.715		72.6	22	71.7	5.56		73.3	20.7	69.6	7.98		74.6	18.4	62.5	14.99		77.6	16.4	61	18.22		76.2	15.2	58.6	20.26	
		Middle	71.2	26.2	75.3	72.1	23.3	73.4	3.582	3.744	72.9	21.9	72.3	5.51	5.470	73.7	20.7	70.2	7.91	7.807	75	18.2	62.7	15.40	14.819	77.4	16.1	61.2	18.42	18.451	77	15.1	59.5	20.16	20.363
		Bottom	71	26.3	75.3	71.6	23.5	72.6	3.936		72.7	22.3	72.2	5.34		73.6	21.2	70.4	7.54		74	19.1	63.6	14.06		77.4	16.5	60.7	18.71		77	15.4	58.8	20.67	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	14.2	1	-1.3	14.6	0.7	-1.7	0.640		19.3	-0.1	-2.8	5.43		19.9	0.1	-0.8	5.79		20.1	0.3	-0.1	6.06		21.4	0.3	-0.1	7.33		21.2	0.4	-0.1	7.13	
		Middle	16.1	0.7	-2	14.6	1.2	-2.2	1.594	0.978	17.8	0.9	-3.1	2.03	3.181	21.4	0.2	-1.1	5.40	5.539	19.7	0.3	-0.3	4.00	4.620	19.5	0.2	0	3.98	5.175	20.3	0.3	0	4.67	5.403
		Bottom	16	-0.2	-0.8	15.7	0.4	-0.6	0.700		17.8	0.8	-1.1	2.08		21.4	0.3	-0.6	5.43		19.7	0.3	-0.1	3.80		20.1	0.2	0.1	4.22		20.3	0.2	0.1	4.41	
	Red	Top	29	21.6	17.2	29.2	21.9	17.2	0.361		29	21.7	17.2	0.10		34.9	18.5	12.9	7.93		39	18.2	13.7	11.13		39.4	19.1	15.2	10.88		37.5	19.4	15.1	9.03	
		Middle	28.3	21.9	16.2	28.3	22.1	16.8	0.632	0.671	28.4	21.9	17	0.81	0.737	33.3	18.9	13	6.65	6.093	38.2	17.7	12.8	11.28	10.522	37.8	18.4	13.6	10.45	10.452	35.9	18.4	13.2	8.89	8.922
		Bottom	29.9	22.1	16.1	30.5	22.9	16.3	1.020		29.4	22.9	17	1.30		32.1	20	14	3.70		38.1	18.6	14	9.16		39.4	19.1	15	10.02		38.3	19.5	15.1	8.85	
	Yellow	Top	71.8	25.9	74.5	72.8	22.8	71.3	4.566		73.4	21.8	70.5	5.95		74.2	20.2	67.7	9.19		75	17.8	61.7	15.48		77.5	15.7	59.4	19.09		76.5	15.2	58.4	19.89	
		Middle	70.8	26.5	75.2	71.9	23.3	72.3	4.456	4.267	72.5	21.8	71.4	6.28	5.939	73.5	20.5	68.6	9.32	8.929	75.2	18	61.7	16.55	15.802	78.2	15.8	59.9	20.08	19.929	77.3	14.8	58.9	21.09	20.799
		Bottom	70.6	26.2	75.8	71.9	23.5	73.5	3.778		72.6	22	72.7	5.59		73	20.7	70.1	8.28		74.5	18.8	62.9	15.37		76.7	16.1	58.9	20.61		77.8	15.2	58.9	21.41	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	15.4	1.1	-1.3	15.9	0.4	-1.1	0.883		18.4	0	-1.6	3.21		22	0.5	-0.5	6.68		19	0.2	-0.2	3.87		21.3	0.2	0	6.11		20.2	0.3	0.1	5.06	
		Middle	16.1	0.7	-0.6	16.1	0.3	-0.5	0.412	0.658	18.2	0.8	-1.1	2.16	2.090	21.8	0.1	-0.5	5.73	6.253	20.7	0.4	0	4.65	4.022	20.7	0.4	0.1	4.66	4.730	21.1	0.4	0.1	5.06	4.513
		Bottom	17.1	1.1	-0.7	16.8	0.5	-0.6	0.678		17.7	0.8	-1.3	0.90		23.4	0.3	-0.8	6.35		20.4	0.4	0.4	3.55		20.3	0.3	0.2	3.42		20.3	0.3	0.2	3.42	
	Red	Top	27.9	23.3	18.7	27.9	23.5	19.2	0.539		28.6	22.7	17.2	1.76		34	18.8	12.9	9.54		38.9	17.4	12.5	13.94		39.9	18.2	13.8	13.93		37.9	18.3	13.4	12.37	
		Middle	28.7	21.8	17.1	28	22.2	17.8	1.068	0.835	28.3	22.9	17.4	1.21	1.213	33.9	18.2	12.5	7.82	7.766	39.6	17.3	12.7	12.59	11.803	38.3	18.3	13.9	10.71	11.408	37	18.1	13	9.97	10.264
		Bottom	30.9	21.8	16.5	30.8	22.6	16.1	0.900		30.4	22.2	16.3	0.67		34.9	19.3	12.9	5.93		38.3	17.9	13.5	8.89		39.7	18.7	14.3	9.59		38.6	19.1	14.3	8.45	
	Yellow	Top	71.6	26.2	75.1	71.9	23.2	72.6	3.917		73	22.1	73.1	4.77		73.5	20.6	70.6	7.43		75.1	18	62.6	15.35		77.7	16.1	60.3	18.93		77.7	15.1	59	20.48	
		Middle	71.5	25.8	75.2	72.7	23	73.3	3.590	3.765	73.3	21.7	72.6	5.18	5.033	74	20.1	70	8.11	7.599	75.1	17.6	62.2	15.79	14.483	78.1	15.7	60.3	19.17	18.134	77.9	14.9	59.2	20.39	19.907
		Bottom	72	25.4	74.7	72.9	22.7	72.2	3.788		73.7	21.5	71.8	5.15		73.8	20	70.2	7.26		74.3	18.6	64.7	12.31		77.1	16.4	62.1	16.30		77.4	15.2	59.8	18.85	

Table J-1 – Continued

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 4	Black	Top	15.6	0.7	-0.8	14.7	0.9	-0.6	0.943		16.7	-0.1	-1.3	1.45		21.8	0.2	-0.5	6.23		19.3	0.2	-0.3	3.77		20	0.3	0.3	4.55		20.5	0.4	0.4	5.05	
		Middle	14	0.8	-1.3	14.4	0.7	-0.8	0.648	0.819	17.1	0	-1.8	3.24	2.233	22.1	0.3	-0.5	8.15	7.331	19.7	0.2	-0.3	5.82	4.677	20.3	0.2	0.1	6.48	5.467	20.7	0.3	0.1	6.86	5.865
		Bottom	15.5	0.8	-0.6	16	0.1	-0.5	0.866		17.3	0	-1	2.01		23.1	0.4	-0.6	7.61		19.9	0.3	-0.2	4.45		20.8	0.2	0	5.37		21.1	0.3	0.2	5.68	
	Red	Top	27.4	23.9	17.7	27.8	24.1	18.4	0.831		27.7	23.5	17.8	0.51		31.8	19.7	14.1	7.07		38.3	17.9	13.4	13.16		39.1	18.6	14.4	13.26		37.5	18.8	14.2	11.84	
		Middle	27.8	24.1	18.8	28.1	24.3	18	0.877	0.790	28.1	24.1	17.9	0.95	0.731	33.1	19.4	13.7	8.73	6.954	39	18	13.6	13.77	12.688	38.3	19.1	14.7	12.33	12.434	35.8	19.1	14.2	10.50	11.108
		Bottom	28.5	22.4	17.7	29.1	22.2	17.9	0.663		29	21.9	17.9	0.73		32.1	20.2	14.9	5.06		38.2	18.4	14	11.13		39.4	19	15.1	11.71		38.6	19.2	14.8	10.98	
	Yellow	Top	72	26.2	75.5	73.4	22.8	72.4	4.809		74.1	21.5	71.6	6.46		74.5	20.1	69	9.26		75.9	17.8	62.5	15.96		77.9	16	59.4	19.95		77.1	15.7	60.1	19.32	
		Middle	71.2	26.1	74.4	72.4	22.7	71.9	4.387	4.267	73.4	21.3	72.2	5.72	5.861	74.2	20	68.8	8.81	8.194	75.1	17.7	61.7	15.72	14.659	78.1	15.5	59.8	19.32	18.553	77.6	15.3	60.4	18.80	18.646
		Bottom	72.5	25.1	74.7	72.9	22.2	72.6	3.603		73	21.1	71.1	5.40		74	20.1	70.8	6.52		74.4	18.5	64.5	12.30		77.3	16.2	61.8	16.39		77.4	15.1	60.8	17.81	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 5	Black	Top	15.3	0.1	-0.9	14.1	0	-1.6	1.393		17	-0.3	-1.9	2.01		23.4	0.1	-0.9	8.10		20.7	0.5	0.2	5.53		20.8	0.4	0.3	5.64		20.6	0.4	0.1	5.40	
		Middle	15.2	0.7	0.1	14.6	0.7	-0.7	1.000	1.167	17.2	0.5	-1.6	2.63	2.211	22.4	0.2	-0.3	7.23	8.188	21.6	0.5	0.2	6.40	6.499	21.2	0.4	0.3	6.01	5.902	21.2	0.4	0.3	6.01	5.878
		Bottom	14.3	-0.6	-1.2	14.4	0.5	-1.3	1.109		15.4	0.9	-1.9	1.99		23.5	0.2	-1	9.24		21.6	0.6	0.4	7.57		20.1	0.3	0.3	6.06		20.3	0.4	0.1	6.22	
	Red	Top	30.6	21	14.4	30.6	21.7	14.6	0.728		31	21	14.4	0.40		34.3	19.1	12.5	4.57		38.7	17.4	12.5	9.07		40.1	18.3	13.9	9.89		40.1	18.2	13.5	9.94	
		Middle	28.1	21.8	15.3	28.5	22.3	15.7	0.755	0.674	29.4	22.1	15.8	1.42	0.891	33.3	19.4	12.8	6.25	4.635	39	16.8	11.7	12.52	10.470	38	18.3	13.5	10.65	10.525	39.5	17.6	12.1	12.56	11.150
		Bottom	29.6	21.7	15.6	30.1	21.9	15.6	0.539		30.4	21.9	15.8	0.85		32.1	20.7	14.1	3.08		37.7	17.3	12.2	9.82		39.7	17.9	13.3	11.03		39.5	17.9	12.9	10.94	
	Yellow	Top	71.5	26.1	76.3	72.2	22.7	73.3	4.588		73	21.2	72.4	6.44		74.1	20	69.3	9.64		75.1	17	61.6	17.66		77.9	15	59.9	20.81		77.1	15.3	60.7	19.78	
		Middle	71.3	26.3	75.8	72.4	23	72.9	4.529	4.386	73.3	21.6	72.2	6.25	6.035	73.7	20.3	69.8	8.82	8.297	75.1	17.8	62.6	16.15	15.784	77.4	15.5	60.6	19.62	19.352	76.8	15.7	60.9	19.10	19.525
		Bottom	71.8	26.4	76.2	72.1	23.6	73.3	4.042		73	22.2	73	5.41		73.5	21.5	72.4	6.43		74.2	19.5	64.8	13.54		77.1	16.8	62.4	17.63		77.1	15.9	60.4	19.70	

Table J-2 – Color Measurement of ADA Solutions Coupons in Condition B

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	15.9	-0.4	-0.3	16.4	-1	-0.5	0.806		23	0.3	-0.1	7.14		25.3	0.5	1.9	9.70		23.7	0.3	1.2	7.97		23	1	2.5	7.76		22.3	0.9	1.9	6.89	
		Middle	16.4	-0.3	-0.8	17.3	0.1	-0.6	1.005	0.604	24.7	0.5	0.5	8.44	7.909	23.4	0.7	1.9	7.57	7.849	22.2	0.4	0.4	5.96	5.729	20.9	0.5	1.2	4.99	5.262	21.1	0.5	1.2	5.17	5.035
		Bottom	16.4	0.6	-0.4	16.4	0.6	-0.4	0.000		24.5	0.7	0.5	8.15		22.5	0.6	1.1	6.28		19.6	0.2	0	3.25		19.3	0.5	0.5	3.04		19.3	0.4	0.5	3.04	
	Red	Top	26.7	23.1	17.3	26.8	22.5	18.1	1.005		28.5	22.4	16.5	2.09		32.1	19.2	13.9	7.48		36	17.9	12.7	11.61		33.8	19.3	14.8	8.43		35.6	18.3	13.7	10.73	
		Middle	29.2	22.5	16.1	28.1	23.3	17.1	1.688	1.207	30.3	21.6	15.6	1.51	2.289	30.9	19.8	15.2	3.32	6.672	35.9	17.6	12.1	9.21	10.910	35.3	18.1	13.2	8.06	9.550	35.6	17.9	13.1	8.43	10.645
		Bottom	27	22	17.1	26.9	22.6	17.8	0.927		29.4	20.7	15.3	3.27		35.6	19.2	15.3	9.22		37.7	18.3	13.4	11.91		37.9	18.4	13.1	12.16		38.4	18.3	12.7	12.77	
	Yellow	Top	70.7	25.8	73.2	71.8	22.9	71.6	3.490		72.7	21.8	69.7	5.68		72.9	20.1	63.1	11.80		74.5	16.8	58.8	17.40		73.7	17.1	61.7	14.73		75.1	16.4	61.3	15.79	
		Middle	71.5	26.6	74.9	71.9	23.3	72.3	4.220	4.113	73	22.1	69.9	6.89	6.695	73.5	19.6	63.6	13.44	13.129	74.2	16.2	58.2	19.86	18.987	75.6	15.5	59.1	19.74	18.315	74.9	15.8	59.3	19.28	17.918
		Bottom	71.2	25.9	73.7	73	22.6	71	4.628		74.1	20.9	68.9	7.51		74.7	18.3	62.3	14.14		75.6	14.7	58.1	19.70		76.6	14.6	57.5	20.48		76.2	14.7	59.6	18.69	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	17.4	0.6	-1.4	17.4	0.6	-2	0.600		24.6	0.8	-0.4	7.27		25.3	0.6	2.1	8.64		23.3	0.6	1.3	6.49		22.3	0.9	2.1	6.03		22.5	0.9	1.6	5.92	
		Middle	16.7	0.8	-0.9	17.5	0.6	-1.7	1.149	0.650	25.9	0.3	0.3	9.29	8.582	24.7	0.7	1.9	8.48	7.968	22.1	0.6	0.8	5.66	5.334	20.8	0.7	1.2	4.61	4.716	21.4	0.7	1	5.07	4.881
		Bottom	16.2	0.1	-1.1	16.4	0.1	-1.1	0.200		25.3	0.4	0.1	9.18		22.6	0.6	1.1	6.79		19.8	0.5	0.2	3.85		19.3	0.5	0.5	3.51		19.5	0.5	0.4	3.65	
	Red	Top	29.6	21.6	17.1	29.3	22.2	17.9	1.044		31.2	20.6	16.1	2.14		32.7	20.2	16.1	3.55		36.7	19.1	14.6	7.93		33.7	20.7	16.7	4.22		34.7	20.1	15.7	5.50	
		Middle	28.9	22	17.3	29.1	22.9	18.3	1.360	1.212	31.3	20.5	15.5	3.35	3.543	32.6	20.5	16.7	4.04	6.038	37	19.3	14.5	8.99	10.184	35.5	19.9	15.3	7.21	8.387	35.5	19.9	15.2	7.24	8.814
		Bottom	26.6	23.6	18.3	27	24.2	19.3	1.233		29.6	20.7	15.3	5.14		35.5	18.9	15.2	10.53		38.3	18.5	13.5	13.64		38.2	18.4	13.1	13.73		38.3	18.6	13.2	13.71	
	Yellow	Top	69.8	26.1	75.5	72.1	23.6	73.8	3.799		72.8	22.3	70.9	6.68		72.5	20.6	64.7	12.42		74.4	17.9	60.5	17.70		73.3	17.5	61.8	16.55		74.1	16.6	60.5	18.27	
		Middle	70.5	26.1	76.3	72.5	23.3	73.5	4.436	4.162	73.3	21.9	70.1	7.99	7.562	73.8	19.1	63.5	14.96	14.500	74.8	16.5	59.2	20.08	19.142	75.2	15.3	58.9	21.01	19.586	74.4	16.5	60.1	19.23	18.623
		Bottom	70.4	25.8	75.1	72.6	22.7	73.2	4.250		73.7	21	69.6	8.01		75	17.6	62	16.12		75.4	15.4	59.2	19.65		76.4	14.5	58.2	21.20		75.3	15.5	60.7	18.37	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	13.5	0.7	-1.1	13.8	0.4	-1.1	0.424		23.5	0.1	-0.2	10.06		27	0.3	1.4	13.74		24.4	0.6	1.5	11.21		23.1	0.8	2	10.09		22.8	0.6	1.7	9.71	
		Middle	15	0	-1	15.5	0.1	-1.1	0.520	0.485	26.1	-0.2	-0.1	11.14	10.472	26.1	0.6	1.9	11.49	10.901	22.8	0.7	1.1	8.11	8.113	21.5	0.6	1.2	6.89	6.915	20.7	0.5	1.2	6.13	6.869
		Bottom	15.6	1	0.1	15.5	0.7	0.5	0.510		25.8	0.4	0.3	10.22		23	0.6	1.1	7.48		20.6	0.5	0.2	5.03		19.3	0.5	0.6	3.77		20.3	0.4	0.6	4.76	
	Red	Top	26	22.8	18.9	25.6	23.3	19.8	1.105		27.7	21.6	17	2.82		31.8	19.3	14.5	8.08		36.9	18	12.9	13.34		34.7	18.9	14.4	10.54		36	18	13.2	12.47	
		Middle	26.4	24.1	20.6	26.6	24.1	20.8	0.283	0.837	29.5	21.7	16.6	5.60	3.801	31.7	20.3	16.3	7.81	8.456	36.6	18.5	13.2	13.79	12.898	35.2	19.2	14.3	11.88	11.108	35.6	18.7	13.7	12.70	12.176
		Bottom	28	22	16.6	27.4	22.3	17.5	1.122		30.1	20.5	15.1	2.98		36.7	18.7	14.8	9.48		38.7	18.7	13.7	11.57		38.1	19	13.8	10.90		38.5	18.9	13.6	11.35	
	Yellow	Top	69.7	26.4	76.5	71.7	23.4	74.5	4.123		72.4	22.7	72.5	6.08		72.2	21.1	65.3	12.64		74.3	18.8	62.5	16.58		73.3	18.4	64	15.27		73.4	17.4	62.1	17.38	
		Middle	70.3	26.5	76.3	71.9	23.3	73.9	4.308	4.297	72.5	22.5	71.5	6.62	7.079	72.7	20.3	64.5	13.54	14.227	74.7	17.4	60.1	19.09	18.668	74.8	16.5	60.4	19.31	18.642	72.9	16.7	60	19.20	19.157
		Bottom	71.6	26.2	77.2	72.2	22.7	74.5	4.461		73.3	21.2	70.5	8.53		74.2	18.4	62.9	16.50		76	16.3	60	20.33		75.4	15.9	58.9	21.34		76	15.5	59.8	20.90	

Table J-3 – Color Measurement of ADA Solutions Coupons in Condition C

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	14.7	0.1	-0.4	13.7	0	-1.1	1.225		27.2	0.5	0.8	12.56		20.4	0.5	0.8	5.84		21.9	0.9	1.5	7.49		23	1	2.5	8.84		19.8	0.4	0.6	5.21	
		Middle	13	0.8	-0.1	13.8	-0.2	-0.7	1.414	1.201	28.5	0.5	1.2	15.56	14.208	20.4	0.3	0.2	7.42	7.004	22.3	0.7	1.1	9.38	8.681	20.9	0.5	1.2	8.01	7.777	20.8	0.5	0.6	7.84	6.589
		Bottom	12.9	0	-0.4	13.7	-0.2	-0.9	0.964		27.4	0	-0.6	14.50		20.6	0.4	0.4	7.75		21.9	0.8	1.2	9.18		19.3	0.5	0.5	6.48		19.6	0.3	0.1	6.73	
	Red	Top	25.1	24.9	21.8	25.5	24.4	21.1	0.949		29.5	20.6	15.1	9.10		38.1	17	12	18.10		37.1	17.4	11.7	17.39		33.8	19.3	14.8	12.49		37.5	17.2	11.5	17.86	
		Middle	25.8	24.1	20.3	25.8	23.6	20	0.583	0.977	29.3	20	14.2	8.14	7.976	38.2	17	12.1	16.47	16.081	37.5	17.3	11.6	16.09	15.257	35.3	18.1	13.2	13.29	12.885	36.7	17	11.4	15.76	15.357
		Bottom	26.8	21.9	18.6	26.2	23.1	18.2	1.400		30.4	18.5	14.1	6.69		38	17.1	12.4	13.67		36.7	17.9	12.5	12.30		37.9	18.4	13.1	12.87		36.8	18	12.3	12.45	
	Yellow	Top	71.2	26.2	74.5	71.4	22.7	71	4.954		71.8	21.7	68.8	7.29		76.4	17.2	60.7	17.28		73.7	17.4	60.2	16.98		73.7	17.1	61.7	15.90		73.8	14.9	57.8	20.33	
		Middle	71.2	26	75.2	72.2	22	72.1	5.158	5.058	73	20.3	66.8	10.31	8.947	76.3	16.7	60.8	17.88	17.529	74.9	16.9	61	17.27	17.290	75.6	15.5	59.1	19.72	19.045	74.8	14.7	58.7	20.32	20.330
		Bottom	70.8	26	74.8	72.4	22.1	72	5.061		73.6	20.4	68	9.24		76.3	17.2	60.8	17.43		75	16.9	60.3	17.63		76.6	14.6	57.5	21.51		75.7	14.3	58.9	20.34	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	14.5	0.1	-0.1	15.4	0.3	-1.8	1.934		27.3	-0.1	0	12.80		19.6	0.5	0.7	5.18		21.1	0.8	1.2	6.76		22.3	0.9	2.1	8.14		20.2	0.7	0.7	5.79	
		Middle	14.4	-0.1	-0.5	16.8	-0.6	-1.3	2.579	1.872	28.9	0.1	0.6	14.54	13.692	19.9	0.5	0.4	5.61	6.163	23.2	0.7	1.4	9.04	8.507	20.8	0.7	1.2	6.67	7.151	20	0.6	0.7	5.77	6.182
		Bottom	12.8	-0.5	-0.4	13.3	0.4	-0.8	1.105		26.5	0.4	-0.3	13.73		20.4	0.5	0.4	7.71		22.3	0.8	1.2	9.72		19.3	0.5	0.5	6.64		19.7	0.5	0.1	6.99	
	Red	Top	29.9	22.7	18	28.6	23.2	18.8	1.606		31.6	19.5	13.3	5.93		38.5	18.5	14	10.37		36.5	18.7	13.3	9.04		33.7	20.7	16.7	4.49		35.3	17.9	12.4	9.14	
		Middle	27.3	23.3	18.8	27	23.7	20	1.300	1.630	31.2	20.1	14.3	6.76	6.429	38.3	17.8	13	13.60	12.321	36.7	18.2	12.6	12.36	10.874	35.5	19.9	15.3	9.54	8.898	36.2	17.8	11.9	12.53	11.418
		Bottom	27.7	23.1	18.4	26.6	23.5	20	1.982		31.4	19.5	14.3	6.59		38.6	18.1	13.4	12.99		36.4	18.5	13	11.23		38.2	18.4	13.1	12.67		38	18.3	13	12.58	
	Yellow	Top	71.5	26.4	74.1	72.9	21.8	70.4	6.067		72.5	20.3	65.7	10.43		76.1	18.4	62.9	14.51		74.4	17.9	62	15.07		73.3	17.5	61.8	15.29		74.4	14.7	59.4	19.01	
		Middle	71.3	26	72.4	72.7	21.7	69.4	5.427	5.579	73.2	20.1	65.8	9.05	9.363	76	17.9	62.6	13.56	14.319	74.4	18	63.3	12.51	13.904	75.2	15.3	58.9	17.66	17.564	75	14.9	59.9	17.12	18.131
		Bottom	71.5	25.7	73.7	72.2	21.2	71.1	5.244		73.6	19.7	67.9	8.61		76.1	17.3	62.3	14.89		74.9	17.5	62.7	14.14		76.4	14.5	58.2	19.74		77	14.7	60.2	18.26	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	18.1	0.6	-1.3	20.3	0.6	-0.1	2.506		27.5	1	1.8	9.91		20.4	0.2	-0.1	2.62		21.3	0.5	0.6	3.72		23.1	0.8	2	5.99		21.9	0.7	0.4	4.16	
		Middle	14.8	0.6	-0.7	17.8	-0.3	-1	3.146	2.743	28.6	0.1	1.3	13.95	9.198	19.9	0.2	0.5	5.25	3.289	21.2	0.5	1	6.62	4.356	21.5	0.6	1.2	6.96	4.975	21.2	0.6	0.6	6.53	4.574
		Bottom	19.2	1	-1.3	21	-0.4	-0.1	2.577		22.5	0.3	0.3	3.73		19.7	0.1	0.4	1.99		20.6	0.6	1	2.72		19.3	0.5	0.6	1.97		21.4	-0.2	0.4	3.03	
	Red	Top	27.1	22.4	17.3	27.9	23	18.8	1.803		29.8	20.7	15.5	3.66		38.1	17.9	13.5	12.48		36.4	18.5	13.1	10.92		34.7	18.9	14.4	8.86		36.3	17.3	11.7	11.92	
		Middle	27.5	23	18	26.8	23.7	19.4	1.715	1.283	29.9	20.2	14.6	5.02	4.573	38.4	17.6	12.9	13.19	12.722	37.1	17.8	12.5	12.22	11.490	35.2	19.2	14.3	9.35	9.966	36.8	17.2	11.5	12.74	12.120
		Bottom	28	22.8	18.3	27.9	22.7	18.6	0.332		31.4	20.6	15.3	5.04		38.4	17.9	13.4	12.50		37.1	18.4	13.2	11.32		38.1	19	13.8	11.69		37.4	18.4	12.9	11.70	
	Yellow	Top	70.8	26.1	74.6	72	22.1	73.2	4.405		72.4	20.9	70	7.12		76	18.4	62.5	15.26		74.5	17.9	61.9	15.56		73.3	18.4	64	13.34		72.1	14.3	56.2	21.90	
		Middle	71.7	25.8	73.8	72.3	21.3	72.2	4.814	4.749	73.2	19.4	65.8	10.35	8.804	76.2	17.5	62	15.11	15.110	74.6	17.5	61.7	14.96	14.985	74.8	16.5	60.4	16.60	15.806	74.9	14.4	58	19.74	20.073
		Bottom	71.4	24.8	73.4	73.2	20.6	71.3	5.029		74.4	18.8	67.5	8.93		76.5	17.3	61.5	14.96		75.1	17.2	61.7	14.43		75.4	15.9	58.9	17.48		75.3	13.6	59.1	18.58	

Appendix-J(b)

