Research & Technology Transfer

Alaska Department of Transportation & Public Facilities

Wearing Surface Testing and Screening:

Yukon River Bridge

FINAL REPORT

Prepared by:
J. L. Hulsey, Ph.D., P.E., S.E.

Richard Ward

Elliott Anderson

Date: September 2015

Prepared for:
Alaska Department of Transportation
Statewide Research Office
3132 Channel Drive
Juneau, AK 99801-7898

Publication Number:
T2-10-07

REPORT DOCUMENTATION PAGE			Form approved OMB No.
Public reporting for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-1833), Washington, DC 20503			
1. AGENCY USE ONLY (LEAVE BLANK) T2-10-07	2. REPORT DATE September 2015	3. REPORT TYPE AND DATES COVERED Final Report (07/01/2014 – 06/30/2015)	
4. TITLE AND SUBTITLE Wearing Surface Testing and Screening: Yukon River Bridge			5. FUNDING NUMBERS T2-10-07 AUTC Report # 410008 DTRT06-G-0011
6. AUTHOR(S) J.L. Hulsey, Ph.D., P.E., S.E. Richard Ward Elliot Anderson			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Alaska Fairbanks The Alaska University Transportation Center Institute of Northern Engineering Fairbanks, AK 99775			8. PERFORMING ORGANIZATION REPORT NUMBER INE/AUTC 15.13
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) State of Alaska, Alaska Dept. of Transportation and Public Facilities Research and Technology Transfer 2301 Peger Rd Fairbanks, AK 99709-5399			10. SPONSORING/MONITORING AGENCY REPORT NUMBER T2-10-07
11. SUPPLENMENTARY NOTES			
12a. DISTRIBUTION / AVAILABILITY STATEMENT No restrictions			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) There is a demand and a need for cheaper and alternative surface coverings in environments with high temperature fluctuations. Our design for an alternative surface covering involves a basic two-part component epoxy with the addition of a solvent. The purpose of the solvent is to disrupt the reaction that forms the ordered chains to form a more disordered crystalline structure. The solvent in the finished product is 3% by volume of isopropyl alcohol. This mixture of epoxy and solvent has higher impact strength than epoxy alone, as well as a much lower brittle transition temperature of –27°C compared with 10°C for epoxy. An environmental chamber, tensile tester, Charpy impact tester, and 4-point bending test were used to determine these conclusions. The final product can be tailored with different aggregates to fit a specific need, such as decking surface material to coat the wooden planks on the Yukon River Bridge.			
14- KEYWORDS : Bridge decks (Pdybbsf), Bridges (Pdyb), Steel bridges(Pdybmmm)			15. NUMBER OF PAGES
			16. PRICE CODE N/A
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT N/A

NSN 7540-01-280-5500

STANDARD FORM 298 (Rev. 2-98)
Prescribed by ANSI Std. 239-18 298-102

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

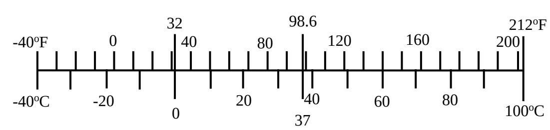


Table of Contents

Table of Figures

List of Tables

Abstract

There is a demand and a need for cheaper and alternative surface coverings in environments with high temperature fluctuations. Our design for an alternative surface covering involves a basic two-part component epoxy with the addition of a solvent. The purpose of the solvent is to disrupt the reaction that forms the ordered chains to form a more disordered crystalline structure. The solvent in the finished product is 3% by volume of isopropyl alcohol. This mixture of epoxy and solvent has higher impact strength than epoxy alone, as well as a much lower brittle transition temperature of −27°C compared with 10°C for epoxy. An environmental chamber, tensile tester, Charpy impact tester, and 4-point bending test were used to determine these conclusions. The final product can be tailored with different aggregates to fit a specific need, such as decking surface material to coat the wooden planks on the Yukon River Bridge.

Executive Summary

Consider that the State of Alaska has a bridge on the Dalton Highway that crosses the Yukon River on a 6% grade. The bridge is over 2,295 ft long and has a 30 ft wide roadway supported by 6 spans. The superstructure is supported by two closed box girders. The box girders support a stiffened orthotropic steel deck. This structure was built in the 1970s, and at the time, a two-layer wood deck (approximately 6 in. thick) was installed as a temporary wearing surface. The bridge carries heavy trucks to the North Slope, and during the winter, trucks typically must use tire chains to cross the structure.

Traction for the temporary wood deck is low, especially when the deck is wet. Further, the overall life expectancy of the upper wood layer is only about 7 years, which is approximately the half-life of most traditional material wearing surfaces. Costs to replace and maintain a timber deck are excessive, and with cost increases and deterioration in the quality of timber available for boards, the need to find cost-effective alternatives is paramount. Due to the demand for cheaper and alternative surface coverings in environments with high temperature fluctuations, a solution to the problem was sought. The design tested in this project involves a basic two-part component epoxy with the addition of a solvent. The purpose of the solvent is to disrupt the reaction that forms the ordered chains to form a more disordered crystalline structure. Testing 20 different combinations of solvents with epoxy, we found one that met and exceeded our criteria.

The solvent in the finished product is 3% by volume of isopropyl alcohol. This mixture of epoxy and solvent has higher impact strength than that of epoxy alone, as well as a much lower brittle transition temperature of –27°C compared with 10°C for epoxy. An environmental chamber, tensile tester, Charpy impact tester, and 4-point bending test were used to determine these conclusions. Through trial and error in application of the epoxy and solvent mixture during testing, a final mixture application was determined.

In conclusion, the final product can be tailored with different aggregates to fit a specific need such as decking surface material to coat the wooden planks on the Yukon River Bridge.

1. Introduction

The Yukon River Bridge, located about 50 miles north of Fairbanks, Alaska, on the Dalton Highway, is a two-lane bridge with an orthotropic steel deck structure. The bridge was designed to carry highway traffic and the oil pipeline across the Yukon River. When the bridge was built in the early 1970s, a two-layer temporary timber wearing surface was installed over the steel deck. Because the bridge is on a 6% grade, trucks typically use tire chains to provide traction. The chains tend to cause serious wear on the timber surface over time. Due to the severe climate changes of this region and intense loading from passing trucks, the timber surface deteriorates at a rapid rate.

Over a 30-year period, the timber surface has been replaced four times: in 1981, 1992, 1999, and 2007. As the quality of the timber wood decreases, the time between replacements also decreases, which has resulted in an increase in material costs. Therefore, the Alaska Department of Transportation and Public Facilities (ADOT&PF) is interested in finding an alternative wearing surface that provides a longer life, is relatively lightweight, and offers flexible and improved traction. The alternative wearing surface must also be easy to install and maintain, and, overall, be a more economic option than timber.

Figure 1: Yukon River Bridge.

1.1 Yukon River Bridge Project 2006

In 1992, the ADOT&PF installed panels of alternative wearing surfaces produced by participating companies. These wearing surfaces included Transonite, a fiber-reinforced plastic surface supplied by Martin Marietta Composites, ultra high-density polyethylene by Ultra Poly, Inc., and Super Panel, a fiber-reinforced polymer supplied by Creative Pultrusions, Inc. and Compositech, Inc. The ADOT&PF also installed Cobra-X, a high-density polyethylene panel with a contoured surface. These wearing surface panels were subjected to service conditions from 1992 to 2006. The only test surface that did not suffer from intense damage and that met the weight requirements of the Yukon River Bridge was Cobra-X. By 2006, however, Cobra-X, which was reported by truckers to provide lower traction than the existing timber deck, was no longer manufactured.