AlertCast (NPG) Products

Table J-4 – Color Measurement of AlertCast Coupons in Condition A

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	23.6	0.4	-0.95	23.45	0.45	-0.9	0.166		23.6	0.5	-0.9	0.112		22.7	1.1	-0.7	1.167		24.8	0	-0.9	1.266		27	0.1	-0.5	3.443		28.1	0.3	-0.3	4.548	
		Middle	23.25	0.2	-0.8	23.2	0.2	-0.8	0.050	0.173	23.1	0.2	-0.5	0.335	0.216	22.3	0.9	-0.5	1.218	1.044	24.4	0.4	-0.2	1.312	1.062	27.1	0.2	-0.2	3.896	3.070	28.2	0.4	-0.2	4.990	4.387
		Bottom	23.8	0.3	-0.7	23.5	0.3	-0.65	0.304		23.6	0.3	-0.7	0.200		23.2	0.5	-0.3	0.748		23.9	0.3	-0.1	0.608		25.6	0.2	-0.2	1.871		27.4	0.3	-0.3	3.622	
	Red	Top	44.9	32.45	23.45	45.25	32.15	23.5	0.464		45.5	31.6	23.3	1.051		38.7	15.9	12.7	20.686		49.6	27.5	22.3	6.922		53	22.8	19.3	13.265		53.4	21.9	19.7	14.058	
		Middle	44.15	32.15	23.2	44.65	31.85	23.25	0.585	0.719	45	31.8	23.5	0.967	1.000	38.2	17.4	13.7	18.526	19.063	49.7	27.5	22.1	7.324	7.031	52.7	23.1	19.3	13.047	13.080	53.4	22.4	20.1	13.793	13.997
		Bottom	43.9	32.25	23.45	44.95	32	23.7	1.108		44.7	31.7	23.3	0.982		36.3	18.2	15.2	17.978		49.2	28	22.6	6.847		52.4	23.3	19.6	12.930		53.3	22.3	19.9	14.141	
	Yellow	Top	74.65	14.3	63.65	74.7	12.3	60.95	3.360		76	11.7	60.6	4.229		68.2	16.5	56	10.245		74.3	10.6	53.9	10.434		74.8	9.4	49.6	14.881		75.5	9.3	47.4	17.023	
		Middle	74.2	14.7	64.55	74.85	12.85	62.05	3.177	3.141	75.3	12.4	61.4	4.052	4.099	71.3	16.7	57.3	8.061	9.637	74.9	11	55.3	9.987	9.851	75.1	9.6	49.5	15.916	15.048	75.9	9.3	47.4	18.060	17.441
		Bottom	74.15	14.9	64.55	74.25	13.3	62.15	2.886		74.4	12.7	61.2	4.016		68.5	16.4	55.7	10.606		75	11.3	56.2	9.133		74.5	10.2	51	14.346		74.9	9.8	48.1	17.239	

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	23.6	0.4	-0.95	23.45	0.2	-1	0.255		23.8	0.4	-0.9	0.206		22.2	0.9	0	1.764		22.6	0.2	-0.5	1.115		27.3	0.1	-0.5	3.739		28.6	0.3	-0.3	5.043	
		Middle	23.25	0.2	-0.8	23.8	0.05	-0.95	0.589	0.559	24.4	0.3	-1.3	1.258	0.625	23.7	0.1	-0.2	0.757	0.997	23.9	0.3	-0.3	0.826	0.934	27.2	0.2	-0.1	4.012	3.499	29	0.4	-0.2	5.785	5.119
		Bottom	23.8	0.3	-0.7	23.05	0.6	-0.5	0.832		23.6	0.5	-1	0.412		24.1	0.6	-0.5	0.469		24.6	0.2	-0.4	0.860		26.5	0.3	-0.2	2.746		28.3	0.4	-0.2	4.529	
	Red	Top	44.9	32.45	23.45	44.75	31.3	23.1	1.211		44.7	30.7	22.8	1.877		35.9	18.3	15.4	18.602		48.9	26.9	21.4	7.142		51.5	23.1	19.4	12.140		53.2	21.6	19.6	14.193	
		Middle	44.15	32.15	23.2	45.4	31.7	23.15	1.329	1.308	45.3	31.2	23.1	1.495	1.714	37.3	18.1	14.9	17.698	18.140	49.5	26.9	21.1	7.784	7.893	51.8	23.5	19.7	12.066	11.881	53.4	22.2	19.9	13.981	14.078
		Bottom	43.9	32.25	23.45	45.2	31.85	23.2	1.383		45.6	31.9	23.1	1.771		37.8	17.6	14.7	18.122		49.9	26.5	20.7	8.754		51.3	24.2	20.1	11.436		53.1	22.3	19.7	14.061	
	Yellow	Top	74.65	14.3	63.65	75.55	12.6	62.7	2.145		76.3	12.2	62.3	2.992		68.2	16.5	55.9	10.320		76.5	10.1	51.4	13.081		77	8.8	46.2	18.447		77.4	8.8	45.1	19.543	
		Middle	74.2	14.7	64.55	75.1	13	63.4	2.241	2.333	74.8	12.4	61.4	3.946	3.473	71.4	16.6	57.2	8.092	9.792	76.5	10.1	51.4	14.120	13.528	76.6	9.2	47.4	18.170	18.094	77.5	9.1	46.1	19.562	19.500
		Bottom	74.15	14.9	64.55	75.2	12.75	63.5	2.613		75	12.3	62.4	3.479		68.3	16.4	55.4	10.963		76.1	10.4	52.1	13.381		76.3	9.4	47.9	17.666		77	9.3	46.2	19.396	

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	23.6	0.4	-0.95	23.9	-0.05	-1.05	0.550		24	-0.1	-0.8	0.658		22.6	0.8	-0.7	1.106		21	0.1	-0.6	2.641		25.6	0.1	-0.7	2.038		27.2	0.4	-0.3	3.658	
		Middle	23.25	0.2	-0.8	23.7	0.5	-1.05	0.596	0.444	23.8	0.6	-0.9	0.687	0.573	22.7	1.1	-0.7	1.059	1.126	22.6	0.3	-0.2	0.890	1.550	26.8	0.3	-0.3	3.586	2.927	28.3	0.5	-0.3	5.084	4.489
		Bottom	23.8	0.3	-0.7	23.9	0.35	-0.55	0.187		23.9	0.5	-1	0.374		22.7	0.4	-0.2	1.212		22.8	0.3	-0.2	1.118		26.9	0.3	-0.1	3.158		28.5	0.3	-0.2	4.727	
	Red	Top	44.9	32.45	23.45	44.6	32.55	24	0.634		44.8	31.5	23.6	0.967		38.3	17.1	13.5	19.447		50.2	26.5	21.4	8.228		52.6	22.5	19.6	13.157		53.6	21.6	19.8	14.378	
		Middle	44.15	32.15	23.2	44.55	32	23.95	0.863	0.723	45.2	31.8	23.9	1.310	1.147	37.3	18	14.6	17.919	18.344	50.4	26.4	21	8.773	8.597	53.2	22.4	19.2	13.891	13.659	54.4	21.4	19.7	15.260	14.906
		Bottom	43.9	32.25	23.45	44.5	32.25	23.75	0.671		45	31.9	23.6	1.164		36.6	18.5	15.1	17.666		50.3	26.7	21.1	8.791		53	22.6	19.2	13.928		54	21.7	19.7	15.079	
	Yellow	Top	74.65	14.3	63.65	75.65	12.4	61.95	2.739		75.9	11.7	61	3.917		68.2	16.7	56.4	9.996		75.2	10.3	53.5	10.924		75.4	9.3	47.6	16.828		75.9	9	47.1	17.423	
		Middle	74.2	14.7	64.55	75.85	13.1	63	2.772	2.829	76.2	12.6	62.5	3.551	3.794	71.2	16.7	57.8	7.653	9.611	75.6	9.8	52.2	13.360	12.132	76.1	8.8	47.5	18.142	17.338	76.5	8.7	47.4	18.314	18.084
		Bottom	74.15	14.9	64.55	75.8	13.1	62.85	2.975		75.9	12.4	62.1	3.913		68.2	16.4	55.2	11.184		75.6	10.4	53.4	12.111		74.9	9.5	48.4	17.045		76.3	9.1	47.1	18.514	

Table J-4 – Continued

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 4		Top	23.6	0.4	-0.95	24.15	0.2	-0.45	0.770		24.3	0.1	-0.7	0.802		22.7	0.3	-1	0.907		21	0.2	-0.4	2.665		26.5	0.1	-0.6	2.936		27.6	0.2	-0.3	4.057	
	Black	Middle	23.25	0.2	-0.8	24.2	0.35	-0.6	0.982	0.752	24.2	0.8	-0.6	1.141	0.772	22.4	-0.1	-0.6	0.923	0.903	23.5	0.3	-0.2	0.658	1.451	27.8	0.3	-0.4	4.569	3.713	28.7	0.3	-0.3	5.474	4.919
		Bottom	23.8	0.3	-0.7	24.3	0.35	-0.75	0.505		24	0.4	-1	0.374		23	0.5	-1	0.877		24.7	0.3	-0.2	1.030		27.4	0.3	-0.2	3.635		29	0.4	-0.2	5.225	
		Top	44.9	32.45	23.45	45.8	32.1	23.45	0.966		46.4	31.2	23.4	1.953		36.6	18.1	14.9	18.652		49.1	29.1	23.9	5.391		52.4	24	20.4	11.703		55	21.6	19.6	15.315	
	Red	Middle	44.15	32.15	23.2	45.75	32.2	23.6	1.650	1.256	47	31.8	23.3	2.873	2.133	37.5	17.4	13.9	18.662	18.248	49	30.5	25.3	5.537	5.268	51.9	24.5	20.5	11.219	11.982	54.1	22.6	20	14.158	14.989
		Bottom	43.9	32.25	23.45	45.05	32.3	23.4	1.152		45.4	31.8	23.6	1.573		37.4	18.4	15.1	17.430		47.9	29.5	23.9	4.875		52.6	23.4	19.5	13.024		54.5	21.7	19.4	15.494	
		Top	74.65	14.3	63.65	75.25	12.9	61.95	2.283		76.4	12	61.4	3.663		72.1	16.8	57.4	7.198		75.8	10.7	55.8	8.712		76	9.3	48.4	16.105		76.7	9	47.3	17.309	
	Yellow	Middle	74.2	14.7	64.55	75.25	13.3	62.55	2.658	2.409	76.7	12.3	61.8	4.424	3.953	69.3	16.3	55	10.852	8.650	75.7	11	54.5	10.814	10.374	76.5	9.5	47.8	17.689	17.169	76.7	9.4	47.6	17.934	17.946
		Bottom	74.15	14.9	64.55	75	13.35	63.1	2.286		75.1	12.5	61.8	3.772		71.2	16.5	57.4	7.898		76	10.7	53.9	11.597		76.4	9.6	47.8	17.712		77.1	9.2	47.1	18.593	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 5		Top	23.6	0.4	-0.95	23.95	0	-1.2	0.587		23.5	0.2	-0.9	0.229		22.2	0.3	-0.6	1.447		23	0.2	-0.4	0.838		25.9	0.1	-0.6	2.346		27	0.3	-0.3	3.463	
	Black	Middle	23.25	0.2	-0.8	23.5	0.15	-1.15	0.433	0.443	23.6	0.2	-1.4	0.695	0.490	22.7	0.3	-0.9	0.568	0.979	24.3	0.3	-0.3	1.167	1.270	26.9	0.2	-0.6	3.655	3.304	27.4	0.4	-0.4	4.174	4.089
		Bottom	23.8	0.3	-0.7	23.5	0.25	-0.75	0.308		24.3	0.4	-0.5	0.548		22.9	0.3	-0.5	0.922		25.6	0.2	-0.8	1.806		27.7	0.3	-0.4	3.912		28.4	0.5	-0.2	4.631	
		Top	44.9	32.45	23.45	45.2	31.65	23.1	0.923		45.9	31.4	23.1	1.492		38.6	16.6	13.4	19.797		49.6	26.5	21.1	7.938		51.7	23.4	19.6	11.957		53.4	21.9	19.9	14.006	
	Red	Middle	44.15	32.15	23.2	44.8	31.55	23.2	0.885	1.152	46.7	31.5	23	2.639	1.969	38.2	17.1	12.9	19.183	19.232	49.4	27	21.4	7.571	7.684	51	24.4	20.2	10.770	11.675	53.3	22.1	19.7	14.035	14.181
		Bottom	43.9	32.25	23.45	45.45	31.75	23.2	1.648		45.6	31.8	23.7	1.776		36.9	17.5	14.3	18.716		49.3	27.4	21.4	7.542		51.7	23.6	19.5	12.299		53.3	21.9	19.6	14.502	
		Top	74.65	14.3	63.65	75	12.55	62	2.431		74	11.9	60.1	4.334		70.7	16.6	57.5	7.663		75.7	10.7	55.6	8.881		75.6	9.6	49.2	15.225		76.6	8.9	46.6	17.991	
	Yellow	Middle	74.2	14.7	64.55	75.35	12.5	61.6	3.856	3.215	74.5	11.6	59.3	6.104	5.149	69.3	16.7	56.8	9.385	9.358	76.2	11.1	56.2	9.310	8.884	76.3	10.2	51.4	14.056	13.906	76.6	9.3	46.9	18.613	18.130
		Bottom	74.15	14.9	64.55	75.1	13	61.95	3.357		74.9	12.2	60.4	5.007		68.5	16.4	55.2	11.027		76.1	11	57.3	8.460		75.7	10.3	53.1	12.436		76.5	9.4	47.8	17.786	

Table J-5 – Color Measurement of AlertCast Coupons in Condition B

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	23.7	0.4	-1.1	23	0.5	-1	0.714	0.611	24.2	0.5	-0.7	0.648	0.748	23	0.3	0.4	1.658	1.885	25.5	0.5	0.5	2.410	2.137	23.8	0.5	0.6	1.706	2.535	23.9	0.3	0.8	1.913	2.100
		Middle	23.4	0.3	-1.2	23.7	0.2	-1.1	0.332		23.6	0.4	-0.7	0.548		22.6	0.5	0.8	2.163		24.4	0.4	0.5	1.975		21.9	0.6	0.8	2.518		21.7	0.5	0.9	2.709	
		Bottom	23.9	0	-0.9	23.8	0.6	-0.4	0.787		24.4	0.6	-0.2	1.049		23.1	0.4	0.7	1.833		25.4	0.4	0.4	2.025		21.1	0.6	0.9	3.382		23.6	0.4	0.7	1.676	
	Red	Top	44.4	32.1	23.1	44.9	32.1	23.3	0.539	0.683	45.4	31.3	23.1	1.281	1.893	45.5	31.3	24.8	2.177	3.884	49	27.5	21.5	6.699	7.902	47.7	28.5	23.2	4.885	6.570	47.5	28.5	24	4.835	7.366
		Middle	44.7	32.1	23.3	44.9	32.3	24.1	0.849		45.7	30.8	22.8	1.715		46	30.7	24.7	2.369		49.4	27.7	22	6.568		47.5	29	24.1	4.253		48.2	28.3	24.3	5.262	
		Bottom	44.6	31.9	22.8	45.2	31.7	23	0.663		46.5	30.1	22.2	2.685		49.7	27.1	21.6	7.106		51.7	24.6	20.5	10.440		51.9	24.4	21.3	10.573		53	23.5	21.1	12.000	
	Yellow	Top	74.4	15.1	64.9	75.1	13	62.4	3.339	3.257	75.5	12.7	60.9	4.793	4.500	75.2	12.2	60.7	5.166	7.002	75.9	10.6	53.5	12.347	13.234	74.8	11.2	51.2	14.250	14.729	75.9	10.1	51.9	14.009	14.969
		Middle	74.6	14.6	63.7	76.3	12.4	61.6	3.484		75.3	12.3	60.2	4.246		75.4	11.3	58.5	6.210		75.9	10.4	53	11.568		75.6	10.4	52.2	12.284		75.7	9.8	51.7	12.971	
		Bottom	74.5	15.3	64.6	74.9	13.5	62.3	2.948		74.9	13	60.8	4.460		75.9	11.2	56	9.630		76.5	9.9	49.9	15.788		76.4	9.6	48	17.654		76.5	9.1	47.9	17.926	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	23.5	0.2	-1.1	23.7	0.5	-0.9	0.412	0.411	24.1	0.4	-0.3	1.020	0.892	22.9	0.6	0.6	1.847	1.562	26	0.4	0.4	2.922	1.932	23.3	0.5	0.7	1.836	2.527	22.7	0.4	0.9	2.163	1.923
		Middle	23.8	0.1	-0.4	24.2	0.3	-0.2	0.490		24.6	0.5	-0.1	0.943		23	0.4	0.7	1.393		24.8	0.4	0.4	1.315		21.4	0.6	0.9	2.775		22	0.4	0.9	2.241	
		Bottom	24	0.5	-0.7	24.3	0.6	-0.8	0.332		23.9	0.6	0	0.714		23.2	0.4	0.5	1.446		25.1	0.4	0.4	1.559		21.5	0.6	0.9	2.970		24.8	0.4	0.4	1.364	
	Red	Top	44.6	32.3	23.2	45	32.2	23.5	0.510	0.508	45.7	31.6	23.3	1.308	1.677	46.1	31.3	24.4	2.166	3.638	48.7	28.1	22.5	5.911	7.036	48.1	28.7	23.7	5.046	6.244	48.3	28.4	24	5.435	7.386
		Middle	44.6	32	22.9	44.9	31.9	23.1	0.374		45.8	31	22.7	1.575		46.1	31	24.9	2.693		49.3	27.7	22.2	6.409		48	28.5	23.9	4.981		48.3	28.1	24.3	5.555	
		Bottom	44.6	31.6	22.6	45.2	31.5	22.8	0.640		46.3	30.3	22.4	2.149		49	27.5	21.9	6.055		51	25.7	21.4	8.787		50.9	25.6	22.3	8.705		52.6	23.9	21.4	11.168	
	Yellow	Top	74.5	14.2	63.6	76	12.3	61.5	3.205	3.039	75.4	12.2	60.5	3.797	4.283	75	11.6	59.8	4.631	7.386	76.2	10	51.3	13.108	14.733	75.4	9.9	50.6	13.722	15.352	74.9	10.1	51.9	12.404	14.736
		Middle	74.2	14.5	64.3	75.5	12.7	62.1	3.126		75.2	12.3	60.4	4.588		75.2	11.5	58.9	6.258		76.3	9.7	51.2	14.109		75.7	9.7	51.3	13.939		75.8	9.2	51.2	14.222	
		Bottom	74.3	15.1	64.9	75.4	13.5	62.9	2.787		75.1	12.9	61.1	4.463		76.2	10.7	54.7	11.270		76.8	9.4	49.1	16.982		76.6	9	47.7	18.394		76.8	9	48.6	17.583	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	23.7	-0.1	-0.9	23.9	-0.1	-0.9	0.200	0.430	23.9	0.1	-0.5	0.490	0.499	22.4	0.6	0.5	2.035	1.483	25.6	0.4	0.5	2.412	1.740	23.1	0.6	0.9	2.022	2.492	22.7	0.5	1	2.229	1.942
		Middle	23.6	0.1	-0.4	23.8	0.3	-0.7	0.412		23.8	0.4	-0.1	0.469		22.6	0.5	0.6	1.470		24.6	0.5	0.5	1.404		21.1	0.5	0.9	2.846		21.7	0.4	1	2.379	
		Bottom	23.5	0.6	-0.4	24.1	0.3	-0.3	0.678		23.9	0.4	-0.1	0.539		23.3	0.4	0.5	0.943		24.7	0.4	0.3	1.404		21.3	0.6	1	2.608		23.5	0.4	0.8	1.217	
	Red	Top	44.3	31.6	22.3	44.4	31.7	22.7	0.424	0.703	45.3	30.9	22.6	1.257	1.653	45.4	31.1	24.5	2.510	3.923	48.5	28.3	22.5	5.345	7.126	47.7	29.1	23.7	4.446	6.236	47.8	28.7	24	4.853	7.043
		Middle	44.7	31.9	22.8	45.5	31.8	23.3	0.949		45.7	31	23	1.360		45.7	30.8	24.7	2.412		49.2	27.7	22	6.207		47.3	29.4	24.5	3.987		47.8	28.5	24.4	4.871	
		Bottom	44.2	31.8	22.8	44.4	31.7	23.5	0.735		45.9	30.2	22.6	2.343		49.1	27.2	21.5	6.845		51.2	25.2	20.8	9.826		51.7	24.9	21.5	10.274		52.4	24	21.4	11.404	
	Yellow	Top	74.4	14.9	65.5	75.1	12.7	62.9	3.477	3.501	75.4	12.4	61.1	5.158	5.299	73	12.1	59.3	6.946	8.449	76.4	10	51.6	14.873	15.681	75.4	10.2	51.3	14.991	15.905	75.3	9.7	51.3	15.149	15.818
		Middle	74.3	15	65	75.3	12.9	62.9	3.134		75.2	12.6	60.9	4.835		75	12	59.7	6.130		76.1	10.1	50.8	15.129		75.6	10.2	52.2	13.732		75.3	9.8	52.3	13.760	
		Bottom	73.8	15.2	65.1	75.7	12.9	62.6	3.892		75.4	12.5	60.1	5.903		77.5	10.7	54.3	12.271		76.5	9.7	49.2	17.040		76.6	9.2	47.3	18.992		76.9	9	47.9	18.544	

Table J-6 – Color Measurement of AlertCast Coupons in Condition C

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	23.8	-0.2	-1.4	24	0.2	-0.2	1.281		26.1	-0.1	-0.6	2.437		27.8	0.3	-0.2	4.206		28.3	0.4	0	4.751		27.1	0.5	0.4	3.824		30.6	0.3	0.4	7.052	
		Middle	24	0.3	-1.4	24.6	0.8	-0.5	1.192	0.899	25.2	0.5	-0.2	1.709	1.552	27.7	0.3	-0.1	3.922	3.884	28.7	0.4	0.1	4.935	4.866	27	0.5	0.5	3.557	3.779	29.9	0.4	0.1	6.089	5.930
		Bottom	24	0.2	-0.3	24	0.4	-0.2	0.224		24.4	0.3	0	0.510		27.5	0.5	0	3.526		28.9	0.4	0	4.913		27.9	0.5	0.3	3.957		28.6	0.5	0.3	4.649	
	Red	Top	44.8	31.9	23.3	45.3	31.1	22.8	1.068		49	27.4	21.1	6.537		52.4	24	19.6	11.570		54.2	22.4	19.9	13.790		52.9	23.8	21.7	11.566		54.1	21.5	21	14.140	
		Middle	44.8	31.7	22.9	45.2	31.6	23.2	0.510	1.203	49.7	26.8	20.1	7.474	6.554	51.4	25	20.4	9.731	10.437	53.6	22.9	20	12.778	13.408	52.1	24.3	21.7	10.464	11.463	54.5	21.2	20.1	14.566	14.782
		Bottom	44.7	31.9	23.1	46.7	31.6	23.3	2.032		48.7	28.2	21.6	5.652		51.3	25	20.1	10.008		53.9	22.4	19.7	13.655		53.2	23.2	20.9	12.360		55.3	20.8	20.1	15.639	
	Yellow	Top	74.2	14.8	64.3	76.9	12.9	63.6	3.375		74.9	11.7	57	7.962		75.9	10.9	54.5	10.684		76.7	9.7	48.5	16.790		76.3	10	50.7	14.574		75.9	9	46.1	19.177	
		Middle	74.3	14.5	63.7	74.6	12.7	61.8	2.634	3.011	75.4	12	58.9	5.523	6.241	75.8	11.1	54.5	9.922	9.840	77	9.8	48.5	16.138	16.131	76.5	10	50.8	13.838	14.401	76.4	9.1	46.4	18.244	18.315
		Bottom	74.5	14.2	63.4	75	12.3	61.1	3.025		75.7	11.8	58.9	5.239		75.9	11	55.2	8.913		76.9	9.7	48.8	15.465		76.8	9.7	49.5	14.790		77.1	8.9	46.9	17.524	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	23.6	0	-1.1	22.6	0.4	-1	1.082		25	0.1	-0.6	1.490		27.8	0.3	-0.2	4.306		27.8	0.4	-0.2	4.314		26.7	0.5	0.3	3.438		29.3	0.6	0.2	5.877	
		Middle	23.9	0.1	-0.7	25	0.3	-0.5	1.136	1.397	26.4	0.3	0.2	2.665	2.140	27.8	0.4	-0.1	3.957	3.999	28.3	0.4	0	4.465	4.568	26.8	1.3	-0.2	3.178	3.524	29.5	0.5	0.2	5.686	5.601
		Bottom	24	0.5	-1.1	25.7	0.4	-0.1	1.975		25.6	0.4	0.5	2.265		27.5	0.5	0.2	3.734		28.8	0.4	0	4.925		27.7	0.5	0.3	3.956		29.1	0.5	0.1	5.239	
	Red	Top	44.6	32	23	44.6	31.9	24.2	1.204		50.2	25.8	19.4	9.097		52.6	23.6	19.7	12.060		53.6	22.5	20.3	13.362		51.9	24.1	22	10.803		54	21.3	21.3	14.344	
		Middle	44.8	31.8	23.2	46.5	31.8	24.5	2.140	1.522	49.5	27.7	21.7	6.415	7.145	53	23.8	19.7	11.979	11.392	54.2	22.3	20.1	13.719	13.446	52.1	24.3	22.2	10.514	11.176	55	21.4	20.6	14.797	14.679
		Bottom	45.5	31.9	23.5	46.7	31.7	23.6	1.221		49.8	28.2	21.8	5.922		52.1	25	20.1	10.136		54.3	22.7	19.8	13.258		53.8	23.3	21	12.211		55.2	21	20.5	14.896	
	Yellow	Top	74.2	14.8	63.7	75.6	12.9	62.7	2.563		75.6	12.1	57.1	7.267		76.5	10.6	51.5	13.106		77	9.6	47.9	16.868		76.2	10.1	50.6	14.061		76	9.2	45.4	19.222	
		Middle	74.6	14.5	63.3	77.1	12.4	61.6	3.681	3.291	78.4	11.6	58.7	6.634	6.743	76.6	10.5	51.5	12.619	12.549	77.2	9.3	47.5	16.836	17.042	76.4	9.8	49.8	14.408	14.869	77	9.2	46.1	18.157	18.726
		Bottom	74.5	14.8	64.6	75.2	12.6	61.8	3.629		74.9	12.3	58.8	6.329		76	11	53.4	11.922		76.8	9.7	48.1	17.423		76.6	9.8	49.4	16.138		77	9.3	46.8	18.797	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	24	0.5	-0.8	23.4	0.6	-0.3	0.787		27	0.2	0.3	3.209		27.5	0.5	0.1	3.614		28.6	0.4	0	4.670		27.1	0.5	0.5	3.362		29.1	0.5	0	5.162	
		Middle	24.1	0.2	-0.8	23.2	0.3	-0.9	0.911	0.990	26.3	0.3	0.4	2.508	2.198	26.8	0.6	0.2	2.907	3.099	28.4	0.5	0.1	4.403	4.332	27.1	0.6	0.5	3.294	3.122	28.8	0.6	0.3	4.844	4.833
		Bottom	24.6	0	-1	23.4	0.3	-0.7	1.273		24.8	0.3	-0.2	0.877		27	0.5	0.3	2.775		28.3	0.5	0.2	3.922		26.8	0.5	0.5	2.709		28.9	0.5	0.2	4.492	
	Red	Top	44.6	31.9	23	45.1	31.5	24	1.187		51.3	26.4	20.5	9.022		53.2	23.8	19.6	12.293		54.1	22.7	20.2	13.518		52.3	24.4	22.1	10.787		54.9	21.8	20.8	14.592	
		Middle	44.6	31.8	23.2	45.5	31.5	23.7	1.072	1.155	50	26.7	20.3	7.974	7.522	53.2	23.9	19.6	12.220	11.842	54.8	22.3	19.8	14.347	13.847	53.1	23.8	21.8	11.756	11.745	55.7	21.5	20.3	15.418	14.838
		Bottom	44.7	31.8	23.2	45.6	31.8	24	1.204		48.5	28.1	21.5	5.570		52.3	24.5	20	11.013		54.3	22.6	20	13.676		53.7	23.1	21.1	12.693		55	21.9	20.7	14.503	
	Yellow	Top	74.9	14	63.4	75.1	12.4	62.1	2.071		78.2	10.7	58.4	6.840		76.9	9.6	50.3	13.963		77.8	8.8	46.9	17.541		76.6	9.4	49.7	14.551		76.8	8.7	47.2	17.151	
		Middle	74.5	14.6	64.4	75	12.7	62.5	2.733	2.790	78.2	10.9	57.8	8.423	7.354	76.6	10.3	52.5	12.826	12.720	77.2	9.3	48.2	17.257	17.073	76.5	9.8	51.1	14.280	14.681	77	9.1	47.3	18.136	17.945
		Bottom	74.4	14.1	64	77	12.1	62.6	3.567		77.9	11.1	59	6.801		76.2	10.4	53.4	11.371		77.1	9.4	48.5	16.420		76.8	9.5	49.7	15.212		76.9	8.8	46.4	18.550	

Appendix-J(c)

Redimat (Polyurethane) Products

Table J-7 – Color Measurement of Redimat Coupons in Condition A

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1		Top	13.6	-0.25	0.3	26.15	-0.1	-0.25	12.56		26.1	-0.4	0.4	12.50		23.7	0	1.1	10.13		22.3	0.3	1.5	8.80		20.9	0.4	0.5	7.33		20.5	0	0.8	6.92	
	Black	Middle	12.9	0.05	0.75	21.85	0.05	-1.15	9.15	11.12	26.4	-0.4	0.2	13.52	13.26	23.3	-0.1	0.2	10.42	10.70	22.3	0	0.6	9.40	9.65	21.1	0.5	0.1	8.24	8.37	20.2	0.3	-0.1	7.35	7.74
		Bottom	11.85	-0.05	0.2	23.45	0	-0.85	11.65		25.6	-0.1	-0.4	13.76		23.4	-0.2	0.1	11.55		22.6	-0.1	0.5	10.75		21.4	0	0.1	9.55		20.8	-0.1	0	8.95	
		Top	20.05	16.85	9.75	30.15	9.45	8.8	12.56		32.1	8.8	10.4	14.51		30.4	10.1	12.9	12.75		30.6	10.4	13.8	13.01		30.9	10.7	14.7	13.42		30.2	10.5	13.6	12.58	
	Red	Middle	21.3	15.8	9.05	28.4	10.25	8.25	9.05	10.75	33.6	8.3	9.5	14.41	14.79	31.6	10.1	12.2	12.19	12.83	31.4	10.4	13.5	12.29	12.73	30.4	11.2	14.5	11.56	12.59	30.4	10.7	14.2	11.63	12.58
		Bottom	19.85	16.5	10.5	28.55	10.8	8.2	10.65		33	8.5	9.3	15.44		31.6	9.9	12	13.56		31	10.6	13.1	12.88		30.7	10.8	14.2	12.80		31.3	10.6	14.6	13.52	
		Top	73.5	20.1	79.55	72.35	13.2	59.55	21.19		71.9	12.3	50	30.60		72.7	12.2	53.4	27.33		73.3	11.7	52.9	27.94		72.7	12	52.2	28.54		68.7	12.4	54.8	26.36	
	Yellow	Middle	73.6	20.3	81.1	71.55	13.65	64.25	18.23	19.31	71.9	11.8	47.7	34.51	32.81	72.8	11.6	51	31.34	30.01	72.7	11.5	50.8	31.56	30.62	73.3	11.6	51.4	30.95	30.18	67.7	13.8	55.9	26.69	27.45
		Bottom	73.3	20.6	81.75	71.9	13.75	64.6	18.52		72.7	11.9	49.6	33.31		73.4	11.6	51.7	31.37		72.7	11.5	50.7	32.36		72.7	12	51.9	31.07		72.8	10.9	54.1	29.31	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2		Top	9.05	0	0.4	26	-0.2	-0.1	16.96		25	-0.2	0.2	15.95		22.8	0.1	0.1	13.75		21.6	0.3	0.1	12.56		20.8	0.4	0.1	11.76		25.1	0.6	-0.2	16.07	
	Black	Middle	9.4	0.15	0.2	22.55	0	-0.75	13.19	14.71	27.4	-0.3	0.1	18.01	17.22	24.2	0.2	0.3	14.80	14.69	22.9	0.1	0.3	13.50	13.42	21.2	0.3	0.2	11.80	11.99	19.9	0	0.9	10.52	13.00
		Bottom	8.4	0	0.6	22.3	-0.05	-0.85	13.98		26.1	-0.2	0	17.71		23.9	0.1	0.3	15.50		22.6	0	0.3	14.20		20.8	0.2	0.1	12.41		20.8	-0.5	0.9	12.41	
		Top	19.8	16.45	10.1	29.3	10	8.7	11.57		32	8.9	10.1	14.35		30.9	10.4	12.2	12.81		30.8	10.4	13.1	12.91		29.6	10.3	13.4	12.03		30.4	10.5	13.7	12.68	
	Red	Middle	22.85	14.85	8.25	28.95	10.2	8.5	7.67	11.06	33	8.7	9.9	11.98	14.74	31	10.5	12.6	10.21	12.86	30.9	10.7	13.6	10.52	12.98	30.1	10.9	14	10.06	12.21	30.7	10.1	13.6	10.62	13.05
		Bottom	17.65	18	12.7	28.3	10.2	8.2	13.95		32.5	8.6	9.3	17.90		31.2	10.4	12.2	15.54		31.2	10.5	13.3	15.50		30.2	10.8	14.1	14.54		31.5	10.4	13.8	15.84	
		Top	73.15	20.7	82.3	72.45	12.85	59.25	24.36		72.2	11.9	51.3	32.24		73.5	11.6	52	31.64		73.1	11.5	51.8	31.86		73.6	11.4	50.7	32.94		65.2	13	53.2	31.13	
	Yellow	Middle	73.3	20.5	80.95	72	13.55	64.3	18.09	20.16	72.6	11.8	48.4	33.70	32.81	73.7	11.7	51.4	30.84	31.38	73.5	11.4	50	32.26	31.71	73.6	11.3	49.4	32.87	32.50	69.4	13	52.3	29.87	30.12
		Bottom	73.35	20.55	80.7	71.85	13.65	64.1	18.04		73.1	11.5	49.5	32.49		74.1	11.4	50.4	31.66		73.7	11.6	51	31.02		73.3	11.6	50.3	31.69		73.4	10.8	53	29.37	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3		Top	9.55	-0.05	0.2	25.1	0	-0.2	15.56		24.8	-0.2	0	15.25		22.7	0.3	0	13.16		21.3	0.1	0.2	11.75		20.8	0.5	0.5	11.27		21.9	-0.1	0.1	12.35	
	Black	Middle	9.45	0	0.4	21.65	0	-0.95	12.27	13.30	26.8	-0.4	0.1	17.36	16.27	24	-0.1	0.2	14.55	13.97	22.5	0.2	0.1	13.05	12.57	20.9	0.2	0.1	11.46	11.34	19.8	0.3	1	10.37	11.11
		Bottom	9.8	0.05	0.1	21.85	0.1	-0.8	12.08		26	-0.1	0	16.20		24	0.2	0.1	14.20		22.7	0.2	0.3	12.90		21.1	0.3	0.3	11.30		20.4	0.1	0.4	10.60	
		Top	20.8	16.65	9.8	30.3	9.7	9.7	11.77		32.5	8.7	11	14.20		30.7	10.5	13	12.09		30.5	10.9	13.6	11.90		30.3	11.1	14.5	11.96		31.1	10.3	13.7	12.71	
	Red	Middle	23.5	14.75	8.65	28.2	10.8	9.4	6.19	7.99	33.3	8.7	10.8	11.72	12.50	32.4	10.1	12.4	10.72	11.23	31.1	11.3	13.7	9.76	10.73	30.6	11	14.6	9.99	10.86	26.7	9.5	12.2	7.10	8.73
		Bottom	23.15	14.5	8.4	28.05	11.05	8.95	6.02		33	8.6	9.9	11.58		32.3	10	12.2	10.88		31.5	10.6	13.5	10.53		30.9	11.1	14.8	10.61		25.7	8.9	10.1	6.38	
		Top	73.15	20.2	81.9	72.25	13.3	60.75	22.27		72.5	12	49.1	33.82		74	11.7	52.1	31.00		73	11.4	49.5	33.57		67.6	12.8	47	36.11		66.4	12.8	54.1	29.55	
	Yellow	Middle	72.6	20.4	82.45	71.75	13.55	63.55	20.12	20.34	72.5	11.9	48	35.48	33.86	73.4	11.6	50.4	33.25	32.43	73.2	11.4	49.7	33.97	33.91	72.1	12	50.5	33.04	33.60	68.2	13.7	54.8	28.79	29.64
		Bottom	72.9	20.3	82.3	71.95	13.55	64.95	18.64		73.1	11.7	51.2	32.27		73.6	11.3	50.5	33.06		73.5	11.4	49.3	34.18		71.9	12.3	51.7	31.64		72.7	10.9	53.2	30.58	

Table J-7 – Continued

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 4	Black	Top	8.8	0.1	0.6	24.85	-0.05	-0.05	16.064		25.1	0.2	0.1	16.31		22.8	0.4	-0.1	14.02		21.3	0.5	-0.2	12.53		20.6	0	0	11.82		20.6	0	0.2	11.81	
		Middle	8.2	0.45	0.15	23.6	0	-0.6	15.425	15.56	26	-0.1	0.1	17.81	17.06	23.2	0.5	0.2	15.00	14.59	22.1	0.4	0.1	13.90	13.23	20.2	0.2	0.2	12.00	12.06	20.6	-0.2	0.7	12.43	12.26
		Bottom	8.45	0	0.55	23.6	0	-0.5	15.186		25.5	-0.1	-0.1	17.06		23.2	0.3	0	14.76		21.7	0.3	0.1	13.26		20.8	-0.1	0.5	12.35		21	-0.3	0.6	12.55	
	Red	Top	19.5	16.85	9.9	29.6	9.8	8.55	12.391		32.5	8.7	10.1	15.34		31.2	10.4	11.8	13.49		30.4	10.7	12.9	12.87		30.1	10.4	14.1	13.10		29.4	10.8	13.6	12.18	
		Middle	19.8	17.7	9.95	28.65	10.35	8.75	11.567	11.45	33.6	8.5	10.3	16.59	15.79	32.2	10.3	13.2	14.80	14.08	31.3	10.6	14.2	14.17	13.45	31.3	10.7	15.2	14.45	13.39	26.4	9.6	12.4	10.73	10.79
		Bottom	19.35	16.2	10.6	27.7	10.4	8.4	10.402		32.7	8.5	9.6	15.44		31.8	10.2	12.5	13.95		31.1	10.8	13.8	13.32		30.1	11.1	14.8	12.62		25.7	9.2	10.5	9.45	
	Yellow	Top	73.45	19.95	79.8	72.25	12.6	58.55	22.517		72	11.9	49.3	31.58		73.4	11.7	53.5	27.56		73	11.9	53.2	27.80		60.6	13.6	51.8	31.46		66.8	13.2	54.6	26.92	
		Middle	72.8	20.15	79.85	71.65	13.4	63.85	17.404	19.41	72.3	11.6	48.7	32.31	31.61	72.8	11.3	51.5	29.70	29.06	73.6	11.4	51	30.16	29.57	67.9	13.2	55.1	26.17	27.47	66.9	14.1	57	24.36	26.36
		Bottom	73.25	20.25	79.95	72.15	13.3	63.05	18.306		72.9	11.7	50.2	30.96		73.3	11.3	51.4	29.92		72.6	11.7	50.4	30.77		68.9	13.2	56.6	24.78		72.5	11.1	53.7	27.81	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 5	Black	Top	9.35	-0.1	0.55	25.9	-0.2	-0.2	16.57		25	-0.2	0.1	15.66		22.6	0.2	0	13.26		21.9	0.2	0.3	12.56		20.6	0.2	0	11.27		21.5	0.3	0.6	12.16	
		Middle	8	0	0.7	22.6	0.15	-0.65	14.66	15.14	26.9	-0.2	0.1	18.91	17.36	23.8	0.1	-0.3	15.83	14.77	22.6	0.2	0.2	14.61	13.76	20.8	0.2	0.1	12.82	12.19	29.5	10	13.6	26.99	22.47
		Bottom	8.5	0.05	0.45	22.65	0.1	-0.7	14.20		26	-0.3	-0.1	17.51		23.7	-0.1	0.1	15.20		22.6	0.1	0.3	14.10		21	0.2	0.3	12.50		31	10.6	13.9	28.26	
	Red	Top	22.25	14.6	8.95	29.15	10.1	8.9	8.24		32.8	8.7	10	12.13		30.6	10.1	12.6	10.16		30.4	10.6	13.5	10.16		30.2	10.4	14.1	10.36		26.3	9.3	12.2	7.42	
		Middle	23.25	13.75	7.25	27.45	10.7	7.75	5.21	6.98	33.9	8.4	9.7	12.17	12.34	32	9.9	12.2	10.77	10.86	31.6	10.5	13.4	10.87	10.88	30.4	10.8	14.5	10.60	10.55	25.4	9.3	10.4	5.86	7.89
		Bottom	21.8	14.55	8.45	28.35	10.9	8.25	7.50		33	8.7	9.8	12.71		32	10	11.8	11.66		31.5	10.5	13.4	11.62		30.1	10.7	14	10.70		30	10.5	13.4	10.40	
	Yellow	Top	73.1	20.35	82.35	72.55	13	64.55	19.27		73.3	11.5	49.8	33.73		75	10.9	51.2	32.61		75	10.8	50.9	32.92		74	10.9	51.9	31.90		63.2	11.9	48.4	36.36	
		Middle	73.4	20.3	81.65	71.6	13.1	65.95	17.37	17.67	72.8	11.2	47.7	35.15	33.50	74.6	10.8	50	33.07	32.85	74.6	10.7	49.4	33.67	32.95	74.5	10.6	50.2	32.93	31.32	66.3	13.1	53.6	29.82	31.82
		Bottom	73.45	20.2	80.5	72.15	13.2	65.75	16.38		73.2	11.5	50.1	31.62		75.3	10.6	49.1	32.89		74.6	11	49.6	32.26		72.8	11.2	52.8	29.13		73.6	10.4	52.9	29.29	

Table J-8 – Color Measurement of Redimat Coupons in Condition B

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	14.1	0.8	-0.6	21.8	0	-1	7.75		25.5	0	-0.3	11.43		21.6	0	-0.2	7.55		24.9	0.2	-0.3	10.82		23.4	0.2	-0.1	9.33		21	-0.1	-0.1	6.98	
		Middle	17.2	0.3	-0.2	22.3	-0.1	-0.9	5.16	6.55	25.8	-0.2	-0.2	8.61	9.88	21.3	0.1	0	4.11	6.26	24.9	0.1	-0.4	7.71	8.82	23.8	0.1	0.2	6.62	7.56	21.4	-0.3	0	4.25	5.40
		Bottom	16.1	-0.2	-0.4	22.8	-0.1	-1.1	6.74		25.7	0	-0.1	9.61		23.2	0	-0.2	7.11		24	0.4	-0.4	7.92		22.8	0.3	-0.2	6.72		21	0.1	0.5	4.99	
	Red	Top	15.8	17	9.2	35.8	7.6	7.5	22.16		35.7	8.5	9.6	21.64		29.8	8.3	7.6	16.56		33.7	8.3	8.6	19.91		31.2	7.8	8	17.98		32.1	9.3	13.1	18.44	
		Middle	15.4	17.1	10.8	35.2	7.8	7.3	22.15	21.75	35.7	8.6	10	22.02	21.62	28.6	8	8	16.28	17.16	32.7	8.4	9.5	19.41	18.68	30	7.7	8.4	17.53	16.55	33.2	9.1	13.2	19.66	18.81
		Bottom	15.9	16.9	9.4	34.7	7.9	7.4	20.94		35.5	8.9	10.2	21.18		32.8	9.2	11	18.64		30.6	9	10.2	16.71		27.5	8.8	9.1	14.15		32.1	9.4	13.5	18.32	
	Yellow	Top	71.7	20.5	85.1	73.5	11.6	57.2	29.34		74.5	10.6	49.7	36.86		70	12.8	53.5	32.57		72	10.6	44.6	41.69		70.6	11.8	48.9	37.25		68.8	12.4	48.2	37.89	
		Middle	71.8	20.6	85.1	73.7	11.6	57.2	29.38	28.87	74	10.7	49.8	36.73	36.68	63.3	15.3	50.1	36.41	35.44	71.9	10.7	46	40.33	39.07	66	13.6	47.8	38.39	36.59	65.4	13.3	46.8	39.51	39.29
		Bottom	72	20.6	84.6	73.4	12	58.1	27.90		73.7	10.9	49.5	36.46		72.9	11.1	48.5	37.34		70.5	12.1	50.5	35.18		67.5	14.1	51.4	34.13		70.2	12.5	45	40.46	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	13.2	0.5	-0.4	22.8	-0.2	-0.7	9.63		25.5	-0.1	-0.1	12.32		21.9	0.1	-0.2	8.71		24.9	0.3	0.4	11.73		24.3	0.4	0.5	11.14		21.2	0.3	0.1	8.02	
		Middle	15.3	0.3	-0.3	23.3	-0.2	-0.7	8.03	8.46	25.6	0	-0.2	10.30	10.75	21.6	0	-0.1	6.31	7.36	25.6	0.3	-0.2	10.30	9.87	24.3	0.4	0.4	9.03	8.97	21.1	0.4	0	5.81	6.17
		Bottom	16.2	-0.6	-0.9	23.9	0	-1.1	7.73		25.8	-0.1	-0.3	9.63		23.2	0	-0.2	7.06		23.7	0.3	-0.2	7.59		22.7	0.5	0.5	6.74		20.7	0.2	0.1	4.68	
	Red	Top	19.4	13.9	7.7	35.7	7.7	7.7	17.44		36.5	7.8	11.5	18.55		29.5	8.2	8.5	11.62		33.6	8	9.5	15.48		30.6	7.6	8.6	12.88		33.1	9.5	13.4	15.48	
		Middle	20.4	13.8	6.8	35.4	7.7	7.6	16.21	17.38	36.7	8.2	11.2	17.79	18.77	29	7.8	8.6	10.64	12.82	33.2	8.6	10.3	14.25	14.68	30.1	8.1	9	11.46	12.05	33.4	9.3	13.7	15.39	15.56
		Bottom	18.5	15.4	7.8	35.3	7.7	7.6	18.48		36.9	8.3	10.9	19.96		33.1	9.3	11.2	16.18		31.2	9.3	10.2	14.29		28.2	8.9	9.5	11.80		32.2	9.8	13.4	15.82	
	Yellow	Top	71.9	20	79.8	73.5	11.6	56.4	24.91		74.7	10.3	49.3	32.13		69.8	12.7	53.9	26.99		71.9	11.4	46.5	34.39		70.4	12.1	49.6	31.25		69.4	12.4	48.5	32.31	
		Middle	72.1	20.1	81.5	73.5	11.7	56.7	26.22	25.88	75	10.3	49.9	33.21	33.39	62.4	15.4	49.7	33.58	31.92	72.8	10.9	46.7	36.00	34.96	67.1	13.6	48.5	34.00	32.51	65.4	13.8	47.1	35.61	34.67
		Bottom	71.8	20.3	82.8	73.3	11.9	57.7	26.51		74.6	10.5	49.5	34.82		74	10.7	49	35.21		71	12.1	49.3	34.50		68	13.9	51.4	32.27		70.4	12.5	47.6	36.08	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	13.5	0.4	-0.4	22.5	-0.3	-0.9	9.04		25.6	-0.1	-0.1	12.11		21.6	0	-0.2	8.11		24.6	0	-0.3	11.11		23.4	0.2	-0.1	9.91		20.9	0.1	0.4	7.45	
		Middle	16.1	-0.2	-0.7	23.5	-0.3	-1	7.41	8.80	25.5	-0.1	-0.2	9.41	11.48	21.1	0.1	0	5.06	7.93	24.6	0.1	-0.2	8.52	10.14	24.1	0.2	0.2	8.06	9.39	21.2	-0.1	0	5.15	7.04
		Bottom	12.6	0.4	-0.2	22.5	-0.1	-1	9.94		25.5	0.1	-0.3	12.90		23.2	0	-0.2	10.61		23.4	0.2	-0.4	10.80		22.8	0.3	0	10.20		21.1	0	-0.4	8.51	
	Red	Top	20.6	13.3	6.7	35.9	7.6	7.4	16.34		36.4	8	11.6	17.37		29.4	8.2	8.4	10.31		33.3	8	9.3	14.00		30.8	7.5	8.2	11.83		31.1	7.3	8.8	12.27	
		Middle	21	13.1	6.2	35.4	7.7	7.3	15.42	15.56	36.3	8.2	11.1	16.80	17.07	29.2	8.1	8.2	9.81	11.26	33.4	8	9.8	13.88	12.96	29.9	7.7	8.7	10.71	10.46	30.5	7.5	9	11.38	11.27
		Bottom	21	13.2	6.3	34.9	7.9	7.5	14.92		36.6	8.4	11.2	17.04		33.1	9.4	11.4	13.67		30.5	9.5	10.4	10.99		27.8	8.7	9.7	8.83		29.2	8.4	9.9	10.16	
	Yellow	Top	72	20.3	82.7	71.3	11.8	53.8	30.13		75.1	10.3	49.3	35.00		70	12.7	54.2	29.56		72.1	10.9	44.5	39.34		70.1	11.8	49.1	34.71		69.1	12.2	48.2	35.56	
		Middle	72.1	20.4	82.1	72.5	11.7	55	28.47	28.66	74.7	10.5	49.6	34.07	33.94	63.5	15.4	51	32.65	32.04	73.4	10.3	44.6	38.86	36.89	65.7	13.6	47.4	35.93	34.07	65.4	13.4	47	36.41	36.20
		Bottom	72.2	20.3	82	72.3	12	55.9	27.39		75.2	10.8	50.8	32.75		73.3	11	49.4	33.92		70.5	12.2	50.6	32.47		67.9	13.8	51.4	31.58		69.9	12.4	46.3	36.64	

Table J-9 – Color Measurement of Redimat Coupons in Condition C

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	13.2	0.3	-0.9	23.4	0.2	0.1	10.25		22.5	-0.3	-0.4	9.33		22.9	-0.1	-0.2	9.73		23.2	0.2	-0.1	10.03		22.3	0.4	0	9.14		21.8	-0.2	-0.5	8.62	
		Middle	15.6	0.1	-1.8	24.3	0.1	0	8.88	9.32	22.2	0	0.1	6.87	8.15	23.9	-0.1	0.1	8.52	8.60	22.9	0.2	-0.2	7.47	8.28	22	0.4	-0.1	6.63	7.27	21.8	-0.2	-0.3	6.39	6.92
		Bottom	16	-0.7	0.1	24.8	0.1	0.3	8.84		24.2	0.1	-0.1	8.24		23.5	-0.3	-0.5	7.53		23.3	-0.2	-0.2	7.32		22	-0.1	-0.1	6.03		21.7	-0.2	-0.5	5.75	
	Red	Top	16.8	16.4	8.9	34.9	8.2	9.1	19.87		31.5	7.5	10	17.22		31.1	7.8	8.9	16.69		32.6	9.4	11.2	17.43		32.8	9.6	11.4	17.56		32.9	9	11.2	17.87	
		Middle	19.1	14	5.9	34.9	8.2	8.7	17.06	19.66	30.3	7.2	8.7	13.40	16.84	32.3	7.6	9	14.99	16.72	33.7	9.2	11.2	16.26	17.70	32.3	9.5	11.6	15.07	17.23	32.3	9.1	11	14.98	17.30
		Bottom	15.4	17.7	10.6	35.2	8.2	8.6	22.05		33.1	8.6	10.2	19.91		31	7.9	9	18.49		32.8	9.2	11.7	19.40		32.5	9.4	11.9	19.05		32.4	9.2	11.9	19.05	
	Yellow	Top	71.8	20.6	87.8	70.7	13.3	61.1	27.70		68.2	12	48.1	40.78		69.9	11.6	47.8	41.04		74	9.2	42.9	46.38		74.2	9.4	45.5	43.82		75.3	8.8	46	43.57	
		Middle	71.8	20.6	86.1	69.2	14.5	61.6	25.38	26.83	64.5	15.2	51.4	35.87	37.20	69	12.5	49.8	37.30	37.99	73.4	10	45.7	41.80	43.19	74.2	10	47.4	40.20	41.52	74	9.4	46.8	40.92	41.68
		Bottom	71.8	20.7	87.1	71.5	13.3	60.7	27.42		69.6	12.9	53.1	34.95		68.1	13.5	52.4	35.63		73.5	10.2	47.1	41.39		73.5	10.5	47.9	40.54		73.8	9.8	48.1	40.54	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	14.4	-0.7	-0.1	23.9	0.3	0.2	9.56		20.8	-0.1	-0.2	6.43		23.1	-0.1	-0.3	8.72		23.5	0	-0.4	9.13		22.2	0.2	-0.1	7.85		22.2	0	-0.1	7.83	
		Middle	13.9	-0.3	-0.8	24.5	0.3	0.5	10.70	10.66	21.4	-0.1	0	7.55	8.02	23.8	-0.1	0	9.93	9.60	23.1	0	-0.2	9.22	9.47	21.9	0.1	0	8.05	8.42	22.2	0.1	-0.4	8.32	7.96
		Bottom	13.1	0.5	-1.2	24.7	0.3	0.5	11.73		23.1	0.3	0.1	10.09		23.2	-0.1	-0.4	10.15		23.1	-0.1	-0.5	10.04		22.4	0.1	-0.1	9.37		20.8	0.5	-0.6	7.72	
	Red	Top	16.5	16.5	8.5	34.5	8.6	9.3	19.67		30.5	7.5	8.8	16.65		30.9	8.3	8.9	16.58		32.9	9.3	11.3	18.13		32.8	9.2	11	18.03		32.6	9.4	11.5	17.85	
		Middle	18.1	15.3	8.8	35.1	8.3	8.9	18.39	18.77	29.5	7.6	9.2	13.76	15.51	31.7	7.7	8.9	15.58	15.78	33	9.1	11.3	16.33	17.35	32.4	9.5	11.2	15.62	16.70	31.8	9.5	11.1	15.05	16.41
		Bottom	17.7	16.3	8.6	34.3	8.8	9.7	18.25		32	9.2	10.8	16.12		30.3	7.8	8.6	15.20		33.3	8.9	11.9	17.58		32.3	9.3	11.5	16.45		32.2	9.5	11.8	16.33	
	Yellow	Top	71.7	20.6	83.2	70.8	12.9	59.3	25.13		68.2	12.6	50.9	33.46		69.2	11.9	48.2	36.15		74.2	9.4	43.6	41.23		74.5	9.5	46.1	38.83		74.7	8.9	45.5	39.59	
		Middle	68.8	20.3	75.4	70.2	13.3	58.2	18.62	23.45	62.8	15.1	49.1	27.47	31.86	67.1	13.2	50.2	26.24	31.61	73.3	10.1	46.4	31.07	36.95	74.3	10	47.6	30.15	35.44	74.6	9.2	46.2	31.77	36.38
		Bottom	71.8	20.8	84.4	71.2	12.6	59.1	26.60		69.9	12.6	50.8	34.64		68.8	13.2	53	32.45		74.2	10.2	47.4	38.56		74	10.4	48.6	37.34		73.9	9.9	48.3	37.77	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	11.7	0.2	-0.2	25.4	0.2	-0.1	13.70		21.5	0.1	0	9.80		23.8	0	-0.3	12.10		23.2	0	-0.1	11.50		22.1	0.1	0.1	10.40		21.9	0.2	-0.6	10.21	
		Middle	12.8	-0.3	-0.6	24.7	0.2	0.1	11.93	12.41	22.2	0.2	-0.1	9.43	9.61	23.9	-0.1	-0.1	11.11	11.17	22.7	0	0.1	9.93	10.48	21.7	0.2	0	8.93	9.52	21.6	0.3	-0.4	8.82	8.95
		Bottom	13	0.1	-0.2	24.6	0	0.2	11.61		22.6	0.3	0	9.60		23.3	-0.2	-0.5	10.31		23	-0.1	-0.7	10.01		22.2	-0.3	-0.2	9.21		20.8	0.4	-0.5	7.81	
	Red	Top	14.7	17.9	10.9	34.8	8.1	9.1	22.43		29.6	8.1	9	17.93		31.5	8	8.7	19.62		32.8	9.3	11	20.04		32.7	9.3	11.5	19.96		32.5	9.1	11.5	19.87	
		Middle	19.7	14.2	6.4	35.1	8.4	9.1	16.68	20.48	29.3	7.9	9.3	11.84	16.20	31.1	7.6	9	13.43	17.09	33.4	9.2	11.3	15.39	18.41	32.3	9.6	11.3	14.28	17.72	31.8	9.6	11.4	13.88	17.78
		Bottom	15.4	17.4	9.4	35.6	7.9	8.8	22.33		32.2	9	10.6	18.82		31	8	8.8	18.22		33.3	9.2	11.6	19.81		32.4	9.5	12	18.93		33	9.3	12.3	19.59	
	Yellow	Top	71.7	20.8	88.1	70.9	12.7	59.4	29.83		68.8	12.3	51.1	38.07		70.2	11.3	48.1	41.14		74.3	9.3	43.3	46.33		74.2	9.3	45.5	44.20		74.8	8.8	45.6	44.27	
		Middle	71.8	20.7	86.2	70.1	13.2	59.5	27.79	28.72	64.6	14.7	51.5	35.94	36.01	69.2	11.7	48.1	39.23	38.03	73.8	9.5	44.8	42.93	43.30	74.3	9.4	45.4	42.41	42.27	74.1	9.2	45.8	42.07	42.05
		Bottom	71.9	20.7	86.2	71.8	12.7	58.8	28.54		70.7	12.5	53.2	34.02		68.5	13.2	53.5	33.72		73.7	10.1	47	40.65		73.6	10.3	47.4	40.21		73.8	10	47.9	39.81	