Dr. Leroy Hulsey, a professor at the University of Alaska Fairbanks (UAF) in the Civil Engineering Department, became interested in ADOT&PF's search for an alternative wearing surface and began a collaborative study. The purpose of this study was to develop a laboratory testing procedure to determine the traction and wear resistance of wearing surface materials. These results would then be used for ranking wearing surface materials based on their eligibility to replace the wood surface of the Yukon River Bridge. The study's mission statement was as follows:

> An ideal wearing surface for the Yukon River Bridge must be flexible, durable, ductile, and lightweight. It must also have sufficient traction to accommodate winter truck chains on a 6% grade. Connections between the wearing surface and the orthotropic steel deck should be designed to accommodate differential thermal strains between the wearing surface and the orthotropic steel deck.

With research funding by ADOT&PF and the Alaska University Transportation Center (AUTC), Dr. Hulsey hired two UAF graduate students, Wilhelm Muench and Zackary Jerla, to carry out the research and produce laboratory procedures for testing alternative wearing surfaces. Zachary focused on the structural durability of the wearing surface system. Five experimental bridge-deck panels were tested at room and cold temperatures and evaluated for structural behavior and stiffness. Zachary's studies provided a basis for ranking the panels based on structural durability and applicability for use on the Yukon River Bridge.

Wilhelm's work focused on test equipment and procedures that would provide a reliable scientific method for finding the coefficient of friction of a wearing surface and assess the amount of damage caused by tire chains. Once the apparatus was designed and built by Wilhelm, tests for measuring the traction and wear of four alternative wearing surface panels were conducted. The wearing surface panels included Transonite, ultra high-density polyethylene, Super Panel, and Cobra-X—all tested by ADOT&PF on the Yukon River Bridge. The results were used as a basis for ranking the various wearing surfaces for possible use on the Yukon River Bridge.

1.2 Yukon River Bridge 2011

Although procedures were developed to test alternative wearing surfaces, the ADOT&PF did not replace the timber surface on the Yukon River Bridge in 2007. In summer 2011, Dr. Hulsey hired Ty Wardell, an undergraduate student, to continue the research using the same test equipment and procedures developed by Wilhelm. Instead of a focus on developing test procedures, the new focus of the research was on finding an alternative wearing surface by cooperating with and providing feedback to interested companies.

2. Scope of Work

Part 1

Due to a limited amount of time in 2012, Richard Ward, an undergraduate student in Mechanical Engineering, was hired by Dr. Hulsey. Richard was hired to continue the research that was previously conducted by Ty Wardell and Wilhelm Muench. The focus of this effort was to test the different materials given to UAF by interested companies and compare the materials with the mixture developed by Dr. Hulsey.

Part 2

After the alternative wearing surfaces were tested by Richard Ward, Dr. Hulsey hired an undergraduate in Civil Engineering, Elliott Anderson. Elliott and Dr. Hulsey used the information gathered by Richard Ward, Ty Wardell, and Wilhelm Muench to continue perfecting an alternative wearing surface that would have a longer life, be relatively lightweight, and offer flexible and improved traction compared with the existing wooden surface. Dr. Hulsey and Elliott developed several tests to determine the appropriate percentage of isopropyl alcohol. After multiple tests, Dr. Hulsey selected a 3% isopropyl alcohol mixture with Type III dot epoxy and hardener. Following the decision on the percentage of isopropyl alcohol to use, further tests were run to determine the number of sealings of the epoxy mixture that would be applied to the wooden planks. Dr. Hulsey and Elliott determined that two seal coatings would be the most practical, based on the data gathered. With the conclusion of the testing sections mixture, Elliott applied the epoxy mixture to the boards that would be installed on the Yukon River Bridge.

3. Test Results and Data

Part I

3.1 Project Basis

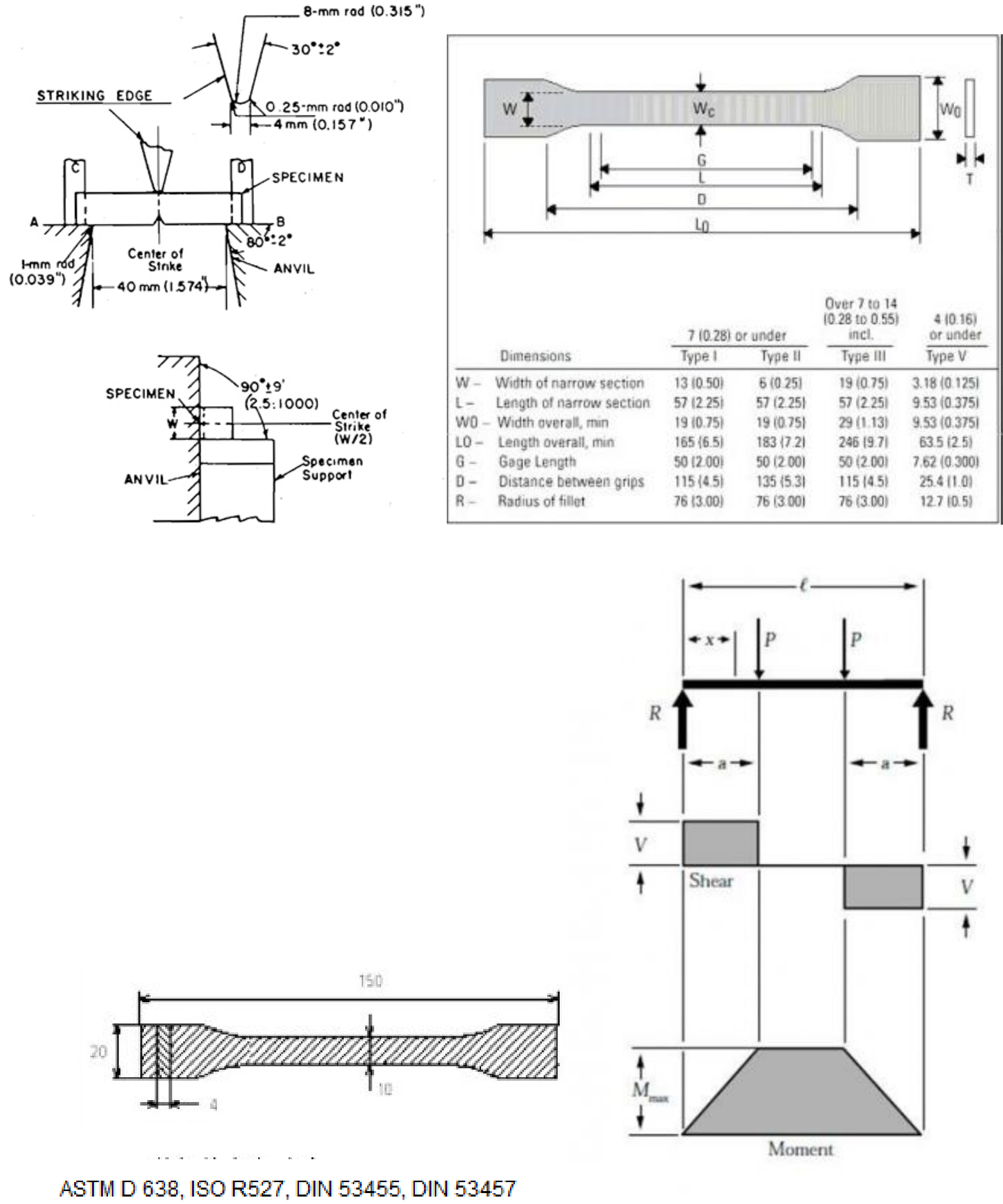
Fairbanks, Alaska, has a temperature differential that can range from as low as −60°F to a high of 100°F. At low temperatures, most surface coverings, such as epoxy, are very brittle and crack with minimal impact. The materials that are strong and resilient at low temperatures are not cost-effective and tend to be bulky. This project on wearing surface testing developed following a determination by ADOT&PF that the annual cost and maintenance of bridges in extreme environments could be reduced. According to the National Bridge Inventory, only 8 years ago it was found that almost a quarter of the nation's major bridges are functionally obsolete. With rising material costs, the number of bridge repairs will only rise. Therefore, our mission was to develop a surface material that is impact- and wear-resistant and will maintain its resistance in extreme environments.