Appendix-J(d)

SafeRoute (Polyolefin) Products

Table J-10 – Color Measurement of SafeRoute Coupons in Condition A

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1		Top	22.1	0.8	-0.9	23.6	0.4	-0.6	1.581		23.3	0.9	-1	1.208		24.2	0.6	-0.9	2.110		29.8	0.2	-2	7.801		31.9	0.2	-1.5	9.837		32.2	0.3	-2.3	10.209	
	Black	Middle	22	0.4	-0.3	23.7	0.5	-0.2	1.706	1.647	22.3	0.6	-0.6	0.469	0.822	23.4	0.7	-1.4	1.806	1.968	28	0.4	-1.8	6.185	7.206	33.4	-0.1	-2.4	11.603	10.377	31.2	0.1	-2.7	9.513	9.739
		Bottom	22.1	0.1	-0.6	23.7	0.4	-0.3	1.655		22.8	0.3	-0.3	0.787		24	0.4	-1.1	1.987		29.6	0.3	-2	7.632		31.6	0.4	-2.5	9.693		31.4	0.3	-2.5	9.494	
		Top	38.5	15.5	12.2	46.8	29.6	22.7	19.441		38.9	16.2	13.4	1.446		38.9	16.1	13	1.077		39.3	16.1	12.9	1.221		39.2	16.4	13.6	1.806		39.1	16	13.4	1.432	
	Red	Middle	36.2	17.4	14	46.9	29.7	22.3	18.294	18.571	38.8	17.6	14.2	2.615	1.670	38.5	17.5	13.7	2.322	1.506	39.6	16.7	12.8	3.673	2.497	41.7	15.7	11.6	6.237	4.447	42.8	14.9	10.5	7.878	5.434
		Bottom	35.9	17.7	14.9	46.7	29.9	22.5	17.979		36.7	18.2	15	0.949		37	17.9	14.9	1.118		38.2	17.2	13.8	2.598		40.3	16.3	12.3	5.299		41.6	15.5	11.5	6.992	
		Top	69.2	16.8	57.4	75.2	11.7	59.3	8.101		68.3	16.4	55	2.594		67.9	16.3	53.5	4.141		67.5	16.3	52	5.683		67.4	16.1	51	6.685		67.1	16.3	50.7	7.039	
	Yellow	Middle	71.1	16.7	57.9	74.9	12	59.7	6.306	7.757	71.5	16.4	56.2	1.772	2.002	71.2	16.6	55	2.903	3.428	71.5	16.6	53.8	4.121	4.774	70.4	16.4	52.1	5.850	6.185	70.9	16.3	51.8	6.116	6.688
		Bottom	68.4	16.5	56.4	75.2	12.1	60	8.863		68.7	16.3	54.8	1.640		68	16.2	53.2	3.239		68	16.4	51.9	4.519		68.7	16.1	50.4	6.021		68.3	16.2	49.5	6.907	

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2		Top	22.7	0	0.3	24	0.2	-1.1	1.921		22.6	0.7	-0.3	0.927		24.4	0	-0.6	1.924		29.8	0	-1.7	7.376		32.4	0	-0.8	9.762		33	-0.2	-1.8	10.514	
	Black	Middle	23.7	0.5	-0.4	24.4	0.3	-0.7	0.787	1.331	24	0.4	-0.2	0.374	0.508	24.4	0.2	-1	0.970	1.162	32	0.2	-2.4	8.543	7.344	36.6	0	-2.7	13.113	10.926	35.3	-0.1	-2.8	11.861	10.515
		Bottom	23.6	0.4	-0.3	24.6	0.3	-1.1	1.285		23.8	0.5	-0.3	0.224		23.9	0.5	-0.8	0.592		29.5	0.4	-1.9	6.113		33.3	0.4	-2.3	9.904		32.5	0.6	-2.5	9.170	
		Top	35.9	18.3	15.5	46	29.4	22.2	16.435		36.4	18.6	15.9	0.707		36.3	18.1	15.3	0.490		37.4	17.7	14.8	1.761		38.6	16.8	14.3	3.314		39.8	16.3	13.5	4.818	
	Red	Middle	36.7	18	14.9	46.1	30	22.5	17.033	16.911	37.4	18.4	15.7	1.136	1.096	37.6	18.3	15	0.954	0.894	38.2	18	14.8	1.503	1.662	38.8	17.5	14.4	2.216	2.833	39.9	17.1	13.6	3.569	4.022
		Bottom	36.9	17.8	14.6	46.6	29.7	22.5	17.266		38.2	18	15.2	1.446		38	18.2	15	1.237		38.6	18	14.8	1.723		39.8	17.4	14.1	2.970		40.2	16.7	13.4	3.680	
		Top	67.9	16.7	56.5	75.5	11.5	58.3	9.383		68.5	16.3	55.4	1.315		67.9	16.4	54.1	2.419		68	16.5	53.1	3.407		67.9	16.3	52.2	4.319		67.9	16.5	51.7	4.804	
	Yellow	Middle	71.2	16.6	57.6	75.8	11.6	57	6.821	7.527	71.4	16.3	55.8	1.836	2.055	71.2	16.3	54.7	2.915	2.824	71.4	16.4	53.4	4.210	4.538	71.3	16.3	52.8	4.810	5.761	71.9	16.6	52.5	5.148	5.936
		Bottom	71	16.6	57.7	75.3	11.9	58	6.377		69.2	16.3	55.3	3.015		70.1	16.4	54.7	3.138		68.4	16.4	52.3	5.997		68.7	16	49.9	8.154		70.1	16.3	49.9	7.857	

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3		Top	22.6	0.6	-1	23.8	0.1	-1.1	1.304		22.9	0.4	-0.6	0.539		24.3	0.4	-1	1.712		29.5	0.4	-1.8	6.949		30.2	0.6	-1.7	7.632		30.6	0.7	-1.9	8.051	
	Black	Middle	22.6	0.9	-1.2	24.1	0.4	-0.6	1.691	1.712	22.6	1	-0.3	0.906	0.707	23.5	0.5	-0.5	1.208	1.373	28	0.5	-2	5.474	5.739	31.7	0.4	-2.2	9.168	8.879	30.4	0.8	-2.6	7.925	8.349
		Bottom	22.1	0.1	-0.4	24.2	0.4	-0.7	2.142		22.7	0.2	-0.1	0.678		23.3	0.1	-0.4	1.200		26.8	0.4	-1.3	4.795		31.8	0.4	-2	9.836		31	0.5	-2.1	9.070	
		Top	36.1	18.2	14.7	46.3	29.4	22.2	16.904		38.8	17.4	14.2	2.860		38.8	17.3	13.8	2.985		39.4	17.2	13.7	3.590		40.1	16.7	13.5	4.437		40.7	16.7	13.1	5.096	
	Red	Middle	35.9	18.3	15.1	46.6	29.7	22.5	17.298	17.442	37.8	18.3	15.2	1.903	2.426	37.9	18	14.6	2.083	2.310	38.9	17.6	13.9	3.306	2.591	40.6	16.6	12.6	5.588	4.519	41.9	16.2	12	7.072	5.861
		Bottom	37.7	17.1	13.5	46.2	30.2	22.7	18.125		37.3	18.7	15.4	2.516		37.4	18.4	14.8	1.863		38.3	17.6	13.9	0.877		41.1	16.8	12.6	3.530		42.5	15.9	11.3	5.415	
		Top	68	16.8	56.4	76.1	11.5	59.7	10.227		68.2	16.3	55.5	1.049		69.4	16.7	55.5	1.667		68.1	16.7	54.5	1.905		67.9	16.5	53.9	2.520		67.9	16.7	53.5	2.903	
	Yellow	Middle	71.2	17	58.2	75.4	12.3	60.6	6.745	9.179	71.4	16.3	57.3	1.158	1.110	71.6	16.6	56.6	1.697	2.063	71.1	16.8	56	2.211	2.014	69.7	19.3	54.8	4.370	3.431	71.7	16.9	55.6	2.650	2.723
		Bottom	68.2	16.6	55.6	76.4	12.2	60.6	10.564		68.1	16.1	54.6	1.122		71	16.3	55.4	2.823		67.9	16.5	53.7	1.926		71.5	16.4	54.8	3.401		67.9	16.6	53	2.617	

Table J-10 – Continued

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 4	Black	Top	21.6	0.6	-0.8	23.9	0.2	-0.9	2.337		22.6	0.4	-1	1.039		23.7	0.3	-1.5	2.234		31.5	0.2	-2.1	9.993		31.6	0.3	-2.1	10.089		31.1	0.2	-2.4	9.642	
		Middle	22	0	-0.7	23.3	0.2	-0.9	1.330	1.924	22.7	0.1	-0.5	0.735	0.791	23	-0.1	-0.9	1.025	1.594	29.8	-0.2	-2.1	7.927	9.283	33.7	0.2	-2.1	11.785	10.953	32	0	-2.6	10.179	10.191
		Bottom	22.2	0.4	-0.6	24.3	0.3	-0.7	2.105		22.8	0.4	-0.6	0.600		23.6	0.4	-1.2	1.523		32	0.3	-2.2	9.930		33	0.5	-2.6	10.984		32.8	0.4	-2.4	10.752	
	Red	Top	36.7	17.8	13.9	47.4	30	23.1	18.654		36.8	18.2	15.3	1.459		37.2	17.4	14.3	0.755		38.1	17.3	14	1.490		38.5	16.9	14.5	2.100		39.3	16.6	13.8	2.865	
		Middle	37.9	17	13.2	47.3	30.8	23.4	19.566	18.663	38.5	17.5	14.3	1.349	1.351	38.1	17.2	13.6	0.490	0.688	38.8	16.9	13.4	0.927	1.376	41.6	16.1	12.2	3.937	3.806	41.1	15.8	12.4	3.510	3.758
		Bottom	36.8	18.2	14.9	46.4	30.5	23.4	17.768		37.7	18.7	15.6	1.245		37.5	18.5	15.2	0.819		38.5	18.2	14.7	1.712		41.5	16.3	13.1	5.380		41	16.8	12.8	4.900	
	Yellow	Top	71.6	16.8	57.9	76.5	11.7	59.9	7.350		71.6	16.4	55.5	2.433		68.9	16.6	52.7	5.863		71.7	16.8	52.7	5.201		72.8	16.6	51.4	6.613		72.6	16.3	50.3	7.682	
		Middle	69	16.5	55.1	75.4	12	59.9	9.179	7.857	71.9	16.2	55.2	2.917	2.490	71.7	16.3	54	2.922	4.147	71.9	16.5	53.2	3.467	4.625	71.7	16.2	51.6	4.431	6.666	71.7	16.1	51.3	4.679	7.209
		Bottom	71	16.8	58.2	75.6	11.9	60.3	7.041		72	16.3	56.4	2.119		71.5	16.4	54.6	3.657		71.2	16.6	53	5.208		71.4	15.9	49.3	8.954		72.5	15.9	49.1	9.267	

	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 5	Black	Top	21.3	0.3	-0.3	23.5	0.6	-1	2.328		21.9	0.2	-0.4	0.616		22.1	0.1	-0.9	1.020		28.3	0.3	-1.9	7.181		31.7	0.1	-1.9	10.524		31	-0.1	-2.4	9.933	
		Middle	22.6	0.5	-0.8	23.1	0.3	-0.9	0.548	1.875	22.9	0.4	-0.7	0.332	0.677	23.8	0.5	-1.1	1.237	1.254	30.3	0.3	-2	7.796	7.817	32.7	0.7	-2.3	10.213	10.724	31.9	0.2	-2.9	9.539	9.884
		Bottom	21.5	0.1	-0.8	24.2	0.2	-0.3	2.748		22.5	0.2	-0.4	1.082		23	0	-0.7	1.507		29.9	0.3	-1.9	8.474		32.8	0.5	-2.5	11.434		31.5	0.2	-2.7	10.179	
	Red	Top	38.1	16.6	13	46.4	30.2	23.1	18.864		38.7	16.9	13.6	0.900		38.1	16.3	13.2	0.361		38.7	16.4	13.4	0.748		38.6	16.4	14	1.136		39.4	16	13.6	1.552	
		Middle	37.4	17.3	13	46.5	29.3	22.2	17.648	18.309	37.5	17.8	14.5	1.584	1.113	37.1	17.2	14.3	1.338	0.736	38.6	17.1	13.2	1.233	0.912	39.5	16.2	13	2.371	1.860	39.9	15.9	12.7	2.881	2.641
		Bottom	37.1	17.3	14.1	46.2	30.4	23.3	18.414		37.4	17.3	14.9	0.854		37.2	16.9	14.4	0.510		37.8	17.1	14.3	0.755		38.9	16.4	13.6	2.074		40.1	16.2	12.7	3.489	
	Yellow	Top	71.1	16.9	58.3	74.6	11.4	58.5	6.522		71.1	16.5	56.6	1.746		70	16.5	54.8	3.691		70.2	16.7	54.1	4.300		70.3	16.4	53.3	5.088		70.5	16.4	53.1	5.258	
		Middle	71.2	16.9	58.2	75	10.9	57.5	7.137	7.382	71.2	16.5	56.4	1.844	1.912	67.7	16.4	53.5	5.881	4.287	67.8	16.5	52.6	6.564	5.356	70.9	16.4	52.7	5.531	5.548	69.6	16.1	51.5	6.935	6.950
		Bottom	68.7	16.7	56.1	75	11.5	58.4	8.486		68.2	16.1	54.1	2.147		68	16.4	52.9	3.289		67.7	16.4	51	5.206		68.5	16.2	50.1	6.024		68.3	15.8	47.5	8.656	

Table J-11 – Color Measurement of SafeRoute Coupons in Condition B

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	21.8	0.2	-0.6	21.8	0.1	-0.3	0.316		23.1	0	-0.7	1.319		24.5	0.3	-1.6	2.881		33.8	0.2	-3.2	12.278		30.8	-0.1	-2.6	9.224		30.3	0	-2.3	8.671	
		Middle	22.2	0.5	-0.4	21.6	0.7	-0.3	0.640	0.555	23	0.6	-0.8	0.900	1.384	25.7	0.2	-1.7	3.746	3.478	30.6	0.4	-2.5	8.659	9.739	27.6	0	-1.4	5.515	8.150	29	-0.3	-1.6	6.951	8.639
		Bottom	22.3	0.7	-0.7	22.8	0.3	-1	0.707		24.1	0.2	-1.2	1.934		26	0.3	-1.5	3.807		30.3	0.3	-2.8	8.281		31.7	-0.1	-3	9.710		32.4	0.1	-2.6	10.295	
	Red	Top	37.7	17.8	14.7	38.4	17.9	15	0.768		39	17.5	14.8	1.338		39.3	17.7	14.6	1.606		40	17.5	14	2.423		41.5	17.1	14.4	3.876		43.2	16.1	13.2	5.949	
		Middle	38.1	16.8	13.3	38.7	16.9	13.5	0.640	0.732	39	16.6	13.5	0.943	1.189	38.7	17.5	14.2	1.288	1.567	38.8	17.9	14.6	1.841	1.961	42.6	16	11.7	4.843	4.369	46.5	14.3	9.9	9.401	8.512
		Bottom	38.3	16.8	13.3	38.9	16.9	13.8	0.787		39.1	16.9	14.3	1.285		38.6	17.9	14.7	1.806		39.2	17.7	14.3	1.619		42.2	15.9	11.5	4.389		47	13.7	9	10.188	
	Yellow	Top	70.2	17	57.6	70.2	16.5	56.9	0.860		71.2	16.5	57	1.269		69.8	16.4	57.2	0.825		68.6	16.6	55.1	2.995		70.7	16.4	54	3.684		68.5	16.1	52.6	5.357	
		Middle	68.4	16.8	56.4	71.9	16.5	57.8	3.782	2.085	71.2	16.5	57.5	3.023	2.029	70.1	16.9	58	2.337	1.608	68.6	16.6	54.5	1.921	2.537	70.8	16.6	53.6	3.693	4.645	71.8	15.9	51	6.444	6.687
		Bottom	69.5	17.2	57.7	68.5	16.8	56.5	1.612		68.6	16.8	56.2	1.794		69.7	16.8	56.1	1.661		68.8	17.1	55.1	2.694		68.8	16.7	51.2	6.557		68.9	16.4	49.5	8.261	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	23.4	0.9	-0.1	23.2	0.9	-0.4	0.361		27	0.4	-1.4	3.860		27.4	0.4	-1.7	4.337		35.5	0.2	-2.9	12.439		35.8	-0.1	-3.6	12.923		32	0.4	-2.6	8.970	
		Middle	23.2	0	-0.3	22.3	0.4	0	1.030	0.620	24.5	0.4	-0.7	1.418	2.279	26.9	0.2	-1.5	3.895	4.197	41.1	-0.1	-4	18.279	17.269	32.3	-0.1	-3	9.493	10.718	31.5	0.2	-2.8	8.671	8.900
		Bottom	23.4	0.7	-0.6	23.6	0.4	-0.9	0.469		24.9	0.4	-0.9	1.559		27.6	0.3	-1.7	4.360		44.1	-0.3	-4.5	21.088		32.7	0	-3.4	9.738		32.2	0.2	-2.7	9.061	
	Red	Top	38.5	17	13.1	39.1	16.9	13.3	0.640		39.4	16.9	13.5	0.990		39.7	17	14	1.500		40.2	17.1	14	1.926		42.2	16.3	12.6	3.799		44.2	15.5	11.5	6.107	
		Middle	37.4	17.7	14.2	37.9	17.8	14.6	0.648	0.609	38.1	17.8	14.6	0.812	1.040	38.4	18.2	15.1	1.435	1.703	38.2	18.4	15.4	1.603	2.054	40.6	16.9	13.2	3.447	5.591	43.8	15.5	11.3	7.363	9.875
		Bottom	38.8	17	13.6	38.5	17.4	13.8	0.539		39.9	16.8	14.3	1.319		40.8	17.3	14.4	2.175		41.4	17.1	14	2.632		46.7	14	9.2	9.527		52.5	11.8	6.8	16.155	
	Yellow	Top	70.1	17.5	58	70.9	17.2	58.6	1.044		70.3	17.1	58.1	0.458		69.1	16.9	57.1	1.473		68.6	17.2	55.5	2.931		68.7	16.9	54	4.280		71.5	17	55.4	2.995	
		Middle	70.2	17.3	58.2	71.5	17.1	58.6	1.375	1.485	71.4	17.1	58.7	1.315	1.047	69.3	17	57.7	1.072	1.630	68.6	17.1	55.3	3.318	3.482	69	17	52.7	5.637	6.385	70.5	16.8	52.1	6.128	7.181
		Bottom	69.6	17.2	57.2	68.6	16.7	55.5	2.035		69.9	16.9	55.9	1.367		68.9	16.8	55	2.343		68.8	16.8	53.1	4.196		70.9	16.3	48.1	9.236		70.6	15.8	44.9	12.420	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	22.7	0.6	-0.6	23	0.6	-0.5	0.316		23.7	0.5	-1	1.082		24.7	0.3	-1.4	2.175		31.7	0.4	-2.4	9.180		32.8	-0.2	-2.7	10.347		31	0	-2.7	8.583	
		Middle	22.7	0.1	-1.2	22.4	0.4	-1.2	0.424	0.700	23.1	0	-1.1	0.424	0.967	26.4	0.3	-1.8	3.754	2.650	34	0.2	-2.8	11.413	10.206	27.6	-0.1	-2	4.969	7.871	29	-0.5	-1.7	6.348	8.202
		Bottom	23.3	0.3	-0.9	22.9	0.8	0.3	1.360		24.6	0.2	-0.4	1.396		25.3	0.3	-1.2	2.022		33.1	0.4	-3	10.023		31.4	0.4	-2.7	8.298		32.9	0.4	-2.1	9.675	
	Red	Top	36.9	17.8	14.5	37.1	17.8	14.6	0.224		37.7	17.8	14.7	0.825		38.2	17.9	14.8	1.338		38.9	18.2	15.1	2.126		40.6	17.3	13.8	3.799		40.9	16.7	13	4.411	
		Middle	37.2	17.4	13.8	37.5	17.6	14	0.412	0.464	37.8	17.6	14.1	0.700	0.887	37.9	18.1	15	1.556	1.491	38.5	17.9	14.6	1.606	1.708	40.8	16.7	13	3.754	3.870	43.4	15.4	11.2	7.014	6.714
		Bottom	36.9	17.7	14.3	37.4	18.1	14.7	0.755		37.7	18.1	15	1.136		37.7	18.5	15.4	1.578		37.7	18.4	15.2	1.393		40.6	16.8	12.9	4.057		44.4	15.1	10.7	8.716	
	Yellow	Top	69.7	17	58.3	70.9	16.8	58.4	1.221		71	16.9	58.3	1.304		69	16.5	56.9	1.643		68.5	16.7	57.1	1.723		68.2	16.5	56.8	2.179		71.2	16.6	58.4	1.556	
		Middle	69.8	16.5	56.8	71.8	16.3	57.2	2.049	2.036	69	16.4	56.2	1.005	1.843	68.6	16.3	56.5	1.253	2.313	68.6	16.3	56.7	1.221	2.334	68.6	16.2	56.4	1.300	2.323	71.3	16.1	56.6	1.565	2.247
		Bottom	70.3	17.4	58.4	69.4	16.7	55.8	2.839		69.3	16.8	55.4	3.219		69.5	16.7	54.5	4.042		69.3	16.9	54.5	4.057		72.2	17	55.5	3.490		72.1	16.9	55.3	3.619	

Table J-12 – Color Measurement of SafeRoute Coupons in Condition C

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	22	0.2	-0.5	24.5	0.3	-0.7	2.510		34.3	0	-3	12.553		34.3	0.2	-3.2	12.593		34.6	-0.4	-2.6	12.788		33	0	-2	11.104		34.3	0.2	-3.6	12.685	
		Middle	22.5	0.5	-0.1	25.3	0.9	-0.5	2.857	2.159	32.1	0	-2.4	9.884	9.753	35.8	0.2	-3.3	13.683	13.686	38.5	0	-3.3	16.325	16.673	33.7	0.1	-2	11.367	11.328	33.6	0.9	-3.4	11.587	12.152
		Bottom	22.8	0.4	-0.6	23.9	0.3	-0.5	1.109		29.4	0.1	-2.3	6.822		37.4	0.1	-2.9	14.783		43.4	-0.3	-4.1	20.907		34.1	0.3	-2.8	11.513		34.8	0.6	-2.7	12.184	
	Red	Top	36.9	17.6	14.2	39.1	17.9	14.6	2.256		40.6	17.5	13.9	3.713		40.7	16.6	13.5	3.991		43.7	15.4	12	7.478		49.4	13	8.7	14.410		67.5	7.4	2.8	34.211	
		Middle	37.2	17.1	13.3	39.9	16.6	13.4	2.748	2.449	40.5	16.7	13.4	3.326	3.060	41.3	16.5	13	4.155	4.743	43.4	15.4	11.7	6.625	7.135	48	13.8	9.4	11.947	13.947	62.9	8.2	3.9	28.776	28.258
		Bottom	37.6	17.2	13.6	39.6	16.2	12.9	2.343		39.7	16.8	13.7	2.140		43.6	16.4	13	6.083		44.3	15.2	11.5	7.301		51.1	12.2	7.9	15.484		56.7	10.2	5.8	21.786	
	Yellow	Top	69.9	17.5	58.8	69.2	17.3	55.9	2.990		71.1	17.1	55.4	3.628		70.1	17.3	56.5	2.317		69	17	56.1	2.890		69.4	17.3	56.1	2.753		69.6	16.2	50.6	8.308	
		Middle	68.7	17.3	57.6	69	17.4	56.5	1.145	2.159	68.8	17.1	55.9	1.715	2.322	68.9	17	55.6	2.032	1.764	68.8	16.8	55.7	1.967	2.644	69.5	17.2	55.7	2.064	2.596	68.9	16.8	54.5	3.146	4.327
		Bottom	68.4	16.7	56.3	70.4	17.4	57.3	2.343		70	16.9	56.5	1.625		68.8	17	55.5	0.943		71.4	17	56.9	3.074		71.3	17.1	56.8	2.970		68.2	16.5	54.8	1.526	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	22.1	0.4	-0.9	24.3	-0.2	0.3	2.577		33.4	-0.1	-2.6	11.438		35	0.2	-3.2	13.105		35.9	-0.3	-2.5	13.910		33.6	-0.3	-2.2	11.594		33.4	0.4	-2.9	11.476	
		Middle	22.6	0	-0.8	23.1	0.5	-0.7	0.714	1.388	32	0.1	-2.8	9.611	10.579	38.5	0	-3.8	16.181	13.136	40.1	-0.6	-3.7	17.749	16.170	34.4	0.1	-3.2	12.042	11.936	31.9	0.3	-3.2	9.609	10.824
		Bottom	21.9	0.5	-0.9	22.5	0.3	-0.3	0.872		32.4	-0.1	-2.8	10.687		31.8	0.3	-3	10.122		38.6	0	-3.1	16.852		34	0.7	-2.2	12.171		33.1	-0.3	-2.8	11.388	
	Red	Top	36	17.7	14.5	38.4	18.1	14.8	2.452		39.7	17.8	14.2	3.713		40.9	17.1	13.3	5.080		47.9	13.9	9	13.649		54.5	11.7	6.8	20.917		66.5	7.9	3.4	33.904	
		Middle	37.4	17.2	13.9	38.1	18.4	15	1.772	1.740	39.1	18.1	14.5	2.015	2.348	39.4	17.8	14.4	2.147	2.968	43.5	15.6	11.3	6.821	8.274	49	13.4	8.6	13.308	15.055	63.2	8.7	4	28.912	28.441
		Bottom	39.1	16.5	13.3	38.6	17.2	13.8	0.995		38.8	17.5	14.1	1.315		39.5	17.7	14.4	1.676		43.3	16.2	12.2	4.352		49.2	14.7	9.5	10.940		59.1	10.1	5.2	22.507	
	Yellow	Top	71	17.5	57.5	69.6	16.5	53.8	4.080		71.1	16.1	53.8	3.957		70.2	16.4	53.8	3.942		72.4	16.4	55.1	2.988		72.4	16.9	55.5	2.514		72.3	15.8	50	7.799	
		Middle	71	17.6	57.7	70.8	16	53.8	4.220	4.534	71.6	15.8	53.3	4.792	4.872	73.1	16	53.6	4.876	4.653	73.1	15.9	53.2	5.249	4.510	73.1	15.6	51.7	6.664	5.394	71.2	15.1	46.1	11.868	11.626
		Bottom	68.5	17.1	56.5	69.6	15.4	51.6	5.302		72.2	15.6	52.2	5.868		69.8	15.8	51.7	5.140		72.9	16.2	53.7	5.292		73.9	15.6	52.3	7.004		71	14.1	41.8	15.210	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	22.8	-0.1	-0.4	24.7	0.5	-0.4	1.992		33.5	-0.4	-2.9	10.992		36.1	0	-3.3	13.613		35	0	-3.4	12.564		32.4	0.1	-3	9.948		31.2	0.8	-2.5	8.705	
		Middle	24.3	0	-0.9	22.7	0.3	-0.5	1.676	1.650	25.5	0.4	-1.3	1.327	5.110	36.6	-0.1	-3.1	12.496	12.396	38.5	0.1	-3.3	14.402	14.991	32.6	0.7	-2.7	8.522	9.262	32.1	0.2	-2.9	8.055	8.633
		Bottom	24.8	0.4	-0.7	23.6	0.8	-0.5	1.281		27.7	0.5	-1.5	3.010		35.8	0.2	-2	11.078		42.6	0	-3.4	18.008		33.9	-0.8	-2.3	9.317		33.5	0.4	-3.5	9.139	
	Red	Top	37.1	17.5	13.8	38.2	17	13.8	1.208		40.7	15.6	12	4.451		39.7	17.5	13.9	2.602		44.4	15.4	11.5	7.937		52.4	12.1	7.8	17.299		66.7	7.8	3	32.968	
		Middle	37.2	17.1	13.7	38.5	17.1	14	1.334	1.226	39.6	16.7	13.5	2.441	2.812	39.5	17.3	14	2.328	2.819	41.6	16.3	12.9	4.543	5.970	46.6	14.2	10.2	10.441	12.667	68.1	7.3	2.8	34.200	29.805
		Bottom	37.2	17	13.3	38.3	16.8	13.5	1.136		38.7	16.7	13.5	1.543		40.7	16.6	13.1	3.528		42.4	15.8	12.3	5.430		46.3	13.7	9.9	10.260		56.8	10.4	5.1	22.248	
	Yellow	Top	70.6	17.5	58	71.6	17	56.7	1.715		70.9	16.8	56.2	1.954		72.1	17.1	57	1.847		72.2	16.9	57.4	1.811		71.6	16.8	57.2	1.459		70.9	16.8	55.7	2.423	
		Middle	70.7	17.4	58.7	71.5	17.4	57.7	1.281	1.693	70.3	16.9	56.4	2.387	3.719	71.7	17.4	57.1	1.887	2.399	71.5	16.8	57	1.972	2.583	71.3	17	56.5	2.315	1.811	69	16.9	54.7	4.375	4.501
		Bottom	70.8	17.3	58.1	69.5	17	56.5	2.083		69.7	16	51.5	6.816		68.8	16.9	55.3	3.464		68.4	16.7	55	3.966		71.5	17.2	56.6	1.658		68.2	16.3	52	6.706	

Appendix-J(e)

Armor-Tile (Epoxy) Coupons

Table J-13 – Color Measurement of Armor-Tile Epoxy Couples in Condition A

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	6.4	1.4	0.2	5.3	4.5	-4.8	5.985		5.2	4.6	-9.6	10.379		6.6	-0.3	1.5	2.149		5.5	2.4	-5.2	5.565		6.9	-0.3	0.3	1.775		6.7	2.4	-1.4	1.910	
		Middle	4.8	2.6	-0.8	4.9	4.2	-7	6.404	5.203	5	1.3	-3.5	3.003	6.450	5.8	0.1	1.1	3.295	3.079	5.6	2.4	-4.2	3.499	5.513	6.9	0.3	-1.3	3.154	2.765	5.9	2.7	-2.6	2.112	2.045
		Bottom	8.3	2	1.2	6.5	2.6	-1.4	3.219		6.5	1	-4.4	5.967		5.6	-0.2	2.7	3.792		6.5	3.5	-5.9	7.477		7.8	0.2	-1.6	3.366		8.2	2.2	-0.9	2.112	
	Red	Top	14.5	17.5	12.1	16.3	19	15	3.728		15.9	17.2	12.1	1.432		16.3	17.2	8.7	3.859		16.8	17.9	10.5	2.830		16.2	16.6	6.2	6.206		17.5	17	9.2	4.202	
		Middle	14.1	16.9	12.6	16.1	20.7	15.9	5.416	4.150	15.8	16.4	12.5	1.775	1.812	15.2	19.6	5.8	7.399	4.468	16.5	17.4	9.6	3.874	3.459	17.2	16.1	10.1	4.062	4.799	17.6	17	10.5	4.083	4.032
		Bottom	15.3	15.3	12.7	16.5	17.8	14.5	3.306		16.6	15.1	14.5	2.229		15.9	16.6	11.1	2.147		17	17.7	10.5	3.673		16.2	16.9	9	4.130		17.3	17.1	10	3.812	
	Yellow	Top	32.1	13.9	42.3	31.2	13.9	45.2	3.036		29.4	14.4	43.1	2.860		32.5	13.2	45.3	3.106		36.4	15.2	44.1	4.839		34.3	14.5	43.7	2.676		36.4	14.6	42.6	4.367	
		Middle	32.5	12.7	42.7	31.8	13.1	45.7	3.106	3.591	31.6	13.1	45.1	2.594	4.320	32.3	13.1	43.4	0.831	1.812	35.9	15.1	42.9	4.167	4.517	35.1	13.7	45.7	4.094	2.519	34.2	14.3	42.8	2.337	3.237
		Bottom	32.1	12.7	40.5	32.3	12.2	45.1	4.631		27.1	16.4	36.3	7.505		33.3	12.7	39.6	1.500		35.4	15.1	42.5	4.544		32.8	12.5	40.2	0.787		34.1	13.5	38.4	3.008	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	5.9	1.6	0.8	5.7	5.4	-6.1	7.880		7.2	1.3	-0.2	1.667		7	0.4	4.4	3.951		6.5	4	-4.2	5.579		6.9	1.1	-1.2	2.291		5.6	1.9	-3.6	4.420	
		Middle	5.2	0.5	0.6	4.5	2	-3.2	4.145	5.144	5.3	3	-7.3	8.287	6.807	7.2	1.1	2.3	2.693	2.761	5.8	1.9	-2.7	3.635	4.053	6	-0.2	-1.6	2.443	3.215	6.1	1.3	-0.8	1.847	3.070
		Bottom	5.2	0.8	0.6	6.3	3.6	2.2	3.407		6	4.1	-9.3	10.466		6.5	0	0	1.640		5.9	2.5	-1.7	2.944		6.6	1.8	-4	4.911		7.1	2.9	-0.2	2.943	
	Red	Top	16.1	15	12.6	15.6	17.6	13.7	2.867		16.2	18.6	14.3	3.982		15.9	17.9	8.3	5.190		16.4	17.5	10.5	3.279		16.7	17.1	11.4	2.492		16.7	17	11	2.631	
		Middle	16.1	16.5	11.2	16.2	17.5	13.7	2.694	4.283	16	17.6	11.4	1.122	2.344	16	17.4	8.3	3.038	3.489	16.7	17.5	11.1	1.170	2.625	17.1	17.4	11.5	1.378	2.450	15.9	16.5	10.5	0.728	2.073
		Bottom	15.8	16.9	7.8	16.1	14.9	14.8	7.286		14.5	18	6.9	1.926		15.9	17.3	10	2.238		16.5	17.5	11.1	3.426		17.3	16.4	10.9	3.480		16.3	16.6	10.6	2.860	
	Yellow	Top	32.5	14.1	35.7	33.2	15.3	41.2	5.673		26.7	15.7	36.3	6.046		33.7	14	38.7	3.233		37.5	15.6	44.5	10.232		31.5	14.2	41.9	6.281		35.7	13.7	39.5	4.984	
		Middle	32.2	15.3	34.3	34.2	15.4	44.5	10.395	10.107	31.4	14.2	40.8	6.641	8.604	34.3	14.6	40.8	6.867	6.170	34.1	14.4	42.3	8.272	10.739	29.4	14.1	39.5	6.027	7.571	32.9	12.7	37.7	4.337	7.723
		Bottom	33.2	15	29.3	32	14.7	43.5	14.254		30.3	15.1	42.1	13.125		32.4	13.9	37.6	8.411		33.3	14.4	43	13.713		34.2	13.9	39.6	10.407		35.1	14.3	43	13.849	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	4.8	6.2	-12	9.3	7.2	7.6	19.940		5.8	2.4	-3	9.637		8.3	-5	5.7	21.070		6.3	2.7	-5.1	7.706		5.6	0.6	1.5	14.453		7.2	2.6	-2.4	10.348	
		Middle	4.8	5.7	-11	8.5	7.7	7.3	19.167	18.555	5.6	1.9	-4.2	8.180	9.815	8.1	-4	3.4	18.001	17.360	5.9	2.2	-6.1	6.446	6.965	6.4	1.1	-1.8	10.765	11.691	7.9	2.5	-1.5	10.856	10.944
		Bottom	6.4	3.6	-10	8.4	4.7	6.2	16.558		5.7	-0.1	0.8	11.627		6.8	-0.9	2	13.010		6.7	2.9	-3.5	6.743		6.7	1	-0.7	9.854		8.1	3.8	1.3	11.627	
	Red	Top	16.6	17.1	9.8	17.7	20.3	16	7.063		15.8	17.5	7.9	2.100		15.6	18.2	11.8	2.492		17.4	15.8	12.4	3.015		17.3	16.8	13.9	4.170		17.3	16.9	11.6	1.942	
		Middle	16.1	17.6	10.5	17.9	19.2	15.2	5.281	6.469	16.1	17.7	11.8	1.304	1.607	16.7	17.3	10.4	0.678	1.776	17.6	14.9	12.8	3.851	3.634	17.6	16.9	11.4	1.884	2.849	17.2	17	11.3	1.487	1.607
		Bottom	15.3	17.5	10.8	17.5	20.3	16.9	7.063		16.3	17.6	11.8	1.418		15.5	19.4	11.8	2.156		17.2	14.7	13	4.036		16.8	16.9	12.7	2.494		16.6	17	10.8	1.393	
	Yellow	Top	35.5	15	42.2	31.8	14.8	40.6	4.036		30.7	14.8	43.8	5.064		32.6	14.8	42.4	2.914		35.7	15.9	46.5	4.398		34.5	14.4	41	1.673		33.1	14.2	41.3	2.685	
		Middle	33.9	13.8	39.8	32.8	14.6	41.5	2.177	2.360	26.8	15.7	37.8	7.617	6.247	31.6	15	42.5	3.744	3.631	33.9	15.1	43.1	3.547	3.804	32.7	15.2	39.3	1.910	1.659	34.2	13.1	33.3	6.544	4.770
		Bottom	33.3	14.3	41	32.6	14.8	41.1	0.866		31.4	15.1	46.7	6.061		32.8	14.5	45.2	4.234		35.2	14.3	43.9	3.467		34.5	14.2	41.7	1.393		36.3	14.2	36.9	5.081	

Table J-14 – Color Measurement of Armor-Tile Epoxy Couples in Condition B

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	6.5	4.8	3.1	4.9	1.5	-7.1	10.839		7.3	-0.8	1.9	5.783		5.6	1.2	-2	6.307		6.5	0.4	-1.2	6.152		7.1	3.2	-0.9	4.350		7.7	2.2	-1.2	5.166	
		Middle	9.1	10.1	7.3	4.9	0.8	-1.4	13.410	12.775	6.4	0.3	1.9	11.510	8.231	6.2	0.1	-0.2	12.832	10.964	5.9	1.5	-3.1	13.869	10.377	6.6	2.8	-1.5	11.704	7.768	7.5	1.9	0.1	11.029	7.847
		Bottom	8.1	8.2	4.1	5.5	3.2	-8.8	14.077		5.6	2.3	0.4	7.399		6.2	0.9	-7.4	13.753		6.4	0.9	-4.1	11.109		6.9	3.4	-1.2	7.251		7.4	2.6	-0.6	7.344	
	Red	Top	17.6	20.3	16.2	15	19.3	11.8	5.208		14.8	17.6	11.8	5.873		15.8	18.4	11.2	5.644		16.5	17.8	6	10.559		16.8	16.8	10.1	7.078		17.4	15.9	9.3	8.186	
		Middle	18.7	21	18.4	14.6	18.5	12.3	7.763	5.927	14.9	18	10.8	9.011	7.124	15.8	17.5	9.5	9.993	7.132	16.3	17.2	8.8	10.600	10.312	16.4	17.2	10.6	8.976	7.427	17.2	16.5	9.5	10.085	8.410
		Bottom	17.3	19.7	16.2	15.4	19.3	11.8	4.809		15.1	17.8	10.4	6.488		15.7	18.5	10.8	5.758		16.6	17.1	6.8	9.778		17.1	17.2	10.5	6.227		18.4	17.2	9.8	6.958	
	Yellow	Top	33.9	15.3	46.4	31	14	35.6	11.258		31.4	14.2	38.1	8.738		31.9	14.6	41.1	5.708		33.6	13.9	38.8	7.734		32.3	13.5	43.4	3.847		33.6	13.3	44.1	3.063	
		Middle	35.6	16.3	50	30.9	14.6	40	11.179	10.587	30.3	14.2	36.3	14.839	11.610	32.8	15	42.3	8.296	7.456	34.5	14.2	40.8	9.501	10.851	32.2	13.7	43.7	7.616	6.659	33.3	13.4	43.6	7.393	6.766
		Bottom	35.3	16.6	49.6	33.1	14.9	40.7	9.324		31.9	13.6	39.3	11.254		32.8	14.5	41.9	8.364		33.9	12.9	34.8	15.320		34.2	13.9	41.6	8.515		35	13.7	40.2	9.842	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	5.6	2.5	0.4	6	1.4	0.4	1.170		5.2	3.3	-2.8	3.323		5.9	2.3	-1.8	2.229		6.3	1.5	-1.8	2.516		8.3	4.1	-0.3	3.216		7.5	2.6	0.2	1.913	
		Middle	6.8	8.3	3.8	6.1	-0.8	2	9.303	6.973	5.6	1.2	-3.2	10.042	9.234	5.3	2	-2.3	8.897	8.338	6.2	0.3	-0.4	9.055	8.766	7.2	5	2.1	3.734	5.687	7	2	0.4	7.162	7.100
		Bottom	8	12.3	5.4	5.9	2.8	1.6	10.445		5.6	1.4	-3.6	14.338		5.2	1.6	-3	13.888		7.2	-1.6	0.6	14.727		7.1	3.5	0.5	10.112		6.6	1.8	-0.7	12.224	
	Red	Top	16.3	20.2	12.9	16.2	14	15.6	6.763		14.2	18.3	8.6	5.149		15.5	17.6	9	4.755		16.2	16.7	11.8	3.670		16	17	10.8	3.839		17.5	15.5	10.2	5.552	
		Middle	17.5	17.9	16.5	15.1	17	12.6	4.667	5.432	15	17.5	5.2	11.580	8.957	15.8	17.7	10.2	6.528	6.103	15.5	17.4	11.7	5.224	4.839	16.1	16.9	10.6	6.146	5.231	17.5	16.3	10	6.694	6.222
		Bottom	16.9	18.3	16.5	15.1	16.9	12.2	4.867		14.3	18	6.7	10.143		15.2	17.8	9.7	7.027		16.3	17.3	11	5.622		16.3	16.9	11	5.707		17.8	16.9	10.3	6.420	
	Yellow	Top	36.9	16.7	51.3	32.5	13.8	44.6	8.524		31	13.9	36.4	16.268		32.4	14	36.2	15.986		32.1	13.6	37.3	15.121		32.3	13.8	40.7	11.913		36	13.8	41.6	10.164	
		Middle	35.3	17.2	50.8	32.6	9.3	45.4	9.943	8.670	30.4	14.6	34.6	17.123	16.456	31.9	13.9	38.3	13.368	15.030	31.7	13.8	39	12.797	12.986	31.9	13.3	41.7	10.468	10.495	33.1	13.2	43	9.038	8.372
		Bottom	35.8	16.2	50.3	31.8	13.3	44.6	7.543		30.9	14.4	35.2	15.977		31.9	14.1	35.2	15.736		34.2	14	39.6	11.040		32.4	13.5	42.3	9.102		35	13.7	45	5.914	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	7.5	-1.4	2.3	6.5	1.8	-12	14.201		6.1	2	-1.4	5.216		6.4	0.3	-2.3	5.026		7.8	-3.8	1.6	2.518		7.6	2	1.7	3.454		7	1.5	0.1	3.674	
		Middle	7.5	11	5.6	6	4.4	-13	19.699	17.041	6.6	0.8	-5.3	14.955	12.257	5.7	2.7	-8.6	16.546	12.412	7.1	-1.7	0.9	13.548	9.346	7.5	1.9	0.7	10.335	8.310	6.7	1.5	-0.4	11.265	8.553
		Bottom	7.1	11.8	2.9	6.1	3.4	-12	17.221		8.3	-1	-7.6	16.599		6.4	2	-9.3	15.664		6.5	0.2	0	11.972		7	1.1	-0.2	11.140		6.3	1.6	-0.3	10.720	
	Red	Top	17.5	18.5	17.4	16.9	12.1	18.1	6.466		14.3	18	9.8	8.261		15.9	18	2.2	15.292		16.2	17	8.9	8.729		16.8	15.8	11.7	6.346		17.3	16.4	9.7	7.984	
		Middle	18.3	20.8	18.8	15.9	13.3	15.8	8.427	7.350	14.4	17.7	8.9	11.083	10.218	16.2	17.3	5.6	13.817	12.098	16.6	16.7	9.9	9.945	8.164	16.7	16.1	10.3	9.844	7.523	17.7	16.7	9.7	9.999	8.043
		Bottom	17.8	18.8	15.9	16.4	11.8	16.4	7.156		15.2	18.4	4.9	11.310		16.3	18.2	8.9	7.184		16.8	16	10.9	5.817		17.2	15.3	10.6	6.380		17.4	16.3	10.3	6.146	
	Yellow	Top	36.2	15.4	48.8	30.2	13.8	42.6	8.775		30.1	13.3	39.3	11.483		32.5	14.2	39.5	10.081		31.3	13.5	40.5	9.824		32.3	13.6	43.2	7.058		33.9	13.7	44.4	5.248	
		Middle	35	15.4	47.9	31	10.7	43.9	7.355	10.184	30.3	13.4	37.8	11.318	13.023	30.8	13.7	32	16.533	17.172	33	13	41.3	7.302	10.347	33.7	13.7	45.2	3.445	7.591	34.5	13.7	44.9	3.484	7.354
		Bottom	38.1	15.6	51	31.2	12.2	38.8	14.423		31	13.6	36.5	16.268		31	13.8	27.2	24.902		32.9	12.8	38.4	13.915		32.7	12.6	40.4	12.269		33.9	13.1	38.6	13.329	

Table J-15 – Color Measurement of Armor-Tile Epoxy Couples in Condition C

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 1	Black	Top	8	-2.3	-10	12.4	8.3	4.4	18.650		7.5	4.5	-6.3	7.905		6.4	2.8	-1.6	10.211		5.6	2.1	-1.1	10.477		4.6	0.9	-1.6	9.874		4.7	1.5	-0.7	10.839	
		Middle	8.6	0.8	-17	11.6	8.3	5.8	24.189	20.426	8.8	1.9	-9.5	7.583	6.952	6.9	0.8	0.4	17.483	12.336	4.3	1.5	-1.1	16.486	13.002	3.8	1	-1	16.706	13.494	5.5	2	0.2	17.518	13.861
		Bottom	8.8	-0.7	-14	8.4	4.1	4.2	18.440		7.2	4.2	-12	5.368		6.7	2.2	-5	9.316		4.8	1.2	-2.4	12.044		5	0.7	-0.3	13.903		4.6	0.3	-1.1	13.225	
	Red	Top	15.8	17.4	5.4	15.5	18.2	12.8	7.449		16.8	16.6	6.7	1.825		17.2	18	12.4	7.164		17.4	17.7	11.4	6.217		16.3	16.7	9	3.701		17.2	15.7	9.7	4.831	
		Middle	15.8	17.6	8.3	16.5	18	14.5	6.252	8.812	16.6	17.9	9.9	1.814	4.746	17	17.3	12	3.901	7.338	16.8	17.4	9.9	1.897	6.300	17.3	16.3	9.8	2.488	5.113	18	15.3	9.6	3.438	5.737
		Bottom	15.8	16.7	0.5	16.1	17.6	13.2	12.735		16.2	18.7	10.9	10.598		16.8	16.5	11.4	10.948		16.7	17.7	11.2	10.784		16.7	16.4	9.6	9.149		18	15	9	8.943	
	Yellow	Top	33.5	14.9	28	34.2	16.2	46	18.060		32.5	13.8	38	10.110		33	15	40.5	12.510		32.9	14.7	40.4	12.416		32.4	14	39.2	11.290		32.6	13.6	39.6	11.707	
		Middle	33	14.4	19.7	33.2	14.6	45.7	26.002	22.984	32.3	14.2	38.1	18.414	15.881	31.7	14.7	39.9	20.244	18.920	33.2	14.8	41.2	21.505	18.845	32.4	13.4	38.4	18.736	16.920	33.6	13.3	40.7	21.037	18.200
		Bottom	31.8	16.6	18.4	31.8	14.5	43.2	24.889		32.1	14.5	37.4	19.118		33	14.7	42.3	24.005		33.9	14.3	40.8	22.615		32.6	13.6	38.9	20.734		33.1	12.9	39.9	21.855	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 2	Black	Top	7.2	7.7	3	11.8	8.4	5.8	5.430		8.5	4.3	-2.7	6.763		8	1.2	2.1	6.611		7.5	0.1	1	7.864		7	2.6	-0.2	6.024		5.3	1.3	-0.9	7.732	
		Middle	6.4	2.6	1.2	11.6	6.8	3	6.922	5.821	8.2	4.1	-2.7	4.550	5.458	7.6	-0.4	-0.8	3.800	4.068	7.9	0.1	-0.3	3.279	4.910	7	2.6	-1.8	3.059	3.520	6.6	1.3	-1.2	2.737	3.983
		Bottom	6.1	2	-0.6	8.5	1	3.8	5.111		10.9	1.9	1	5.061		7	0.5	-0.2	1.794		7.2	2.3	-4	3.586		7.2	1.6	-1.5	1.476		6.8	0.7	-0.7	1.480	
	Red	Top	16.5	18.1	9.4	16.4	18.1	14.4	5.001		16.5	17.5	10.6	1.342		16.4	17.7	8.8	0.728		16.9	16.8	10.9	2.025		16.6	17	9.6	1.122		17.1	16.5	9	1.755	
		Middle	16.3	17.9	7.6	17.1	17.7	14.4	6.850	7.176	16.8	18.1	10.9	3.344	4.043	16.9	17.6	8.7	1.288	2.572	17.2	16.3	10	3.022	4.184	17.2	16.8	9.2	2.140	2.849	17.2	16.2	9.1	2.439	3.073
		Bottom	16.5	17.4	4.1	17.8	16.1	13.6	9.676		16.9	18.1	11.5	7.444		16.6	17.4	9.8	5.701		17.4	15.9	11.4	7.507		17.3	16.9	9.3	5.285		16.7	16.3	9	5.026	
	Yellow	Top	32.5	12.4	33.9	32.4	13.7	42.7	8.896		33.4	14.5	38.8	5.406		32.2	14.5	39.4	5.895		32.3	13.3	39.5	5.675		32.7	13.5	38.3	4.540		36.7	14.8	44.1	11.289	
		Middle	31.6	12.7	23.8	31.7	13.4	44.1	20.312	17.823	31.6	14.3	38.3	14.588	13.381	31.6	14.2	37.4	13.682	11.602	32.4	14.1	40	16.280	14.496	32.3	13.9	39.3	15.562	13.180	33.6	14	43.8	20.142	17.187
		Bottom	31.7	13.1	20.8	31.6	11.4	45	24.260		31.8	14.5	40.9	20.149		31.9	14	36	15.228		32.5	14	42.3	21.534		32.9	13.3	40.2	19.438		32.7	13.6	40.9	20.131	

Coupon	Color	Location	0hr			500hr					1000hr					1500hr					2000hr					2500hr					3000hr				
			L*	a*	b*	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)	L*	a*	b*	ΔE	ΔE(avg)
Coupon 3	Black	Top	5.9	3.1	2.6	6.2	2.3	2.7	0.860		6.2	0.8	1.4	2.612		6.3	2.7	-2.7	5.330		7.9	-2.2	1.6	5.752		6.8	1.9	-2.5	5.316		6.9	1.6	-0.3	3.415	
		Middle	7.8	-2.7	1.6	8.1	-4.4	2.9	2.161	2.462	7.7	-2.9	2.9	1.319	1.714	6	2	-2.4	6.429	6.613	7.2	0.2	-0.7	3.750	3.815	6.7	1.3	-4.2	7.131	7.194	7.3	2.6	-0.5	5.723	5.442
		Bottom	7.9	-4.1	2.3	10.5	-4.3	5.8	4.365		8	-5.2	2.8	1.212		6.6	2.8	-1.7	8.081		9	-4	3.9	1.944		6.9	1.3	-5	9.135		6.9	2.4	-0.6	7.187	
	Red	Top	16.5	15.7	13.8	15.7	17.8	13.6	2.256		17.4	13.1	14.7	2.895		15.9	17.3	8.3	5.759		16.5	17.1	12.7	1.780		16.4	16.7	10	3.931		17.4	16.3	9.3	4.628	
		Middle	17.3	15	14.7	16.9	15.9	13.9	1.269	1.962	16.9	15.9	11.4	3.444	2.810	16.6	17.4	9.4	5.860	5.310	17	17	11.5	3.785	3.168	16.9	16.9	10.2	4.901	4.614	17.7	16.3	9	5.860	5.442
		Bottom	16.5	14.2	14.4	16.2	16	12.9	2.362		17.4	13.2	12.8	2.090		17	17.6	11.8	4.309		17	17.2	11.9	3.937		16.9	16.9	10.2	5.009		17.8	16	9	5.839	
	Yellow	Top	34.9	13.6	43.6	31.9	13.2	45	3.335		33.2	14.1	44.6	2.035		32.1	14.2	36.9	7.286		33.4	14.7	43.3	1.884		33.2	14.4	41.8	2.602		33	14	45.1	2.454	
		Middle	31.9	13.1	38	32.8	11.4	45.2	7.453	5.670	32.5	13.3	42.8	4.841	4.366	33.1	14.4	39.6	2.385	4.640	32.8	14.3	39.8	2.343	3.711	33.7	13.8	39.5	2.445	3.402	33	14.1	40.8	3.170	3.742
		Bottom	31.6	12.4	35	32.1	12.6	41.2	6.223		32.3	13.4	41.1	6.221		33.3	14.3	38.4	4.250		33.7	14.3	41.3	6.907		33.6	13.6	39.6	5.158		33.3	13.6	40.2	5.601	

<u>Appendix-K</u>

Abrasion Test Apparatus,
Test Specimen Preparation, and Test Procedure

Abrasion Test

Drexel team has designed an abrasion device to quantify the surface damage of ADA materials after exposure to sunlight.