Involving a basic two-part component epoxy with the addition of a solvent allows us to rearrange and disrupt molecular structure. Initially, from dealing with the ordered chains of straight epoxy, we formulated a product that has a more disordered crystalline and less brittle structure. By decreasing the length of molecular chains, the cured epoxy has more dislocation areas, which allows the product to elastically deform under stress. The percentage of solvent in the finished product that best fits our design criteria is 5% by volume of isopropyl alcohol. Our goal was to obtain 50% of the yield strength of manufactured epoxy, and with our final design, we obtained 63% of the yield strength in tension. Additionally, we increased the ability of the product to absorb impact energy by 350% at room temperature down to −27°C. Potential problems that needed to be addressed for our design included material workability, material strength retention under extreme climate conditions, and curing time of the product.

Most applications of epoxy are for bonding materials at a normal temperature range of 0 to 30°C, but our design was to make epoxy more favorable to a large decrease in temperature for harsh environments, such as that of Interior Alaska. This product can be used on the Yukon River Bridge as a more ductile epoxy to increase wear resistance on the decking surface.

Currently, the wearing surface of the bridge is Douglas fir planks, and they average only 7 years of life before the entire surface needs to be replaced. Not only is the wearing surface unsatisfactory, but in freezing and wet conditions, the traction surface leaves a slippery and unsafe finish for driving. By fully encapsulating the planks with the designed epoxy mixture, the planks become resistant to water intrusion, the expansion of wood from moisture freezing in cold temperatures is greatly reduced, ductility increases, and the brittle transition temperature is reduced. With the epoxy mixture and the aggregate components applied to the bridge wearing surface, the compressive strength of the surface increases, leaving a traction surface with a high friction coefficient.

Codes and standards that the experimentation was based on include ASTM D638 standard size tensile test specimens, replicas of ASTM D6110 Charpy samples, and maintaining ASTM D6272 for the 4-point bending test



Dimensions	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55) incl.	4 (0.16) or under
	Type I	Type II	Type III	Type V
W – Width of narrow section	13 (0.50)	6 (0.25)	19 (0.75)	3.18 (0.125)
L – Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	9.53 (0.375)
W0 – Width overall, min	19 (0.75)	19 (0.75)	29 (1.13)	9.53 (0.375)
L0 – Length overall, min	165 (6.5)	183 (7.2)	246 (9.7)	63.5 (2.5)
G – Gage Length	50 (2.00)	50 (2.00)	50 (2.00)	7.62 (0.300)
D – Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	25.4 (1.0)
R – Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	12.7 (0.5)

Figure 2: ASTM standards.

3.2 Methodology

Our main approach was to select four different solvents and mix them individually into the base epoxy in an attempt to retain a higher ratio of ductility to strength within the cured product. Using this criterion, four different solvents of varying costs and properties were selected. These solvents included DMSO (dimethyl sulfoxide) due to its effective solvent properties and molecular size, kerosene due to its cost, isopropyl alcohol due to its cost and molecular bonding, and acetone due to its cost and strong solvent properties. Also, to increase compressive strength, we added varying amounts of sand, from 150% to 500% by volume.

We mixed these solvents with epoxy at varying percentages by volume and tested how each sample behaves in the environmental chamber at extreme temperature differentials (–50 to 22°C). This procedure allowed us to reduce the number of samples due to inadequate bond strengths at lower temperatures. Testing impact resistance in the Charpy machine, we were able to eliminate some solvents, such as high concentrations at 15% of all solvents, kerosene, and DMSO, because of poor physical results.

Though we knew that adding solvents to the base mixture would increase the ductility of the cured product, we had no quantified data. Our design started by using different mixtures, with the qualitative properties of high and low concentrated mixtures. Overall, we tested 20 different combinations of solvents and epoxy to find the one that met and exceeded our criteria. For most of the products tested, we actually made the epoxy more ductile, but lost too much strength of the original material. Out of the 20 products tested, only two products met our criteria: 5% acetone and 5% isopropyl alcohol.

Epoxy has other qualities that make it very attractive, such as its ability to bond well to itself after a product has been cured. That means if a failure occurs in a product due to wear, the product can easily be patched with the same application. Aware of this property, we ensured that when the chemical structure of the base epoxy was changed, the property was retained in the product.

3.3 Results

3.3.1 Charpy impact tests

Figures 3, 4, 5, and 6 show the Charpy impact tests calculated and graphed by impact strength vs. temperature. The tests were conducted by reducing the temperature of the Charpy samples to –40°C. By attaching a thermistor to the test samples, we conducted the impact tests to view where the brittle-to-ductile transition temperature occurred. The brittle transition temperature is clearly shown in

Figures 3–6 as a large jump that occurs around –27°C, –20°C, or 10°C. The test of 5% isopropyl alcohol has the lowest temperature occurrence as well as the highest impact strength.

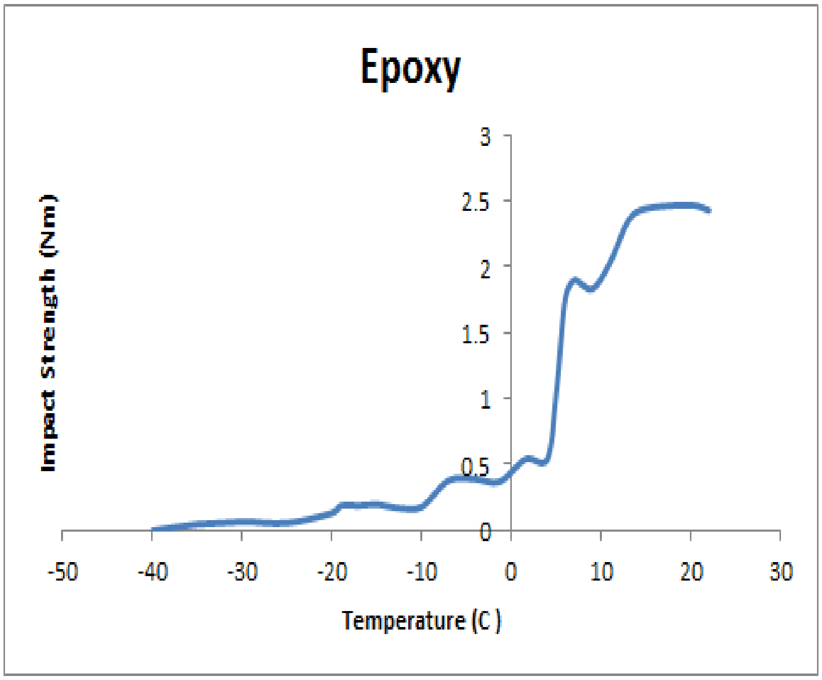


Figure 3: Epoxy samples – temperature rise vs. impact strength.

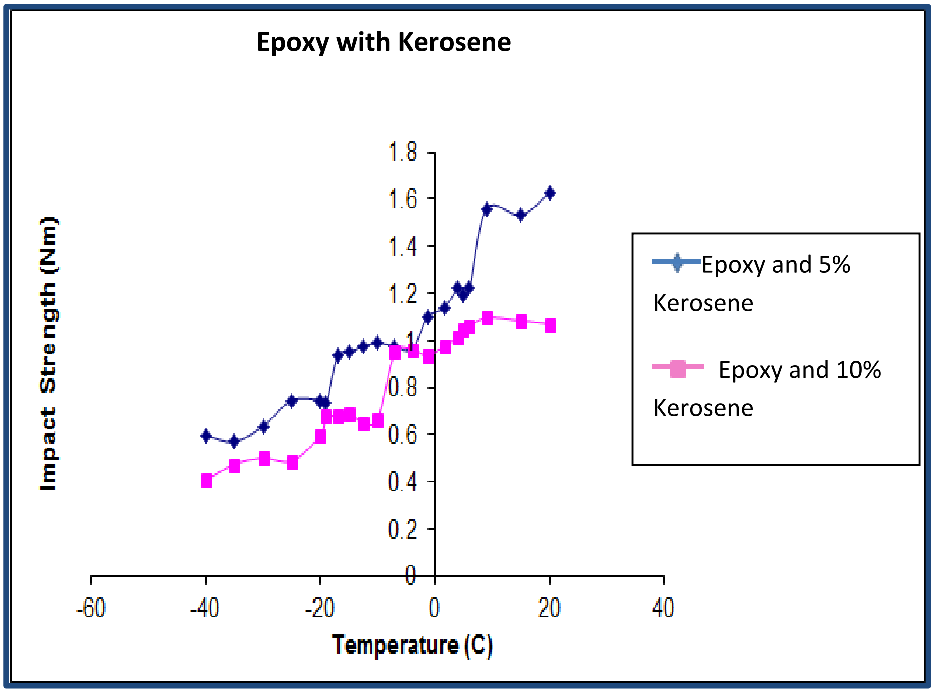


Figure 4: Epoxy with kerosene samples – temperature rise vs. impact strength.

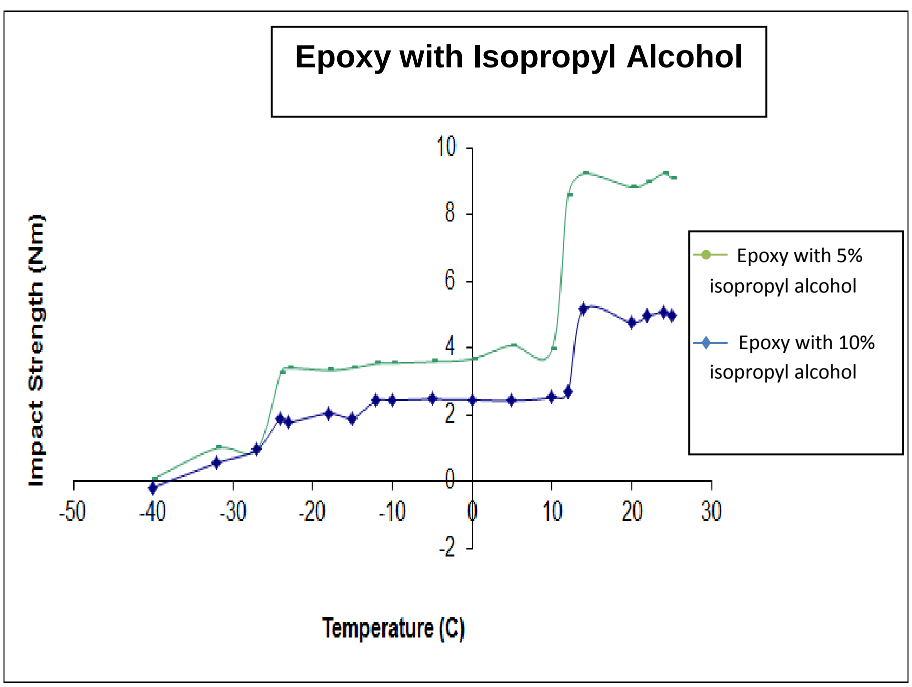


Figure 5: Epoxy with isopropyl alcohol samples – temperature rise vs. impact strength.

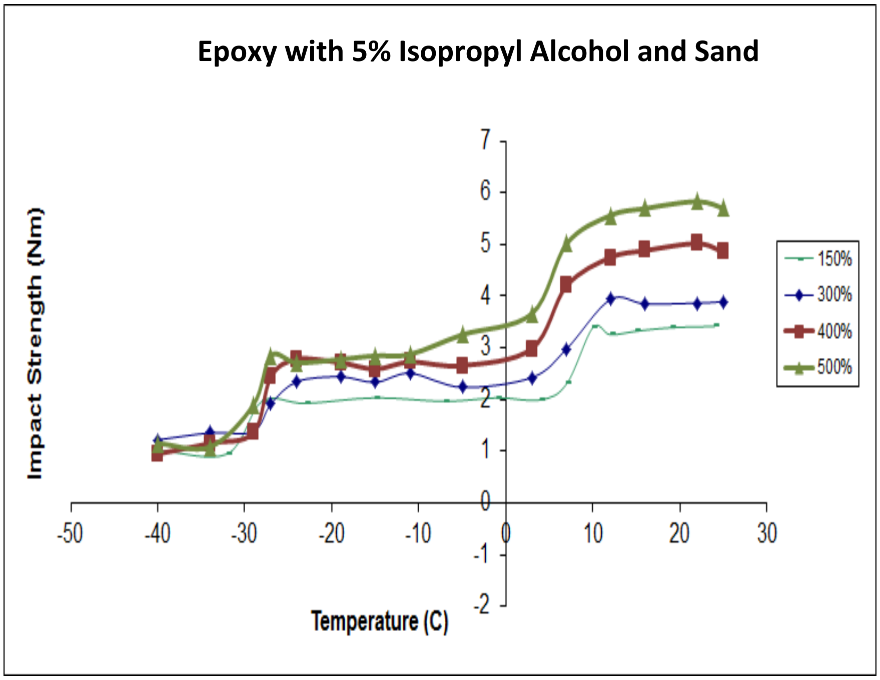


Figure 6: Epoxy with isopropyl alcohol and sand samples – temperature rise vs. impact strength.

3.3.2 Tensile tests

Shown in this section are the Instron tensile tests. We performed a bond test, in which different solutions of epoxy were applied to two halves of an ASTM dog bone metal sample, and tested how much force was required to break the material. In Figure 7, regular epoxy is shown, and in Figures 8 and 9, two solvents are shown. The 60% reduction in strength is clearly indicated.