Test Apparatus

The test apparatus consists of a rotary motor attached with a grinding disc that performs the abrasion, a plexiglass sliding plate where the test specimen is mounded onto lower side and testing weight is placed on the top side, as indicated in Figure 1. The grinding disc is faced upwards. The grinding disc used is 120grit and is rotated at a rate of 1550 rpm. The test specimen is mounded onto a plexiglass plate. The exposed surface is facing the grinding disc. Four ball bearings are installed on each of the four corners of this plate allowing it moving freely along four vertical steel bars. The weight of the plexiglass and clamps used to mound the test specimen is balanced by counter weights, as shown in Figure 2. The counter-weight of 2-lb is attached to the sliding plate to hold it in equilibrium. Thus, there is very little normal load acting onto the test specimen as the specimen surface touches the grinding disc by lowering the sliding plate. Loading pressure is applied on top of the sliding plate so that the test specimen will be lowered at a controlled rate as the specimen's surface is being grinded.

Test Specimen Preparation

The dimensions of the test specimens are 1.3-in in width and 2.3 to 3.5-inch in length cutting out from the ADA coupons. The clamping length has a minimum of 0.5-inch proving a test surface of 1.3-in by 1.3 -in. square.

Test Procedure

The test procedure is carrying in the following steps:

- Measure the initial mass of the test specimen (m_0).
- The test specimen is clamped onto the specimen holder.
- Appropriate weights are placed on top of the plexiglass sliding plate.

- Grinding motor is turned on, and the plexiglass sliding plate is slowly lowered until the surface of the test specimen touches the grinding disc at which starts the stopwatch.
- The grinding motor is stopped after 60 seconds. The test specimen is removed from the clamps and cleaned by air duster.
- Measure the mass of specimen for the grinding duration of 60 second (m_{60}).
- The mass loss due to abrasion is then calculated and recorded.

$$m_{loss} = m_0 - m_{60}$$

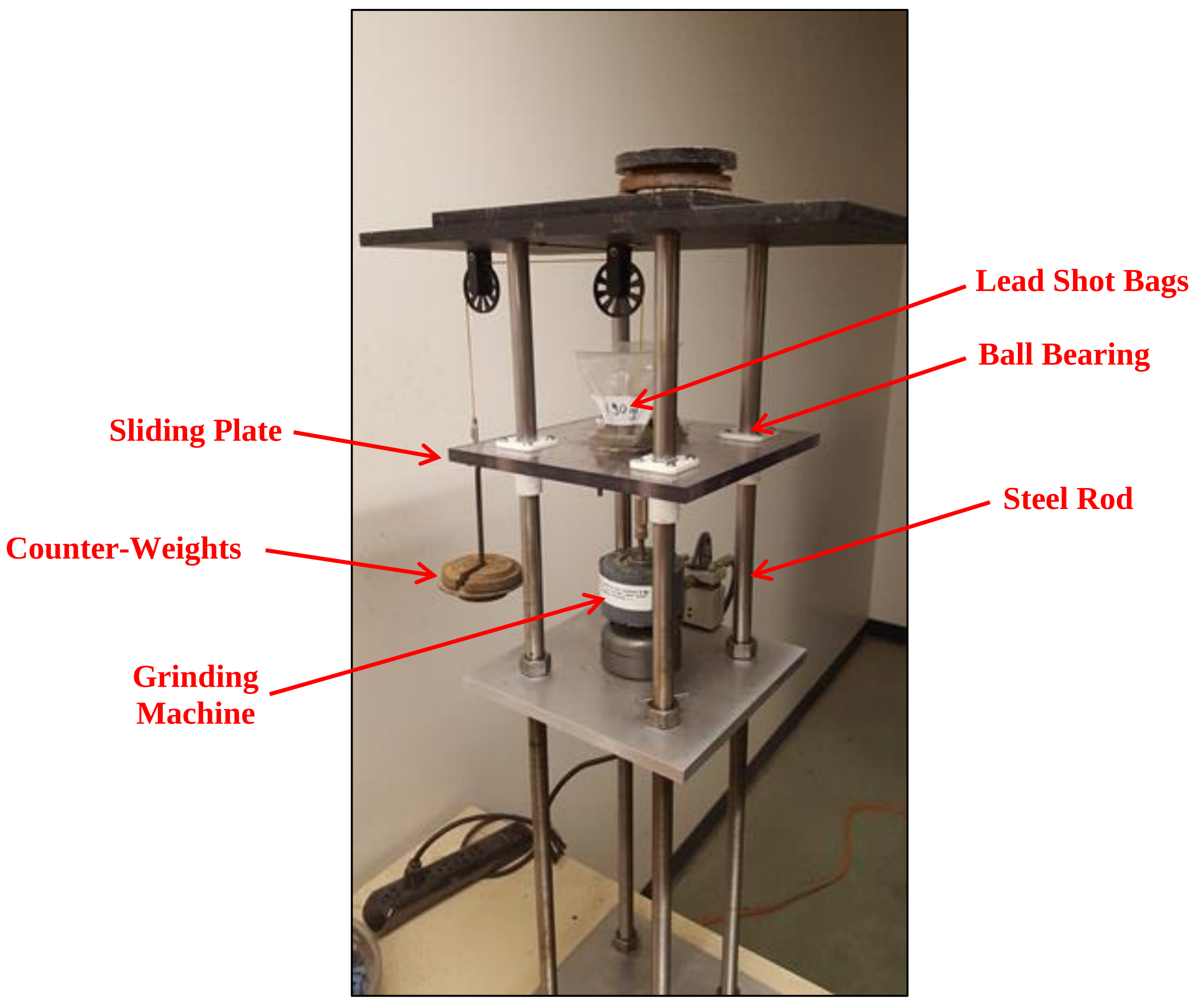


Figure K-1 – Abrasion test apparatus

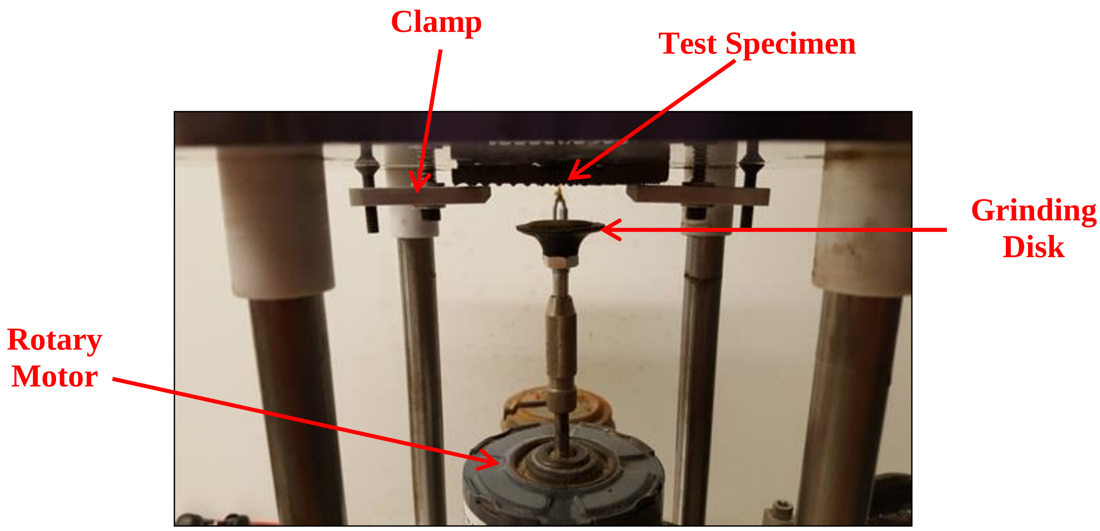


Figure K-2 – Grinding machine and test specimen

Appendix-L

Test Data of Abrasion Test on DWS Products after Exposed in the Xenon Weatherometer

<u>Appendix-L(a)</u>

ADA Solutions (Polyester) Samples

Table L-1 – Abrasion Test Results of ADA Solutions Samples in Condition A

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.1314	0.0303
	1000	0.1040	0.0159
	2000	0.0993	0.0187
	3000	0.0971	0.0076
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.0831	0.0086
	1000	0.1209	0.0528
	2000	0.0761	0.0091
	3000	0.0721	0.0112
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.1047	0.0368
	1000	0.0927	0.0170
	2000	0.0761	0.0092
	3000	0.0611	0.0053

Table L-2 – Abrasion Test Results of ADA Solutions Samples in Condition B

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.1314	0.0303
	1000	0.1180	0.0053
	2000	0.1014	0.0239
	3000	0.0511	0.0094
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.0831	0.0086
	1000	0.0726	0.0154
	2000	0.1163	0.0154
	3000	0.0700	0.0251
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.1047	0.0368
	1000	0.0934	0.0210
	2000	0.1055	0.0287
	3000	0.0593	0.0123

Table L-3 – Abrasion Test Results of ADA Solutions Samples in Condition C

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.1314	0.0303
	1000	0.0972	0.0132
	2000	0.1011	0.0090
	3000	0.1477	0.0126
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.0831	0.0086
	1000	0.1279	0.0206
	2000	0.1160	0.0293
	3000	0.1392	0.0275
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.1047	0.0368
	1000	0.0939	0.0186
	2000	0.0930	0.0203
	3000	0.1026	0.0321

<u>Appendix-L(b)</u>

AlertCast (Polyester, NPG) Samples

Table L-4 – Abrasion Test Results of AlertCast Samples in Condition A

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0860	0.0196
	1000	0.0883	0.0164
	2000	0.1322	0.0133
	3000	0.1033	0.0313
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.1068	0.0299
	1000	0.1135	0.0216
	2000	0.1071	0.0150
	3000	0.0815	0.0161
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.0910	0.0191
	1000	0.1002	0.0144
	2000	0.0557	0.0116
	3000	0.0827	0.0081

Table L-5 – Abrasion Test Results of AlertCast Samples in Condition B

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0860	0.0196
	1000	0.1221	0.0156
	2000	0.1260	0.0237
	3000	0.0699	0.0120
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.1068	0.0299
	1000	0.1248	0.0145
	2000	0.1310	0.0319
	3000	0.0914	0.0337
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.0910	0.0191
	1000	0.1339	0.0115
	2000	0.1021	0.0288
	3000	0.0881	0.0269

Table L-6 – Abrasion Test Results of AlertCast Samples in Condition C

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0860	0.0196
	1000	0.0974	0.0239
	2000	0.1101	0.0423
	3000	0.1498	0.0175
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.1068	0.0299
	1000	0.1219	0.0279
	2000	0.1275	0.0176
	3000	0.1575	0.0149
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.0910	0.0191
	1000	0.1396	0.0226
	2000	0.1316	0.0245
	3000	0.1778	0.0529

<u>Appendix-L(c)</u>

Redimat (Polyurethane) Samples

Table L-7 – Abrasion Test Results of Redimat Samples in Condition A

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0259	0.0078
	1000	0.0332	0.0178
	2000	0.0248	0.0075
	3000	0.0418	0.0081
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.0230	0.0076
	1000	0.0207	0.0038
	2000	0.0260	0.0074
	3000	0.0340	0.0074
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.0291	0.0052
	1000	0.0216	0.0093
	2000	0.0260	0.0059
	3000	0.0240	0.0066

Table L-8 – Abrasion Test Results of Redimat Samples in Condition B

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0259	0.0078
	1000	0.0412	0.0066
	2000	0.0304	0.0056
	3000	0.0173	0.0024
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.0230	0.0076
	1000	0.0277	0.0108
	2000	0.0368	0.0071
	3000	0.0168	0.0095
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.0291	0.0052
	1000	0.0258	0.0103
	2000	0.0321	0.0079
	3000	0.0275	0.0030

Table L-9 – Abrasion Test Results of Redimat Samples in Condition C

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0259	0.0078
	1000	0.0370	0.0174
	2000	0.0506	0.0034
	3000	0.0531	0.0044
	Hours	Avg Mass Loss (g)	Standard Dev
Red	0	0.0230	0.0076
	1000	0.0346	0.0151
	2000	0.0450	0.0098
	3000	0.0327	0.0147
	Hours	Avg Mass Loss (g)	Standard Dev
Yellow	0	0.0291	0.0052
	1000	0.0301	0.0058
	2000	0.0363	0.0089
	3000	0.0375	0.0030

<u>Appendix-L(d)</u>

SafeRoute (Polyolefin) Samples

Table L-10 – Abrasion Test Results of SafeRoute Samples in Condition A

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0396	0.0053
	1000	0.0405	0.0033
	2000	0.0365	0.0054
	3000	0.0414	0.0071
Red	Hours	Avg Mass Loss (g)	Standard Dev
	0	0.0160	0.0029
	1000	0.0210	0.0017
	2000	0.0172	0.0030
	3000	0.0218	0.0042
Yellow	Hours	Avg Mass Loss (g)	Standard Dev
	0	0.0178	0.0089
	1000	0.0217	0.0055
	2000	0.0314	0.0060
	3000	0.0295	0.0040

Table L-11 – Abrasion Test Results of SafeRoute Samples in Condition B

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0396	0.0053
	1000	0.0468	0.0077
	2000	0.0392	0.0100
	3000	0.0207	0.0069
Red	Hours	Avg Mass Loss (g)	Standard Dev
	0	0.0160	0.0029
	1000	0.0201	0.0041
	2000	0.0265	0.0060
	3000	0.0189	0.0024
Yellow	Hours	Avg Mass Loss (g)	Standard Dev
	0	0.0178	0.0089
	1000	0.0315	0.0024
	2000	0.0291	0.0038
	3000	0.0338	0.0029

Table L-12 – Abrasion Test Results of SafeRoute Samples in Condition C

	Hours	Avg Mass Loss (g)	Standard Dev
Black	0	0.0396	0.0053
	1000	0.0515	0.0062
	2000	0.0643	0.0091
	3000	0.0503	0.0114
Red	Hours	Avg Mass Loss (g)	Standard Dev
	0	0.0160	0.0029
	1000	0.0250	0.0028
	2000	0.0215	0.0049
	3000	0.0239	0.0010
Yellow	Hours	Avg Mass Loss (g)	Standard Dev
	0	0.0178	0.0089
	1000	0.0331	0.0041
	2000	0.0328	0.0055
	3000	0.0312	0.0085

Appendix-L(e)

Armor-Tile (Epoxy) Samples

Table L-13 – Abrasion Test Results of Armor-Tile Samples in Condition A

ArmorTile (Black)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0198	0.0095	0.4796	0.000
1000	0.0099	0.0028	0.2787	-49.937
2000	0.0096	0.0035	0.3687	-51.702
3000	0.0205	0.0071	0.3492	

ArmorTile (Red)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0116	0.0015	0.1312	0.000
1000	0.0285	0.0107	0.3753	145.690
2000	0.0332	0.0125	0.3755	186.638
3000	0.0230	0.0063	0.2740	

ArmorTile (Yellow)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0138	0.0041	0.2963	0.000
1000	0.0159	0.0068	0.4296	15.190
2000	0.0141	0.0056	0.3965	2.170
3000	0.0064	0.0019	0.2902	

Table L-14 – Abrasion Test Results of Armor-Tile Samples in Condition B

ArmorTile (Black)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0198	0.0095	0.4796	0.000
1000	0.0122	0.0036	0.2928	-38.588
2000	0.0065	0.0032	0.4905	-67.213
3000	0.0092	0.0014	0.1504	

ArmorTile (Red)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0116	0.0015	0.1312	0.000
1000	0.0110	0.0014	0.1246	-4.957
2000	0.0135	0.0068	0.5080	15.948
3000	0.0218	0.0139	0.6360	

ArmorTile (Yellow)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0138	0.0041	0.2963	0.000
1000	0.0208	0.0113	0.5403	50.633
2000	0.0204	0.0010	0.0515	47.318
3000	0.0128	0.0075	0.5879	

Table L-15 – Abrasion Test Results of Armor-Tile Samples in Condition C

ArmorTile (Black)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0198	0.0095	0.4796	0.000
1000	0.0156	0.0125	0.7991	-21.059
2000	0.0151	0.0083	0.5493	-23.834
3000	0.0170	0.0036	0.2096	

ArmorTile (Red)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0116	0.0015	0.1312	0.000
1000	0.0182	0.0039	0.2167	57.112
2000	0.0347	0.0090	0.2607	198.707
3000	0.0089	0.0034	0.3863	

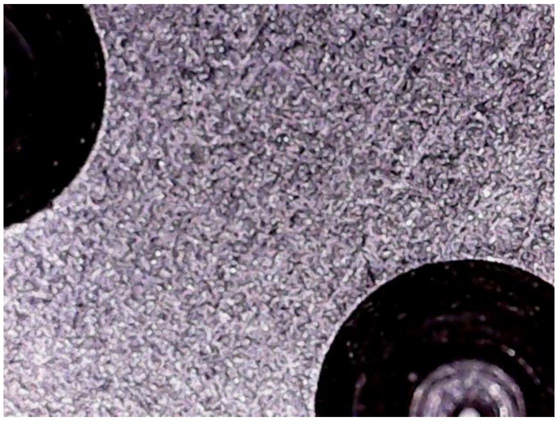
ArmorTile (Yellow)				
Hours	Avg Mass Loss (g)	Standard Dev	COV	% Loss
0	0.0138	0.0041	0.2963	0.000
1000	0.0206	0.0131	0.6354	49.367
2000	0.0083	0.0023	0.2732	-39.602
3000	0.0119	0.0084	0.7091	

Appendix-M

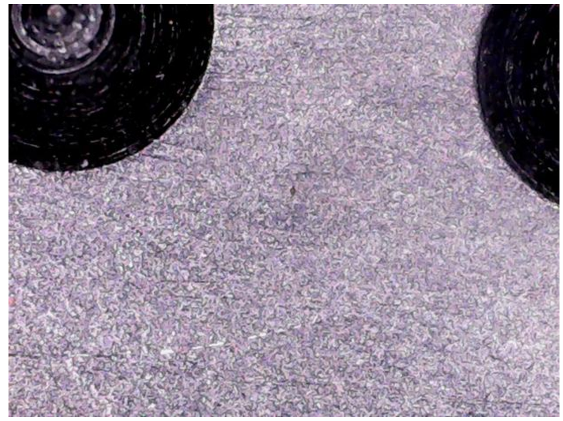
Surface Appearance Photographs of DWS Samples After Outdoor Exposure at Gainesville, Florida

Appendix-M(a)

ADA Solutions (Polyester) Coupons



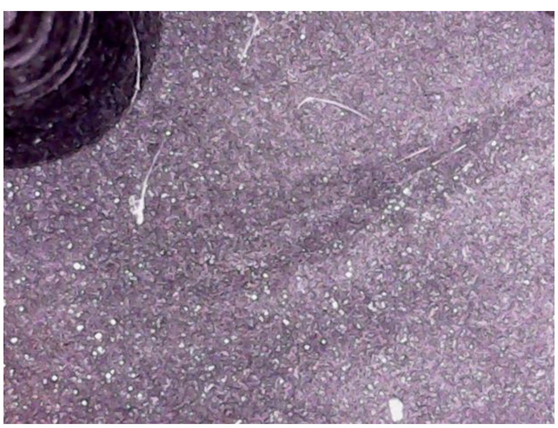
ADA Solutions – Original unexposed black coupon



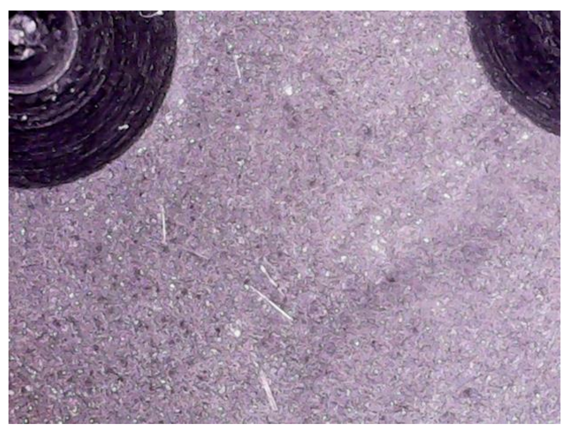
ADA Solutions – Outdoor exposed 8-months black coupon

ADA Solutions – Outdoor exposed 12-months black coupon

ADA Solutions – Outdoor exposed 16-months black coupon

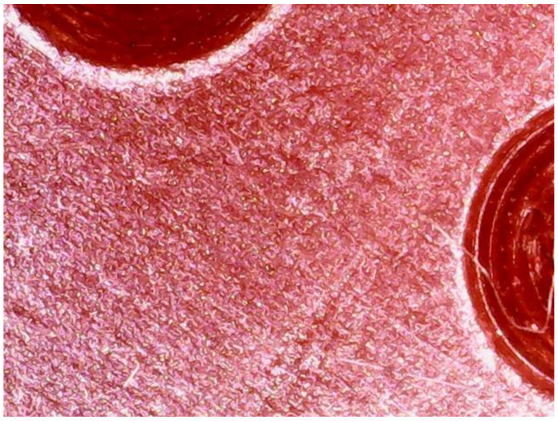


ADA Solutions – Outdoor exposed 20-months black coupon

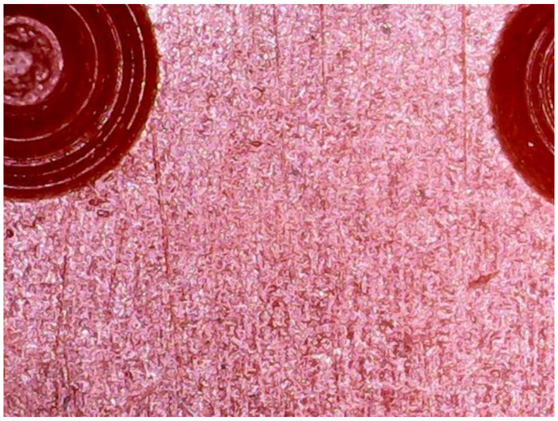


ADA Solutions – Outdoor exposed 24-months black coupon

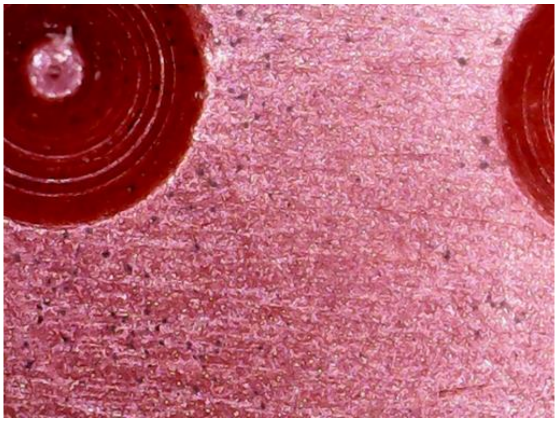
Figure M-1 – Surface morphology of ADA Solutions black coupons after outdoor exposure



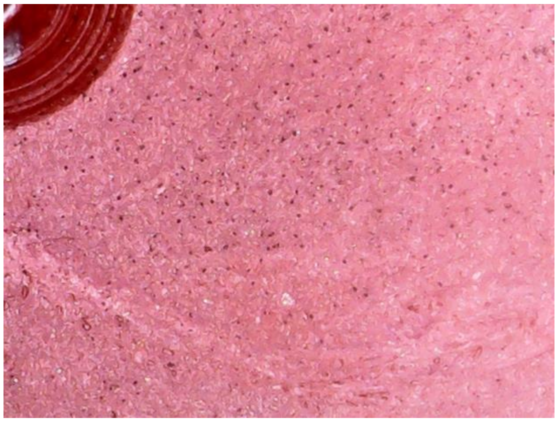
ADA Solutions – Original unexposed red coupon



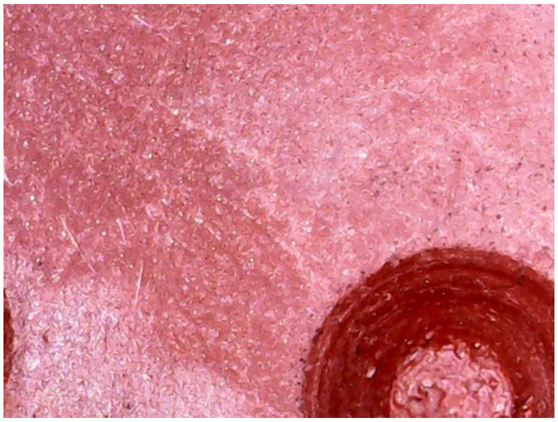
ADA Solutions – Outdoor exposed 8-months red coupon



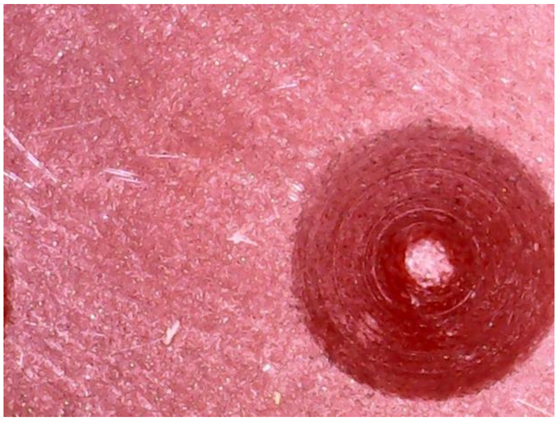
ADA Solutions – Outdoor exposed 12-months red coupon



ADA Solutions – Outdoor exposed 16-months red coupon

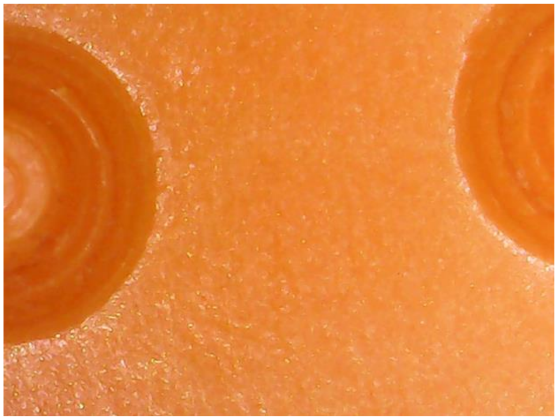


ADA Solutions – Outdoor exposed 20-months red coupon



ADA Solutions – Outdoor exposed 24-months red coupon

Figure M-2 – Surface morphology of ADA Solutions red coupons after outdoor exposure