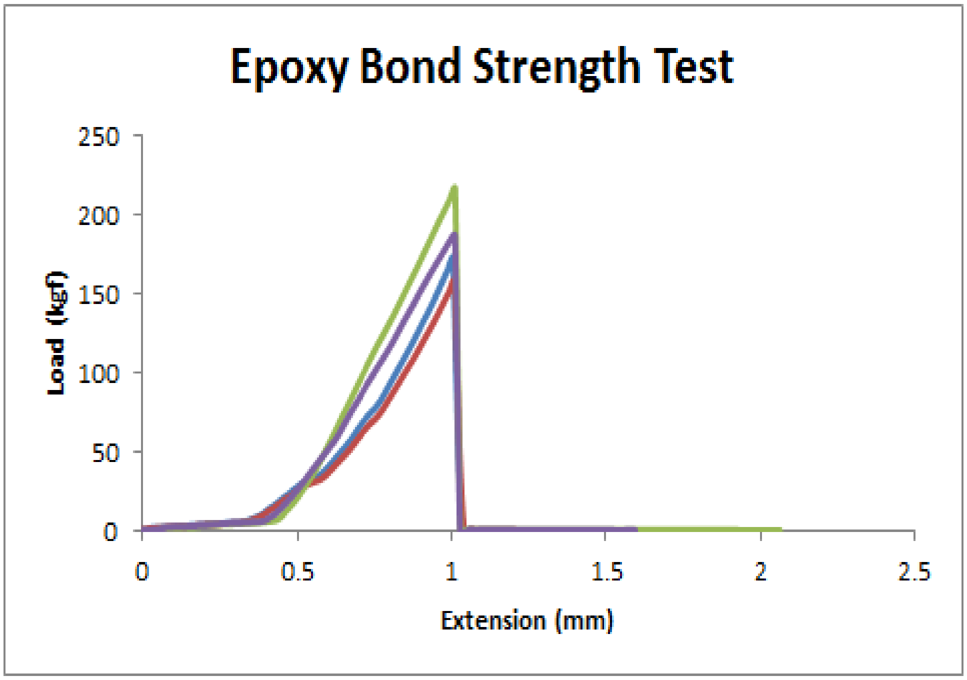


Figure 7: Epoxy samples – extension vs. load.

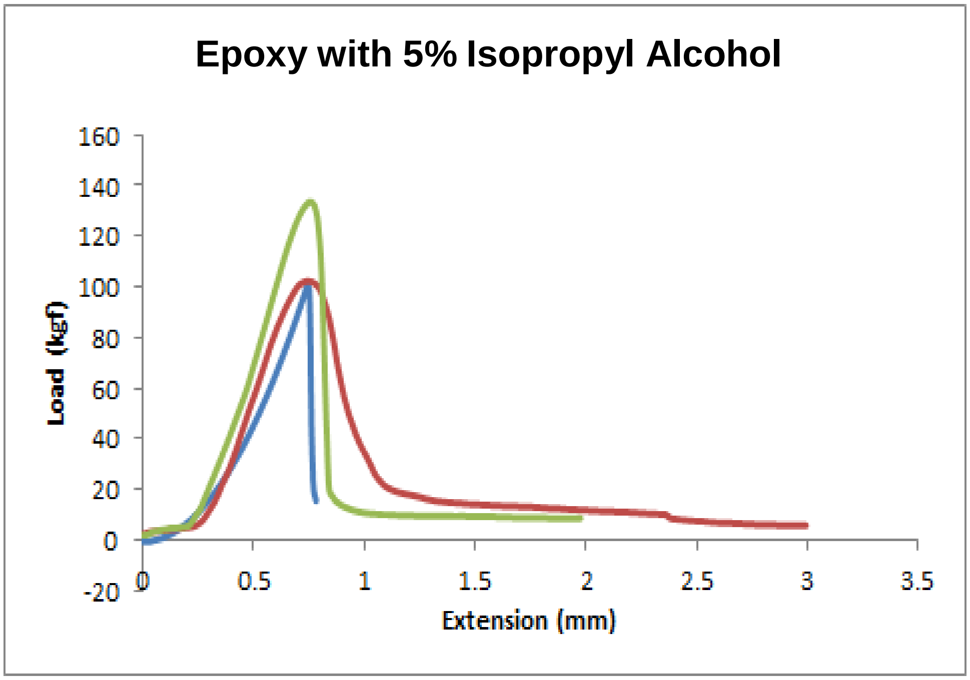


Figure 8: Epoxy with isopropyl alcohol samples – extension vs. load.

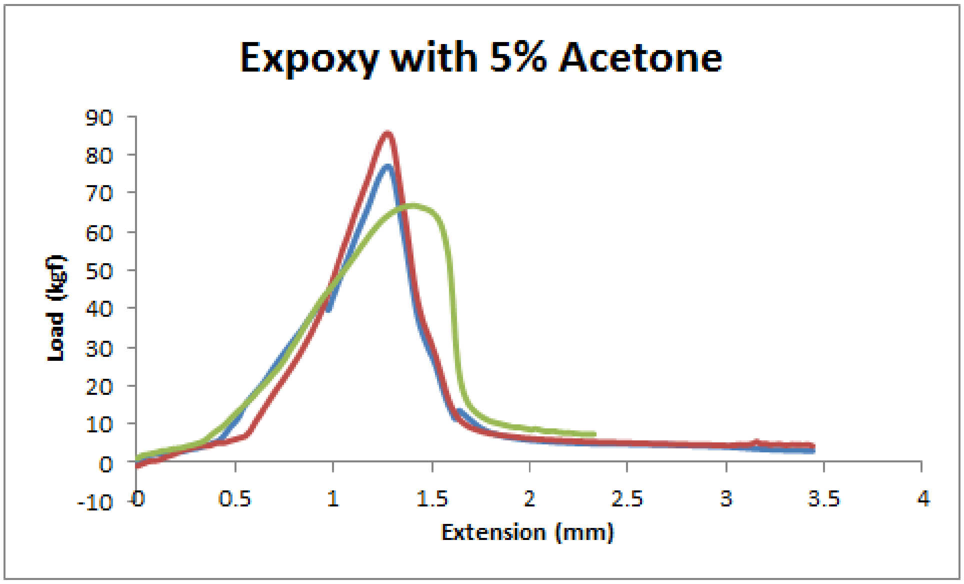


Figure 9: Epoxy with acetone samples – extension vs. load.

Note that the kerosene and DMSO samples were not completely tested because they were deemed failed products. It seems that the composition of these chemicals is not chemically compatible with epoxy; the structural matrix broke down so much that weak characteristics were produced.

3.4 Chemical Theory

The structures in epoxy are shown in Figure 10. These structures bond through a simple deprotonation reaction of the phenol group on the side of the benzene ring. This reaction occurs under the presence of a strong base, in this case sodium hydroxide. The product of this reaction is shown in Figure 11. The reaction continues by opening the epoxide ring and exposing another hydroxyl group. The long chain molecule is shown in Figure 12.

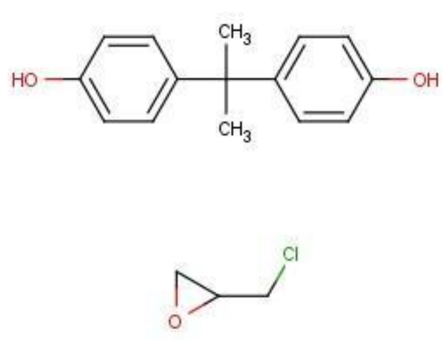


Figure 10: Basic structures in epoxy.

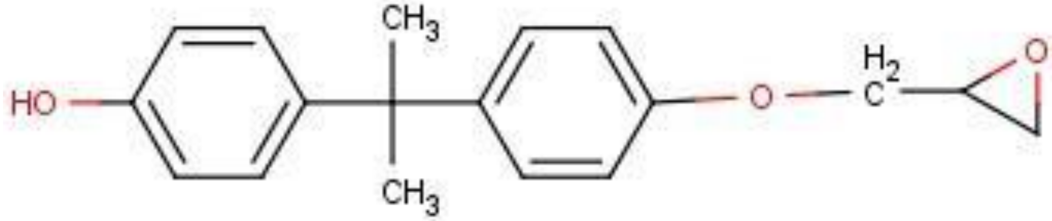


Figure 11: First step of polymerization.

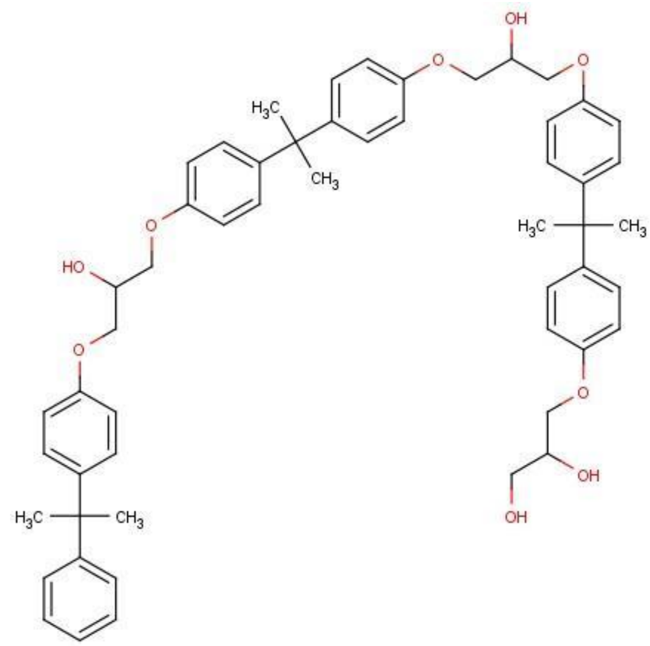


Figure 12: Long chain epoxy molecule.

When a solvent is added to the epoxy mixture, a few things can happen. The first solvent that is shown is acetone. Alcohol attacks the ketone and forms an acetal. This process is shown in Figure 13, where the path of the electrons is also shown.

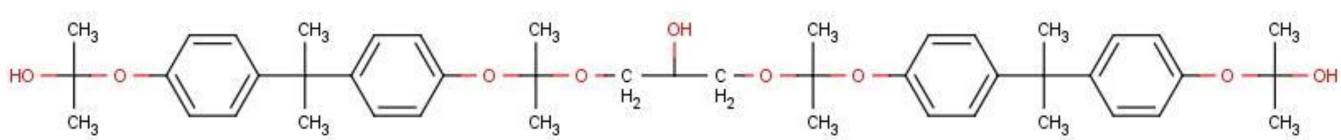


Figure 13: Epoxy mixed with acetone solvent

This reaction had unfavorable properties because it extends the chains. The only cross-linking between these chains occurred at the hydroxyl groups in the middle of the molecule shown in Figure 14.

The addition of the extra carbon and oxygen on each side of the hydroxyl group reduces the amount of cross-linkages throughout the molecule and contributes to a weaker crystalline structure.

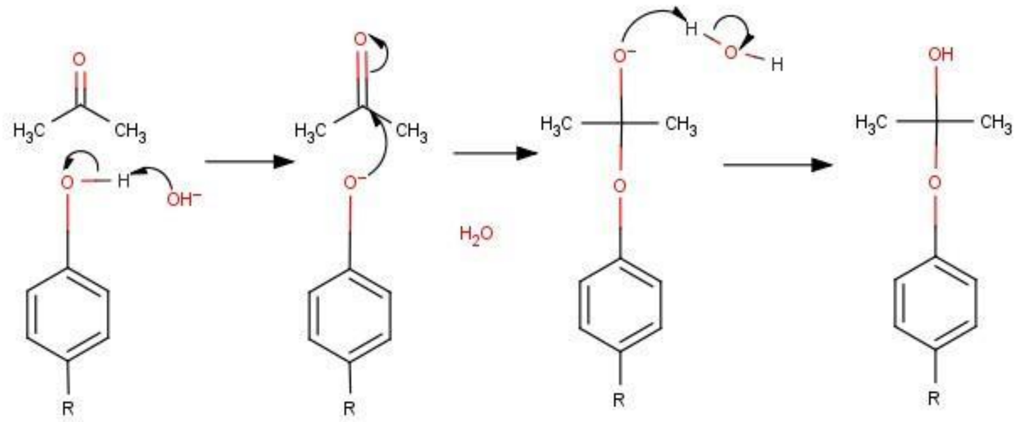


Figure 14: Alcohol and ketone reaction.

Another solvent—isopropyl alcohol—was tried; it did not have a ketone group to react with the hydroxyl group in the same way. This alcohol instead has interesting properties; it is able to hydrogen bond with the hydroxyl groups on the epoxy molecules. This ability is shown in Figure 15. The properties that came of this behavior were a 60% reduction of tensile strength, but a 350% increase in impact strength as well as a 30°C reduction in brittle transition temperature.

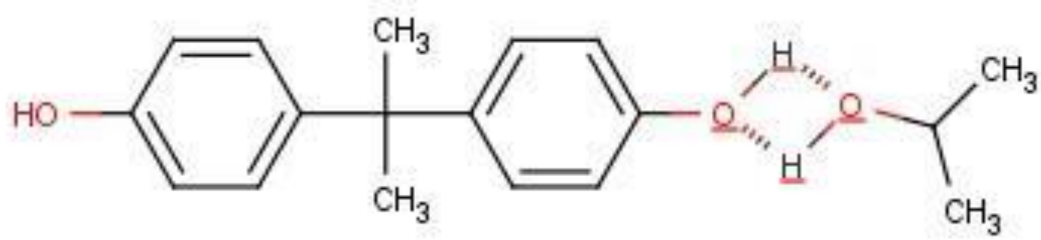


Figure 15: Epoxy hydrogen bonding with isopropyl alcohol.

This final product met our goals and in some cases exceeded them. We were unable to perform direct comparisons to Rhino Liner™, because the company would not provide a sample to test our product against under the same conditions.

3.5 Facilities

Several different apparatuses were used to test the prototypes:

- Environmental Chamber
  - Temperature-controlled chamber.
  - Ability to run bond strength tensile tests across a temperature variation of –50°F to 100°F.
  - After cooling samples to –50°F, Charpy impact tests conducted.
  - Four-point bending test was performed to ensure that product maintained a high bond strength.

Figure 16: Environmental chamber used to freeze the samples.

- Tensile Test
  - Allows the ability to measure bond strength with a variety of different materials.

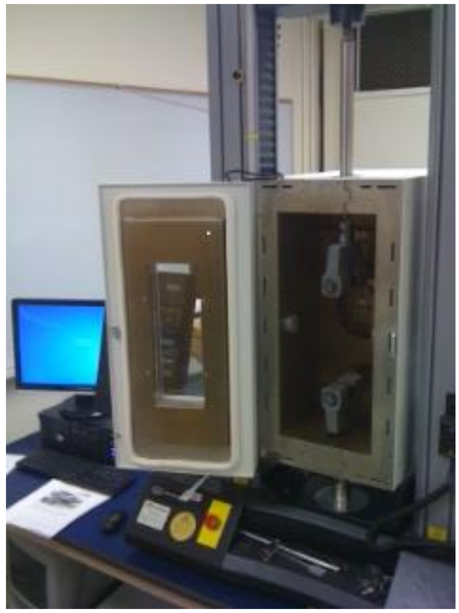


Figure 17: Instron tensile test apparatus.