ADA Solutions – Original unexposed yellow coupon

ADA Solutions – Outdoor exposed 8-months yellow coupon

ADA Solutions – Original exposed 12 months yellow coupon

ADA Solutions – Outdoor exposed 16-months yellow coupon

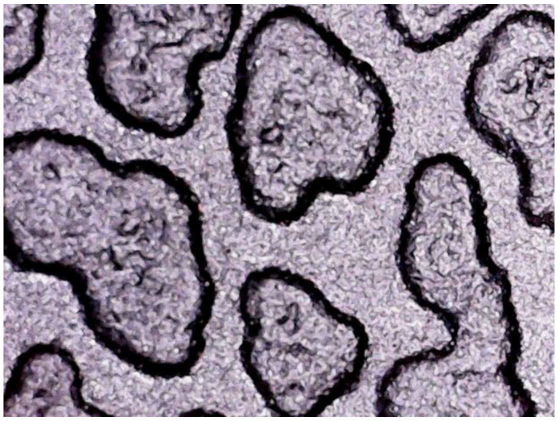
ADA Solutions – Original exposed 20 months yellow coupon

ADA Solutions – Outdoor exposed 24-months yellow coupon

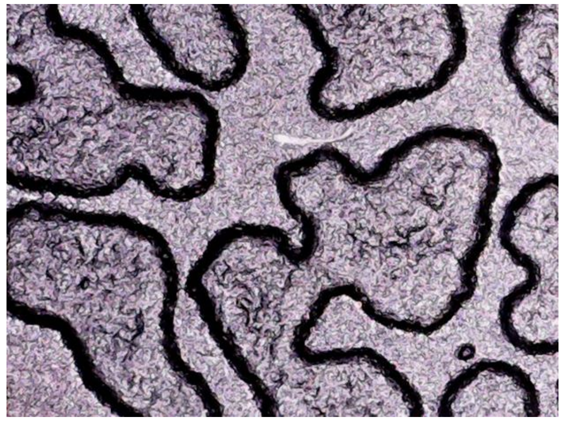
Figure M-3 – Surface morphology of ADA Solutions yellow coupons after outdoor exposure

Appendix-M(b)

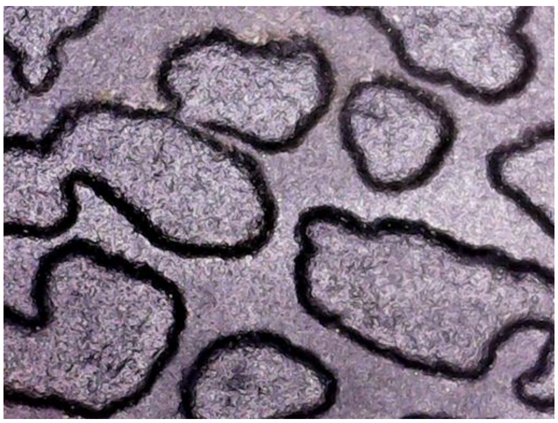
AlertCast (Polyester NPG) Coupons



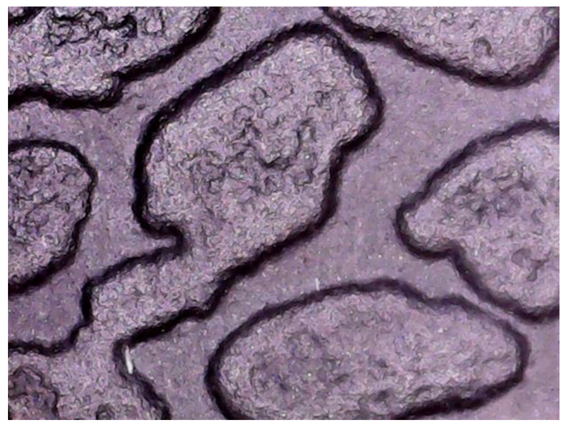
AlertCast – Original unexposed black coupon



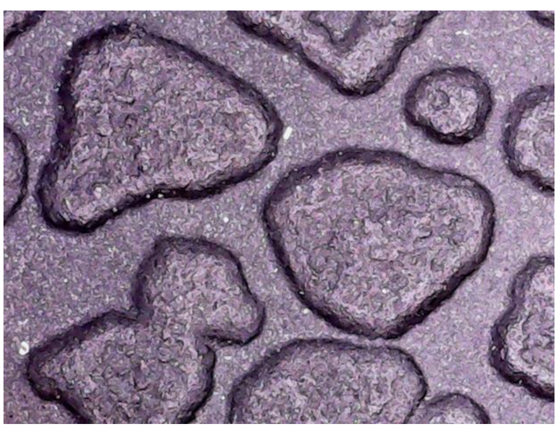
AlertCast – Outdoor exposed 8-months black coupon



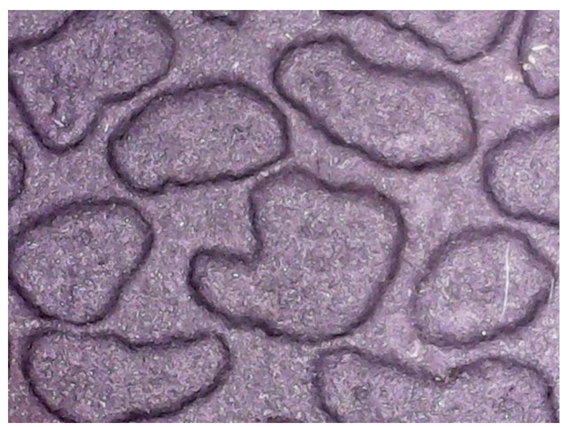
AlertCast – Outdoor exposed 12-months black coupon



AlertCast – Outdoor exposed 16-months black coupon



AlertCast – Outdoor exposed 20-months black coupon

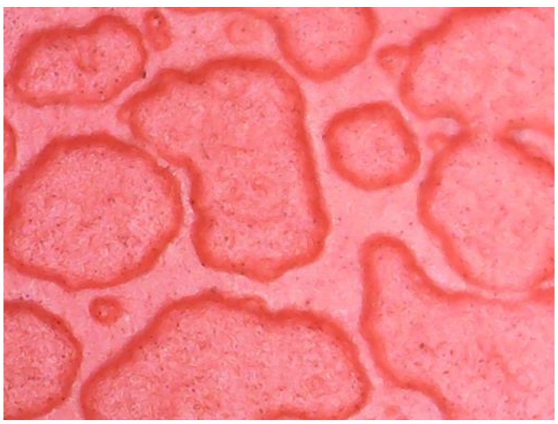


AlertCast – Outdoor exposed 24-months black coupon

Figure M-4 – Surface morphology of AlertCast black coupons after outdoor exposure

AlertCast – Original unexposed red coupon

AlertCast – Outdoor exposed 8-months red coupon



AlertCast – Outdoor exposed 12-months red coupon

AlertCast – Outdoor exposed 16-months red coupon

AlertCast – Outdoor exposed 20-months red coupon

AlertCast – Outdoor exposed 24-months red coupon

Figure M-5 – Surface morphology of AlertCast red coupons after outdoor exposure

AlertCast – Original unexposed yellow coupon

AlertCast – Outdoor exposed 8-months yellow coupon

AlertCast – Outdoor exposed 12-months yellow coupon

AlertCast – Outdoor exposed 16-months yellow coupon

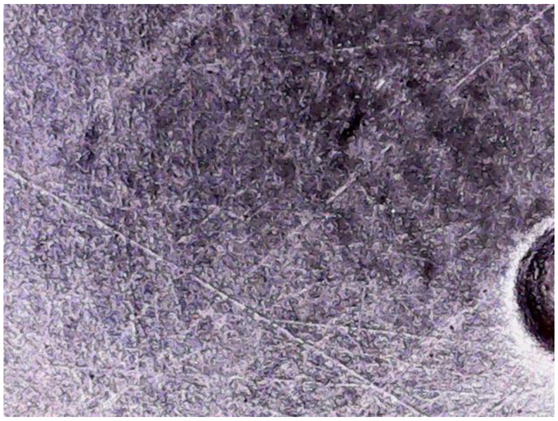
AlertCast – Outdoor exposed 20-months yellow coupon

AlertCast – Outdoor exposed 24-months yellow coupon

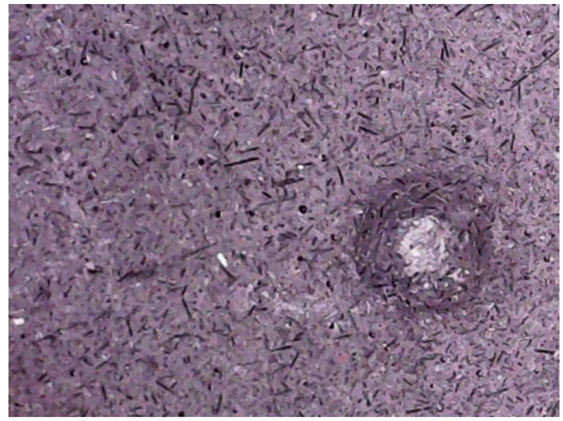
Figure M-6 – Surface morphology of AlertCast yellow coupons after outdoor exposure

Appendix-M(c)

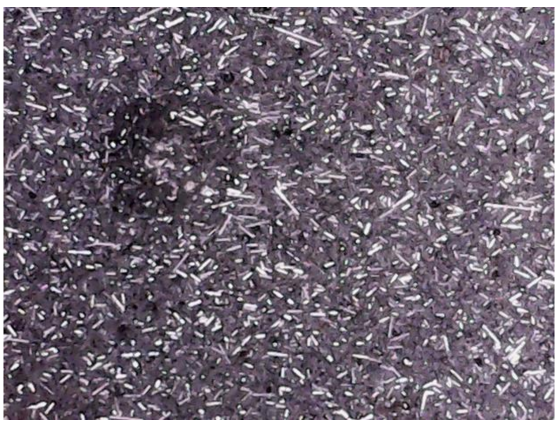
Redimat (Polyurethane) Coupons



Redimat – Original unexposed black coupon

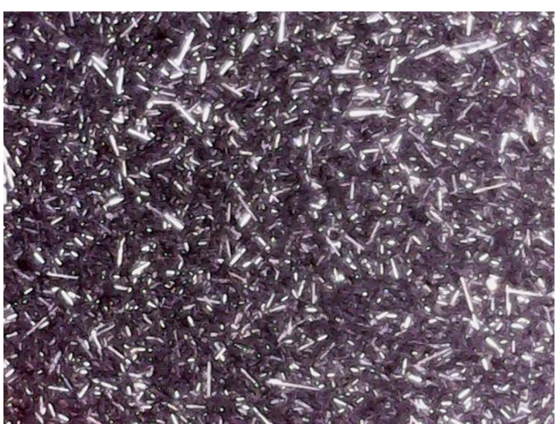


Redimat – Outdoor exposed 4-months black coupon

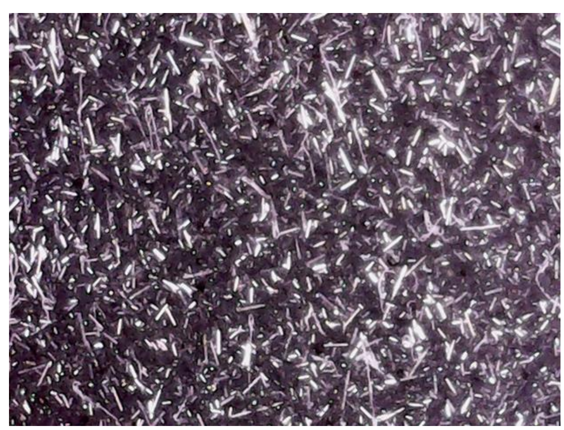


Redimat – Outdoor exposed 8-months black coupon

Redimat – Outdoor exposed 16-months black coupon

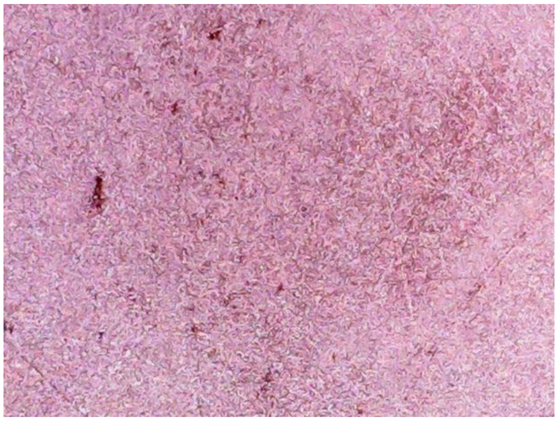


Redimat – Outdoor exposed 20-months black coupon

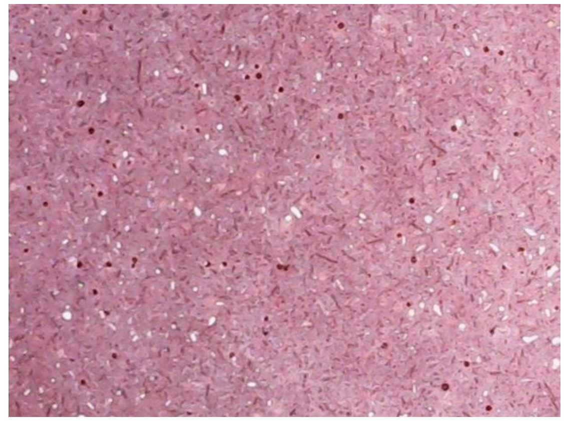


Redimat – Outdoor exposed 24-months black coupon

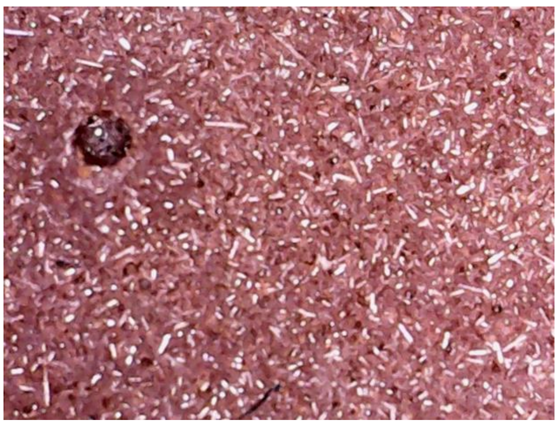
Figure M-7 – Surface morphology of Redimat black coupons after outdoor exposure



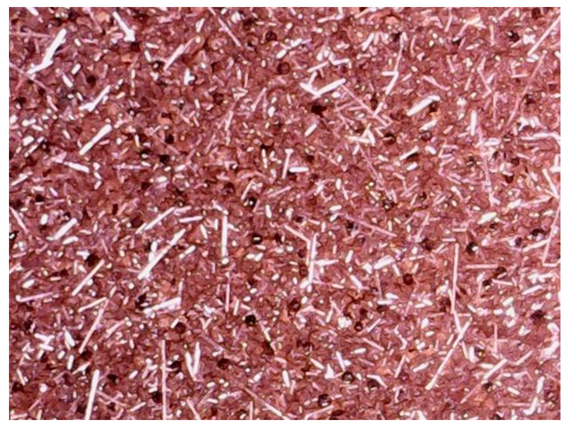
Redimat – Original unexposed red coupon



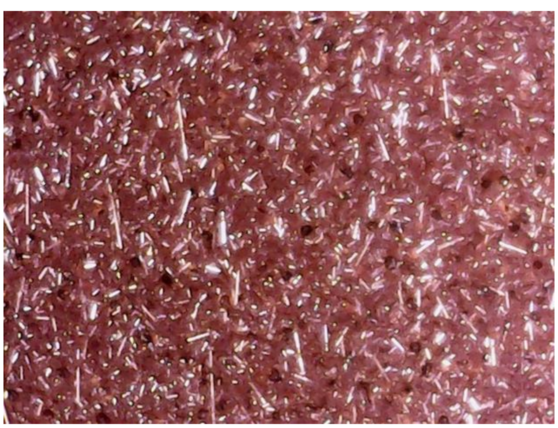
Redimat – Outdoor exposed 4-months red coupon



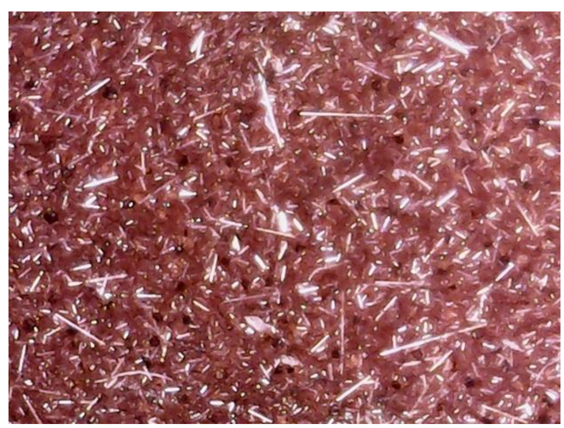
Redimat – Outdoor exposed 8-months red coupon



Redimat – Outdoor exposed 16-months red coupon



Redimat – Outdoor exposed 20-months red coupon



Redimat – Outdoor exposed 24-months red coupon

Figure M-8 – Surface morphology of Redimat red coupons after outdoor exposure

Redimat – Original unexposed yellow coupon

Redimat– Outdoor exposed 4-months yellow coupon

Redimat – Outdoor exposed 8-months yellow coupon

Redimat – Outdoor exposed 16-months yellow coupon

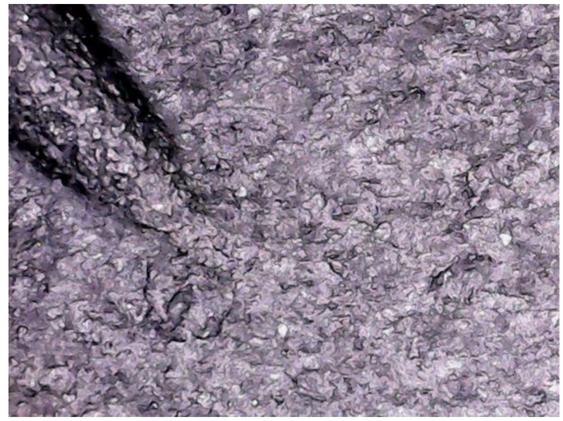
Redimat – Outdoor exposed 20-months yellow coupon

Redimat – Outdoor exposed 24-months yellow coupon

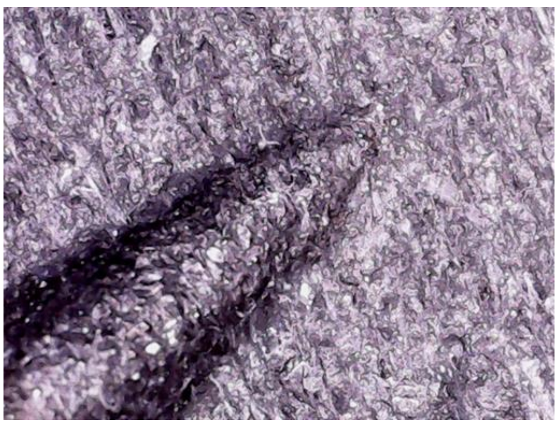
Figure M-9 – Surface morphology of Redimat yellow coupons after outdoor exposure

Appendix-M(d)
SafeRoute (Polyolefin) Coupons

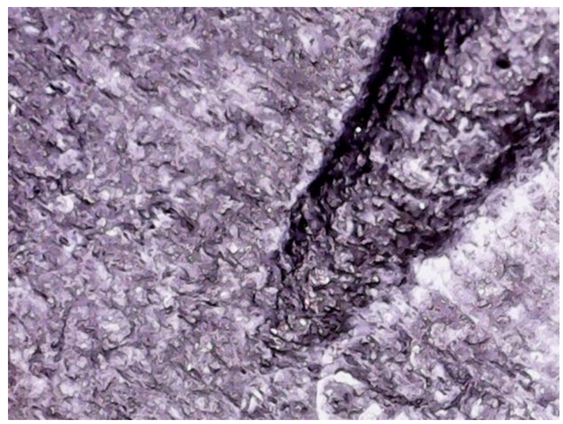
SafeRoute – Original unexposed black coupon



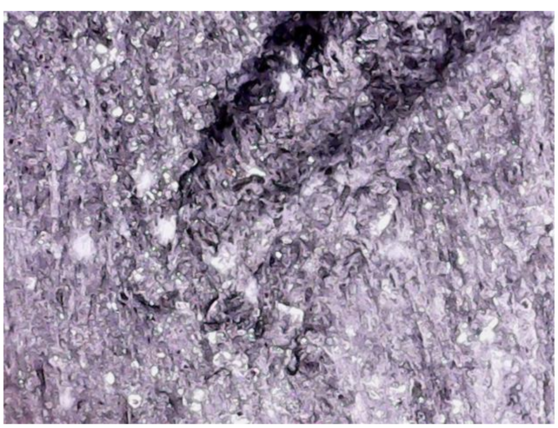
SafeRoute – Outdoor exposed 8-months black coupon



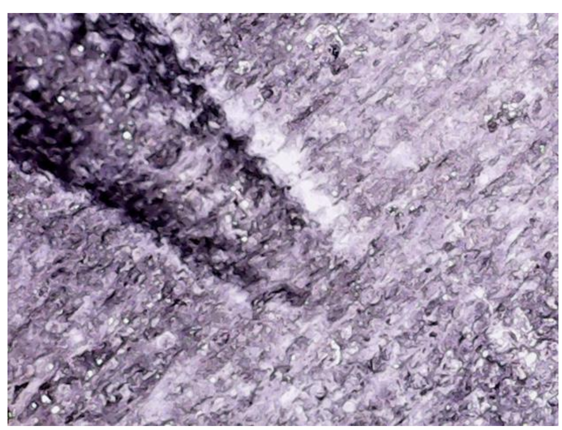
SafeRoute – Outdoor exposed 12-months black coupon



SafeRoute – Outdoor exposed 16-months black coupon

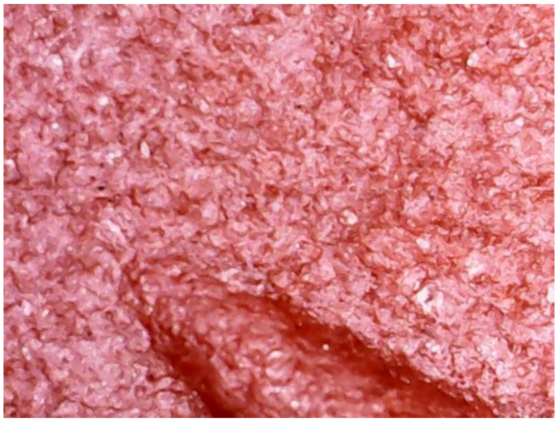


SafeRoute – Outdoor exposed 20-months black coupon

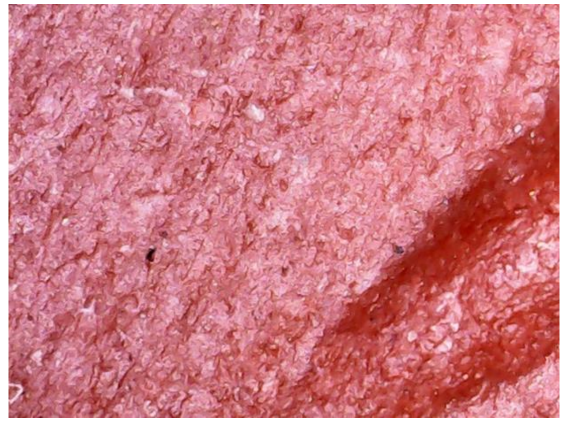


SafeRoute – Outdoor exposed 24-months black coupon

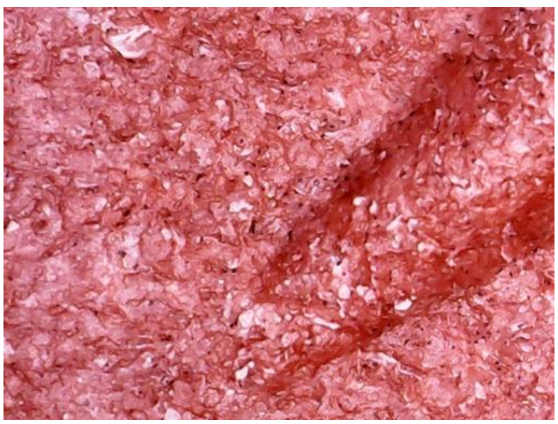
Figure M-10 – Surface morphology of SafeRoute black coupons after outdoor exposure



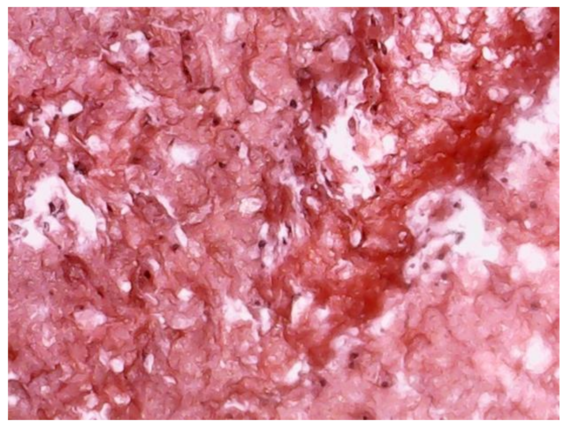
SafeRoute – Original unexposed red coupon



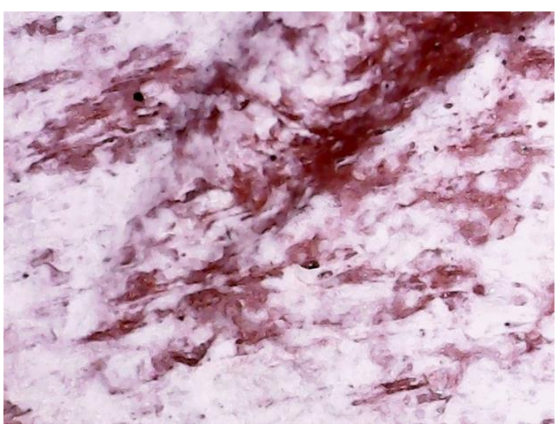
SafeRoute – Outdoor exposed 8-months red coupon



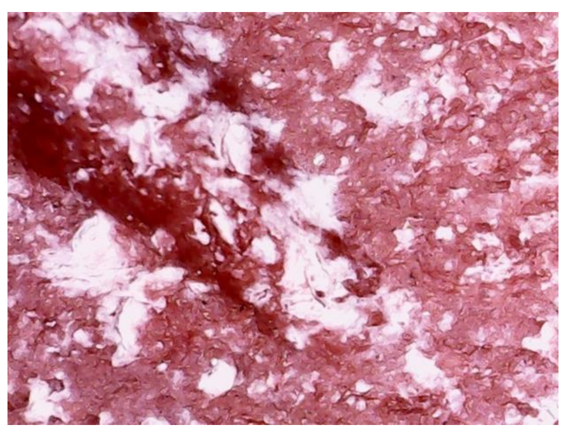
SafeRoute – Outdoor exposed 12-months red coupon



SafeRoute – Outdoor exposed 16-months red coupon



SafeRoute – Outdoor exposed 20-months red coupon



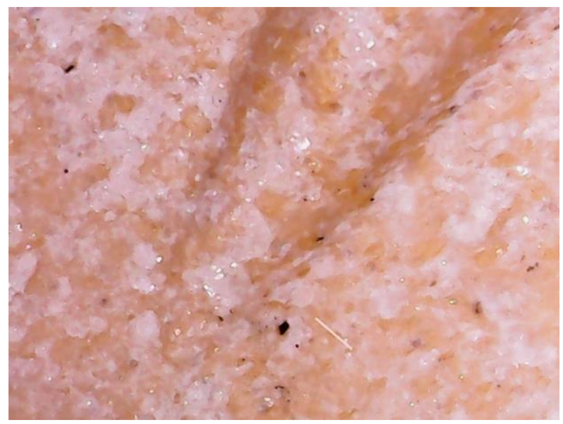
SafeRoute – Outdoor exposed 24-months red coupon