- Charpy Impact Test
  - Measures impact properties of epoxy and its performance in extreme cold.
  - Compared formulated test epoxy with normal strength epoxy.

Figure 18: Charpy.

3.6 Materials Tested

The materials tested are shown in Table 1, and the test results are shown in Tables 2–6.

Table 1: Materials Tested

Material Tested	Max Axial Force	Total Deflection (in)	Axial Displacement (in)	Width (in)	Height (in)	Area (in^2)
FiberGrate #1 (½")	1.0294296	0.12630045	0.8686375	3.013	0.5275	1.589358
FiberGrate FGa#1 (¾")	4.000 kips	0.13291365	0.8315417	3.012	0.84	2.53008
KwikBond #1	2.3366144 kips	0.00980061	0.04373315	3.017	1.975	5.958575
KwikBond #2	2.5155287 kips	0.00703315	0.04328334	3.042	1.9825	6.030765
KwikBond #3	2.3929334	0.01726331	0.05082731	3.032	2.032	6.161024

Table 2: FiberGrate #1 (½")

Final Data for FiberGrate #1 (½")					
Max Axial Force	**Total Deflection (in)**	**Axial Displacement (in)**	**Width (in)**	**Height (in)**	**Area (in^2)**
1.0294296	0.12630045	0.8686375	3.013	0.5275	1.5893575

The FiberGrate #1 (½") sample was tested by using a 4-point bending test within ASTM testing standards. The sample was first cooled in a calibrated environmental chamber to –45.6°C (–50.08°F). This particular sample exceeded the test and did not break within the force parameters that were distinguished within the loading criteria. A max force of 1.0295 lb was applied to the sample, at which point the sample bent far enough to physically slip out of the fixture. This means that at –50°F, the sample was ductile enough to pass this test for the Yukon River Bridge. When the limit was reached, the test was ended, and we concluded that this sample would require on-site testing to be considered for future application.

Table 3: FiberGrate FGa#1 (¾")

Final Data For FiberGrate FGa#1 (¾")					
Max Axial Force	**Total Deflection (in)**	**Axial Displacement (in)**	**Width (in)**	**Height (in)**	**Area (in^2)**
4.000 kips	0.13291365	0.8315417	3.012	0.84	2.53008

The FiberGrate FGa#1 (¾") sample was tested by using a 4-point bending test within ASTM testing standards. The sample was first cooled in a calibrated environmental chamber to –45.6°C (–50.08°F). This particular sample exceeded the test and did not break within the force parameters that were distinguished within the loading criteria. A max force of 4,000 lb was applied to the sample, at which point the sample passed and exceeded the allowed tolerance for application as a test section on the Yukon River Bridge. When this limit was reached, the test was ended, and we concluded that this sample would require on-site testing to be considered for future application.

Table 4: KwikBond #1

Final Data For KwikBond #1					
Max Axial Force	**Total Deflection (in)**	**Axial Displacement (in)**	**Width (in)**	**Height (in)**	**Area (in^2)**
2.3366144 kips	0.00980061	0.04373315	3.017	1.975	5.958575

The KwikBond #1 test sample was run at –45.6°C (–50.08°F). A 4-point bending test was run with a total time of 5.6336 s. Actuator movement was upwards at 0.475 in./min to simulate a static loading scenario. The test sample had positive central breaking.

Table 5: KwikBond #2

Final Data For KwikBond #2					
Max Axial Force	**Total Deflection (in)**	**Axial Displacement (in)**	**Width (in)**	**Height (in)**	**Area (in^2)**
2.5155287 kips	0.00703315	0.04328334	3.042	1.9825	6.030765

The KwikBond #2 test sample was run at –45.6°C (–50.08°F). A 4-point bending test was run with a total time of 5.6182 s. Actuator movement was upwards at 0.475 in./min to simulate a static loading scenario. The test sample had positive central breaking.

Table 6: KwikBond #3

Final Data For KwikBond #3					
Max Axial Force	**Total Deflection (in)**	**Axial Displacement (in)**	**Width (in)**	**Height (in)**	**Area (in^2)**
2.3929334	0.01726331	0.05082731	3.032	2.032	6.161024

The KwikBond #3 test sample was run at –45.6 °C (–50.08°F). A 4-point bending test was run with a total time of 6.5212 s. Actuator movement was upwards at 0.475 in./min to simulate a static loading scenario. The test sample had positive central breaking.

Part II:

3.7 Collecting Data

3.7.1 Determining percent isopropyl alcohol (Figure 19)

In order to test the resistance to moisture migration vs. percent alcohol in an epoxy mix, three different test boards were made. To determine what percent of isopropyl alcohol gave the best results, different percentages of it were added to the Type III dot epoxy. These sample board tests were conducted using the following procedure:

1. Set out even amounts of epoxy and hardener (In this case, 1.5 oz of epoxy and 1.5 oz of hardener were used).
2. Set out a desired amount of isopropyl alcohol.
   A. For the 3–5% isopropyl alcohol mix, 4.43 ml of isopropyl alcohol was used.
   B. For the 10% isopropyl alcohol mix, 8.87 ml of isopropyl alcohol was used.
   C. For the 20% isopropyl alcohol mix, 17.74 ml of isopropyl alcohol was used.
   (All amounts of isopropyl alcohol were taken using a volumetric pipet)
3. Mixed the epoxy and hardener by hand in a beaker, being careful not to mix too fast to avoid unnecessary air formation. Mixed for one min.
4. After mixing the epoxy and hardener homogeneously, added the desired amount of isopropyl alcohol. Mixed for an additional 2 min.
5. Once the mixture was well mixed, applied it to the sample board on all sides of the board. Application for this process was done using a ½ in. paintbrush.
6. Repeated Steps 4 and 5 for the other isopropyl alcohol mixes.
7. Once the board was completely covered in the alcohol/epoxy mixture, set it to dry for at least 6 hr.

Figure 19: Test samples 3–5%, 10%, 20% isopropyl alcohol.

8. After all boards had dried, original dry weights were taken of the samples. (This was done using a digital scale, where each board was weighed 3 times to ensure accurate results; the average was taken for each board).
9. Boards were placed under water in a large container.
10. On days 2, 5, 7, 8, 9, 13, 25, and 38 of being submerged in water, the weights were retaken to determine the amount of water each board absorbed (Figure 20). (This was done using a digital scale, with each board weighed 3 times to ensure accurate results; the average was taken for each board).