Figure M-11 – Surface morphology of SafeRoute red coupons after outdoor exposure

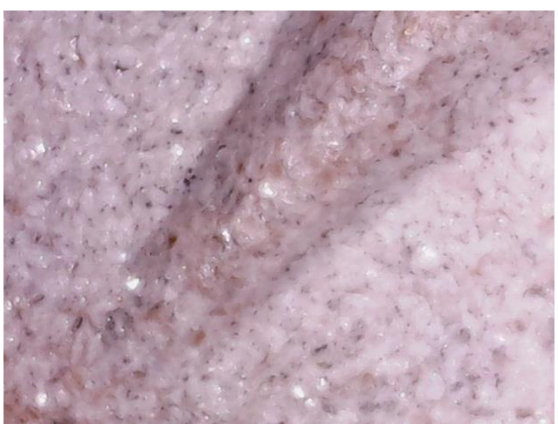
SafeRoute – Original unexposed yellow coupon

SafeRoute – Outdoor exposed 8-months yellow coupon

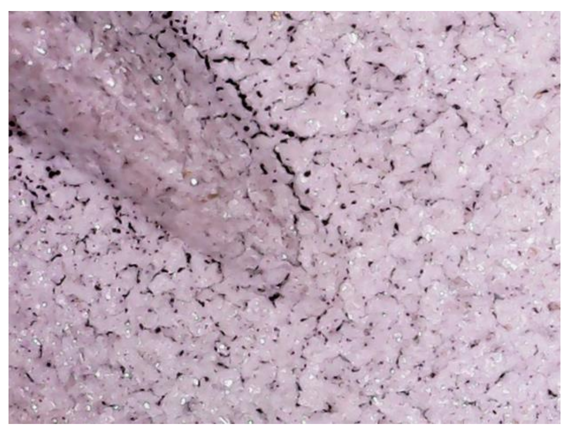
SafeRoute – Outdoor exposed 12-months yellow coupon



SafeRoute – Outdoor exposed 16-months yellow coupon



SafeRoute – Outdoor exposed 20-months yellow coupon

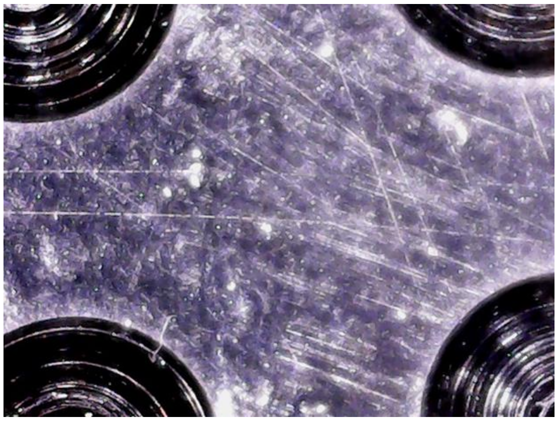


SafeRoute – Outdoor exposed 24-months yellow coupon

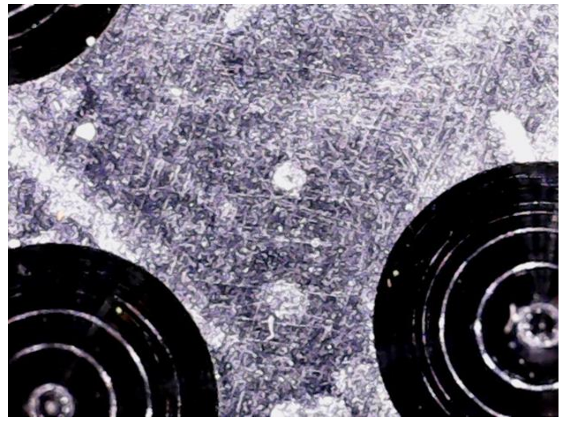
Figure M-12 – Surface morphology of SafeRoute yellow coupons after outdoor exposure

<u>Appendix-M(e)</u>

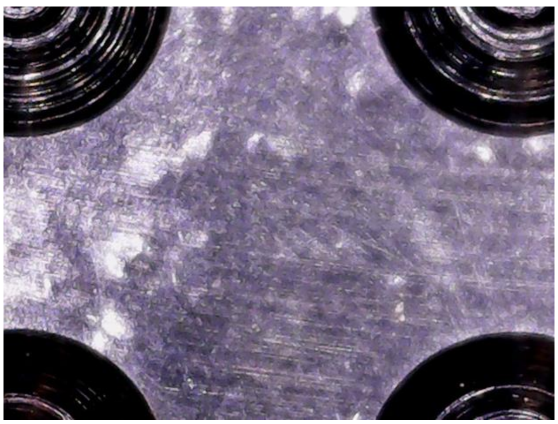
Armor-Tile (Epoxy) Coupons



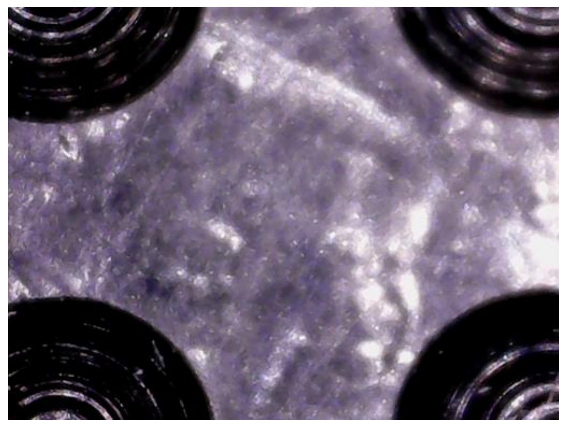
Armor-Tile – Original unexposed black coupon



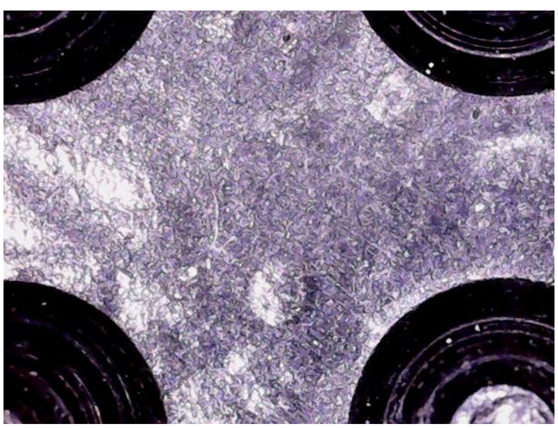
Armor-Tile – Outdoor exposed 4-months black coupon



Armor-Tile – Outdoor exposed 8-months black coupon



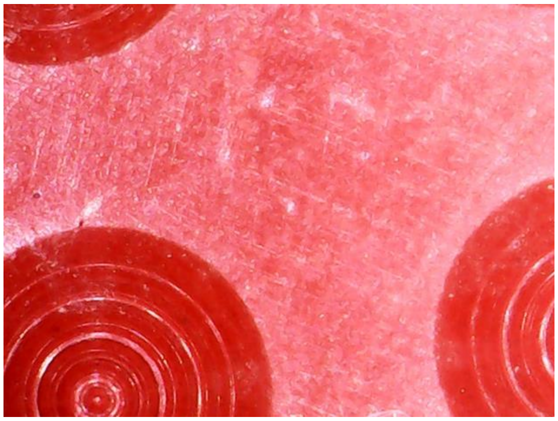
Armor-Tile – Outdoor exposed 12-months black coupon



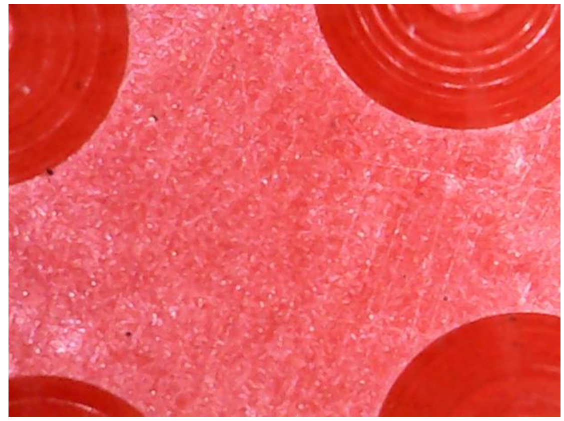
Armor-Tile – Outdoor exposed 20-months black coupon

Armor-Tile – Outdoor exposed 24-months black coupon

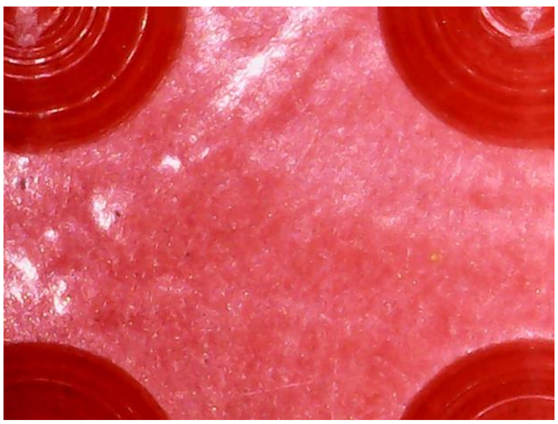
Figure M-13 – Surface morphology of Armor-Tile black coupons after outdoor exposure



Armor-Tile – Original unexposed red coupon

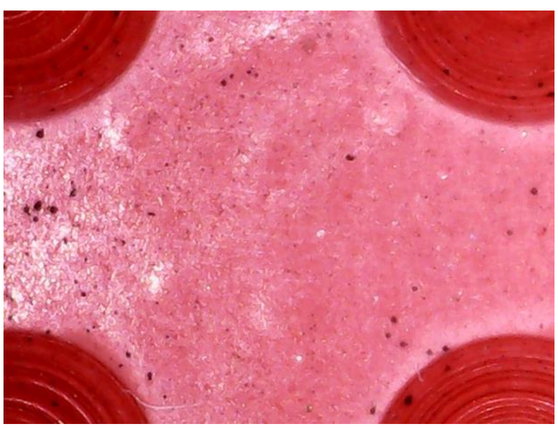


Armor-Tile – Outdoor exposed 4-months red coupon

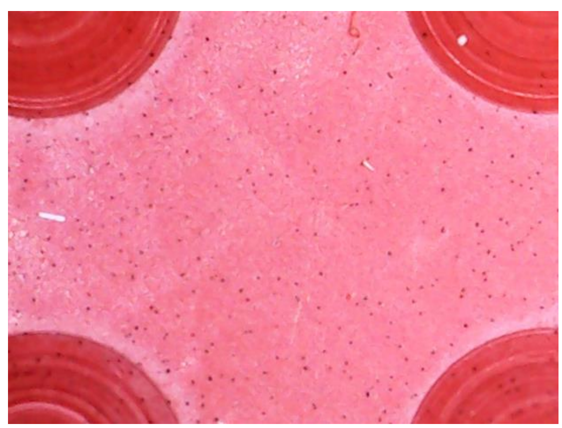


Armor-Tile – Outdoor exposed 8-months red coupon

Armor-Tile – Outdoor exposed 12-months red coupon



Armor-Tile – Outdoor exposed 20-months red coupon



Armor-Tile – Outdoor exposed 24-months red coupon

Figure M-14 – Surface morphology of Armor-Tile red coupons after outdoor exposure

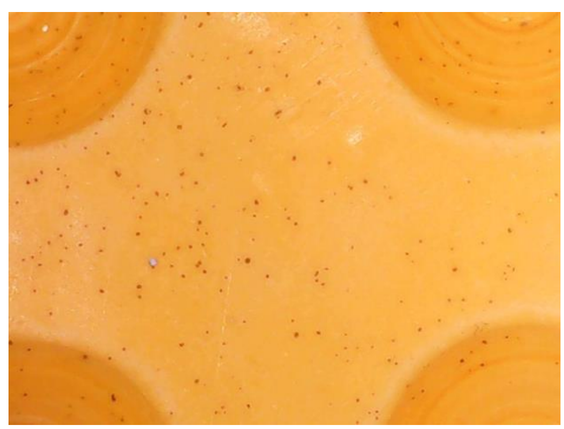
Armor-Tile – Original unexposed yellow coupon

Armor-Tile – Outdoor exposed 4-months yellow coupon

Armor-Tile – Outdoor exposed 8-months yellow coupon

Armor-Tile – Outdoor exposed 12-months yellow coupon

Armor-Tile – Outdoor exposed 20-months yellow coupon



Armor-Tile – Outdoor exposed 24-months yellow coupon

Figure M-15 – Surface morphology of Armor-Tile yellow coupons after outdoor exposur

Appendix-N

Test Data of Color Measurement of DWS Products after Outdoor Exposure at Gainesville, Florida

Appendix-N(a)

ADA Solutions (Polyester) Products

Table N-1 – Color Measurement of ADA Solutions Products

ADA Solutions							
BLACK							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	4.45	5.79	9.83	8.07	13.20	8.93
	Middle	4.01	6.27	7.97	10.01	13.42	9.31
	Bottom	1.21	7.34	9.74	7.94	10.54	10.97
2	Top	2.39	4.41	7.02	11.29	13.26	10.69
	Middle	2.30	8.75	9.30	10.86	10.32	10.28
	Bottom	0.32	8.61	9.31	10.11	9.73	10.68
	MEAN	**2.45**	**6.86**	**8.86**	**9.71**	**11.74**	**10.14**
	STDEV	**1.58**	**1.69**	**1.12**	**1.40**	**1.72**	**0.83**
RED							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	1.67	30.12	8.45	13.31	13.48	17.15
	Middle	0.81	2.70	6.37	10.00	13.97	14.73
	Bottom	0.37	3.35	5.41	7.87	15.52	11.36
2	Top	0.42	3.47	6.37	6.60	13.55	7.93
	Middle	1.43	3.23	4.71	6.88	13.14	12.37
	Bottom	1.22	2.71	5.49	9.00	11.31	12.38
	MEAN	**0.99**	**3.09**	**6.13**	**8.94**	**13.50**	**12.65**
	STDEV	**0.54**	**0.36**	**1.30**	**2.49**	**1.36**	**3.12**
YELLOW							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Middle	5.28	6.31	13.71	12.56	18.13	19.51
	Bottom	4.25	8.57	12.03	12.51	19.30	18.38
	Top	3.75	10.24	10.01	11.33	19.12	17.34
2	Middle	3.01	8.43	10.89	12.94	63.19	22.29
	Bottom	3.07	8.21	9.95	14.01	20.43	21.46
	Top	3.49	10.50	9.82	12.49	23.23	18.38
	MEAN	**3.81**	**8.71**	**11.07**	**12.64**	**20.04**	**19.56**
	STDEV	**0.85**	**1.53**	**1.54**	**0.86**	**1.96**	**1.94**

<u>Appendix-N(b)</u>

AlertCast (NPG) Products

Table N-2 – Color Measurement of AlertCast Products

AlertCast							
BLACK							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	0.33	0.68	0.49	1.17	2.93	1.81
	Middle	0.51	2.69	0.24	0.52	2.69	2.01
	Bottom	0.32	0.71	0.64	1.41	2.52	1.74
2	Top	0.71	0.45	1.06	0.77	1.81	2.31
	Middle	0.70	0.42	0.64	0.93	2.69	2.63
	Bottom	0.62	0.99	0.64	0.54	1.27	2.47
	MEAN	**0.53**	**0.99**	**0.62**	**0.89**	**2.32**	**2.16**
	STDEV	**0.18**	**0.86**	**0.27**	**0.35**	**0.64**	**0.36**
RED							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	0.50	1.57	4.40	5.91	12.40	12.68
	Middle	0.46	2.04	3.90	6.39	10.59	13.40
	Bottom	0.41	2.89	4.23	5.97	11.29	11.40
2	Top	0.71	2.80	3.45	6.00	11.01	13.19
	Middle	0.37	2.19	3.57	6.93	10.88	13.08
	Bottom	0.73	1.92	4.09	6.69	10.10	16.04
	MEAN	**0.53**	**2.23**	**3.94**	**6.32**	**11.05**	**13.30**
	STDEV	**0.15**	**0.52**	**0.37**	**0.43**	**0.78**	**1.52**
YELLOW							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	2.97	6.28	5.58	9.30	12.69	13.19
	Middle	3.23	5.71	7.10	7.75	11.77	13.08
	Bottom	3.76	6.13	5.98	8.52	15.91	16.04
2	Top	3.02	6.41	7.00	8.11	12.89	16.56
	Middle	3.25	5.49	6.73	8.21	11.69	16.02
	Bottom	3.41	6.38	6.73	8.29	13.78	15.52
	MEAN	**3.27**	**6.07**	**6.52**	**8.36**	**13.12**	**15.07**
	STDEV	**0.29**	**0.38**	**0.61**	**0.53**	**1.57**	**1.54**

Appendix-N(c)

Redimat (Polyurethane) Products

Table N-3 – Color Measurement of Redimat Products

Redimat							
BLACK							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	17.32	17.36	14.24	11.61	16.31	14.70
	Middle	17.74	16.76	14.93	13.43	14.11	14.71
	Bottom	18.22	17.42	14.06	14.00	13.73	15.50
2	Top	16.92	17.32	7.44	13.81	14.40	13.30
	Middle	17.04	17.03	7.22	13.65	12.70	14.40
	Bottom	18.70	18.03	6.75	14.21	12.12	15.31
	MEAN	**17.66**	**17.32**	**10.77**	**13.45**	**13.89**	**14.65**
	STDEV	**0.70**	**0.43**	**4.00**	**0.94**	**1.46**	**0.78**
RED							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	17.30	15.27	11.42	7.37	14.69	13.07
	Middle	14.69	10.76	12.74	8.80	12.47	13.87
	Bottom	15.14	13.45	12.41	8.37	12.87	9.72
2	Top	11.32	15.08	12.83	9.44	11.73	14.54
	Middle	12.18	16.17	13.93	9.87	9.64	13.97
	Bottom	11.46	15.73	12.13	7.69	10.36	10.52
	MEAN	**13.68**	**14.41**	**12.58**	**8.59**	**11.96**	**12.62**
	STDEV	**2.41**	**2.01**	**0.83**	**0.97**	**1.82**	**2.01**
YELLOW							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	25.72	29.68	33.48	25.54	31.03	38.09
	Middle	24.88	35.22	37.16	25.64	31.53	35.69
	Bottom	26.77	32.72	36.60	25.50	28.02	40.46
2	Top	22.75	36.51	32.20	27.82	32.42	36.69
	Middle	25.36	39.71	35.14	25.73	31.10	39.74
	Bottom	25.54	28.10	33.88	28.10	32.38	37.79
	MEAN	**25.17**	**33.66**	**34.74**	**26.39**	**31.08**	**38.08**
	STDEV	**1.34**	**4.35**	**1.91**	**1.22**	**1.62**	**1.80**

<u>Appendix-N(d)</u>

SafeRoute (Polyolefin) Products

Table N-4 – Color Measurement of SafeRoute Products

SafeRoute							
BLACK							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	0.71	0.75	3.60	4.46	9.46	17.53
	Middle	0.32	2.44	1.73	5.02	9.77	16.25
	Bottom	0.24	1.88	1.90	5.07	10.39	19.62
2	Top	1.16	4.86	1.99	6.82	10.20	11.69
	Middle	0.22	5.72	2.57	4.64	7.99	11.69
	Bottom	0.67	3.16	1.12	2.76	10.14	13.25
	MEAN	**0.55**	**3.13**	**2.15**	**4.80**	**9.66**	**15.01**
	STDEV	**0.36**	**1.87**	**0.85**	**1.30**	**0.88**	**3.29**
RED							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	2.42	3.10	4.22	9.91	18.95	13.65
	Middle	1.01	5.55	4.39	11.74	17.02	15.12
	Bottom	0.65	7.11	5.54	9.29	17.04	14.64
2	Top	0.24	4.20	3.93	12.13	21.83	14.25
	Middle	0.73	6.12	3.00	6.46	19.09	12.54
	Bottom	2.42	4.08	3.79	7.53	20.15	18.97
	MEAN	**1.25**	**5.03**	**4.14**	**9.51**	**19.01**	**14.86**
	STDEV	**0.94**	**1.49**	**0.83**	**2.25**	**1.85**	**2.20**
YELLOW							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	4.29	15.44	28.86	39.41	56.74	55.66
	Middle	3.52	14.15	26.77	40.24	53.27	55.92
	Bottom	4.25	13.26	26.54	35.73	57.21	56.15
2	Top	4.21	15.29	28.51	41.71	55.59	53.22
	Middle	3.85	15.78	28.53	41.51	55.28	54.33
	Bottom	3.23	16.80	27.83	52.94	58.39	54.48
	MEAN	**3.89**	**15.12**	**27.84**	**41.93**	**56.08**	**54.96**
	STDEV	**0.44**	**1.25**	**0.98**	**5.82**	**1.78**	**1.14**

Appendix-N(e)

Armor-Tile (Epoxy) Coupons

Table N-5 – Color Measurement of Armor-Tile Products

ArmorTile							
BLACK							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	-	6.80	1.89	5.43	3.18	11.45
	Middle	7.37	6.70	4.43	3.73	13.06	6.23
	Bottom	7.55	7.93	10.15	6.78	7.53	9.46
2	Top	-	6.08	2.87	3.77	1.86	8.91
	Middle	3.65	6.31	3.08	2.58	0.73	6.89
	Bottom	2.16	5.01	1.75	2.27	2.69	12.88
	MEAN	**5.18**	**6.47**	**4.03**	**4.09**	**4.84**	**9.30**
	STDEV	**2.70**	**0.96**	**3.15**	**1.72**	**4.65**	**2.56**
RED							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	-	2.33	3.14	5.97	7.91	8.75
	Middle	7.90	4.44	4.31	5.50	10.90	5.80
	Bottom	6.10	2.86	3.44	8.47	7.84	5.24
2	Top	-	2.51	4.05	10.34	12.81	9.93
	Middle	8.38	3.75	3.70	7.55	5.70	8.40
	Bottom	3.78	6.83	3.93	6.65	7.01	6.62
	MEAN	**6.54**	**3.79**	**3.76**	**7.42**	**8.70**	**7.46**
	STDEV	**2.08**	**1.69**	**0.42**	**1.79**	**2.65**	**1.85**
YELLOW							
Test	Time (Mons)	4	8	12	16	20	24
	Location	ΔE					
1	Top	-	5.20	4.91	1.37	6.19	7.92
	Middle	9.45	6.82	4.50	4.95	3.06	9.14
	Bottom	7.82	5.70	2.88	2.03	3.31	9.39
2	Top	-	4.06	3.52	10.38	3.81	8.47
	Middle	7.95	4.52	9.06	8.62	7.77	7.96
	Bottom	9.89	5.79	6.64	3.50	1.77	13.12
	MEAN	**8.78**	**5.35**	**5.25**	**5.14**	**4.32**	**9.33**
	STDEV	**1.04**	**0.99**	**2.27**	**3.64**	**2.23**	**1.95**

Appendix-O

Test Data of Abrasion Test on DWS Products after Outdoor Exposure at Gainesville, Florida

Appendix-O(a)

ADA Solutions (Polyester) Samples

Table O-1 – Abrasion Test Results of ADA Solutions Samples after Outdoor Exposure

ADA Solutions (Black)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.131	0.030	0.231
4	0.098	0.012	0.120
8	0.141	0.021	0.152
12	0.128	0.028	0.219
16	0.139	0.025	0.181
20	0.125	0.018	0.146
24	0.055	0.009	0.164
ADA Solutions (Red)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.083	0.009	0.104
4	0.098	0.015	0.156
8	0.118	0.021	0.177
12	0.136	0.024	0.176
16	0.124	0.025	0.205
20	0.179	0.033	0.187
24	0.056	0.003	0.050
ADA Solutions (Yellow)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.105	0.037	0.351
4	0.117	0.016	0.135
8	0.121	0.028	0.234
12	0.128	0.015	0.121
16	0.129	0.020	0.154
20	0.167	0.047	0.281
24	0.058	0.024	0.420

Appendix-O(b)

AlertCast Solutions (Polyester, NPG) Samples

Table O-2 – Abrasion Test Results of AlertCast Samples after Outdoor Exposure

AlertCast (Black)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.086	0.020	0.228
4	0.074	0.023	0.313
8	0.119	0.011	0.091
12	0.143	0.029	0.201
16	0.140	0.042	0.301
20	0.134	0.069	0.515
24	0.108	0.055	0.509
AlertCast (Red)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.107	0.030	0.280
4	0.101	0.008	0.081
8	0.120	0.012	0.099
12	0.139	0.025	0.182
16	0.111	0.018	0.166
20	0.100	0.010	0.096
24	0.057	0.033	0.576
AlertCast (Yellow)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.091	0.019	0.210
4	0.104	0.023	0.222
8	0.131	0.009	0.065
12	0.145	0.035	0.241
16	0.127	0.037	0.291
20	0.130	0.015	0.115
24	0.071	0.037	0.518

Appendix-O(c)

Redimat Solutions (Polyurethane) Samples

Table O-3 – Abrasion Test Results of Redimat Samples after Outdoor Exposure

Redimat (Black)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.026	0.008	0.300
4	0.025	0.005	0.203
8	0.030	0.010	0.338
12	0.022	0.011	0.500
16	0.033	0.008	0.246
20	0.008	0.003	0.320
24	0.052	0.007	0.125
Redimat (Red)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.023	0.008	0.328
4	0.037	0.003	0.082
8	0.063	0.024	0.377
12	0.051	0.008	0.166
16	0.040	0.005	0.121
20	0.015	0.011	0.696
24	0.054	0.006	0.103
Redimat (Yellow)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.029	0.005	0.178
4	0.029	0.011	0.396
8	0.043	0.011	0.244
12	0.026	0.011	0.414
16	0.030	0.007	0.237
20	0.011	0.006	0.517
24	0.051	0.006	0.112

Appendix-O(d)

SafeRoute (Polyolefin) Samples

Table O-4 – Abrasion Test Results of SafeRoute Samples after Outdoor Exposure

SafeRoute (Black)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.040	0.005	0.134
4	0.034	0.008	0.236
8	0.037	0.006	0.169
12	0.056	0.006	0.108
16	0.022	0.017	0.750
20	0.005	0.002	0.347
24	0.028	0.005	0.177
SafeRoute (Red)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.016	0.003	0.183
4	0.019	0.001	0.066
8	0.026	0.003	0.114
12	0.022	0.004	0.198
16	0.017	0.006	0.366
20	0.002	0.001	0.625
24	0.006	0.004	0.635
SafeRoute (Yellow)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.018	0.009	0.503
4	0.026	0.002	0.085
8	0.025	0.003	0.115
12	0.036	0.007	0.204
16	0.020	0.008	0.411
20	0.008	0.003	0.411
24	0.019	0.009	0.483

Appendix-O(e)

Armor-Tile (Epoxy) Samples

Table O-5 – Abrasion Test Results of Armor-Tile Samples after Outdoor Exposure

Armor-Tile (Black)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.020	0.010	0.480
4	0.017	0.005	0.305
8	0.022	0.008	0.362
12	0.021	0.011	0.535
16	0.016	0.012	0.742
20	0.015	0.004	0.275
24	0.018	0.010	0.537
Armor-Tile (Red)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.012	0.002	0.131
4	0.041	0.020	0.494
8	0.034	0.017	0.486
12	0.036	0.012	0.339
16	0.014	0.010	0.747
20	0.009	0.002	0.242
24	0.023	0.009	0.415
Armor-Tile (Yellow)			
Month	Avg Mass Loss (g)	Standard Dev	COV
0	0.014	0.004	0.296
4	0.019	0.004	0.228
8	0.016	0.005	0.308
12	0.024	0.014	0.584
16	0.014	0.010	0.737
20	0.016	0.006	0.376
24	0.026	0.008	0.324