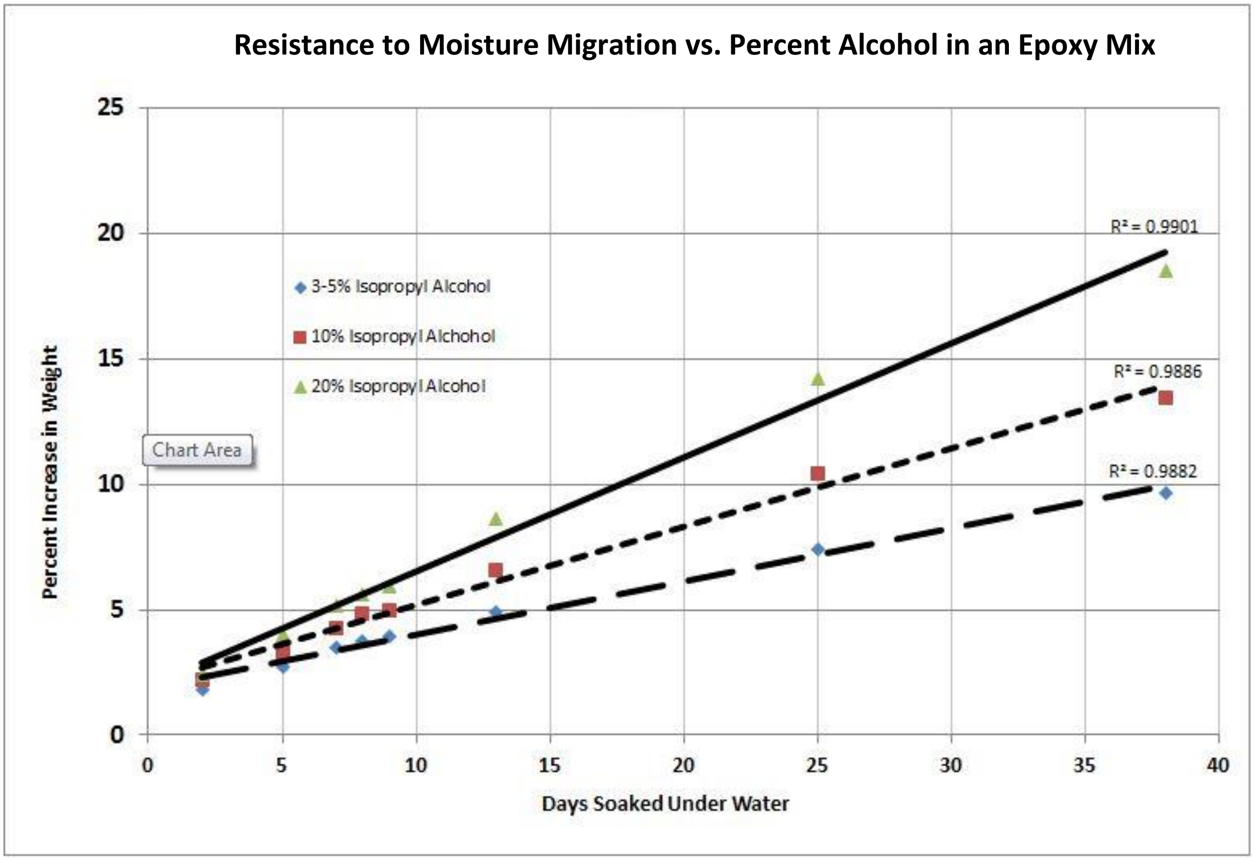


Figure 20: Resistance to moisture migration.

Graph Conclusion for Figure 20: These results gave clear data indicating that 3–5% isopropyl alcohol performed best while still giving the epoxy mobility and workability for application to the planks.

3.7.2 Determining the number of seal coatings (Figures 21–25)

After the amount of isopropyl alcohol was determined to be 3–5%, a test was conducted to determine the number of coatings of epoxy. This test was conducted by submerging boards in water. The following tests were conducted: no sealings, 1 sealing, 2 sealings, and 3 sealings. To determine the number of epoxy sealings that gave the best results, the following procedure was used:

1. Prepared 8 boards: 2 with no sealing; 2 with 1 sealing; 2 with 2 sealings; 2 with 3 sealings.
2. Set out even amounts of epoxy and hardener (in this case, 12 oz of epoxy and 12 oz of hardener were used on each board).
3. Set out 3% isopropyl alcohol (in this case, 21.3 ml isopropyl alcohol was used on each board).
4. Mixed the epoxy and hardener by hand in a beaker, being careful not to mix too fast to avoid unnecessary air formation. This was mixed for 1 min.
5. After the epoxy and hardener were mixed with even consistency, added the desired amount of isopropyl alcohol. This was mixed for an additional 2 min.
6. Once the mixture was well mixed, applied it to all sides of sample boards: 1 sealing on 2 boards; 2 sealings on 2 boards; 3 sealings on 2 boards. Application for this process was done using a ½ in. paintbrush.
7. Once each board was completely covered in the alcohol/epoxy mixture, it was set to dry for at least 6 hr.
8. Steps 2–7 were then repeated in order to coat the sample boards with 2 sealings and with 3 sealings. (At this point, this process should result in 8 total sample boards: 2 with no sealing; 2 with 1 sealing; 2 with 2 sealings; and 2 with 3 sealings.)
9. After all boards had dried, original dry weights were taken of the samples. (This was done using a digital scale. Each board was weighed 3 times to ensure accurate results, and the average was then taken for each board).
10. Boards were then placed under water in a large container.
11. On days 1, 2, 3, 7, 14, 20, 26, and 117 of being submerged in water, the weights were retaken to determine the amount of water each board absorbed. (This was done using a digital scale. Each board was weighed 3 times to ensure accurate results, and the average was then taken for each board).

Figure 21: Test samples: no sealing, 1 sealing, 2 sealings, and 3 sealings submerged in water.

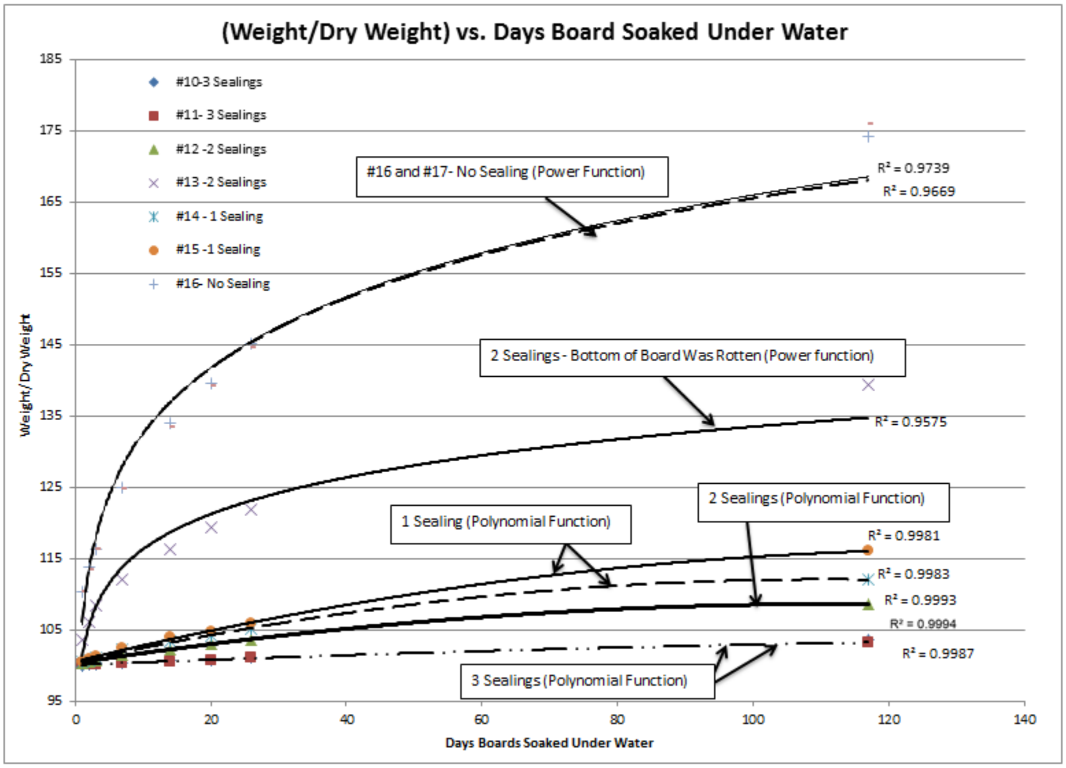


Figure 22: (Weight/dry weight) vs. days boards soaked.

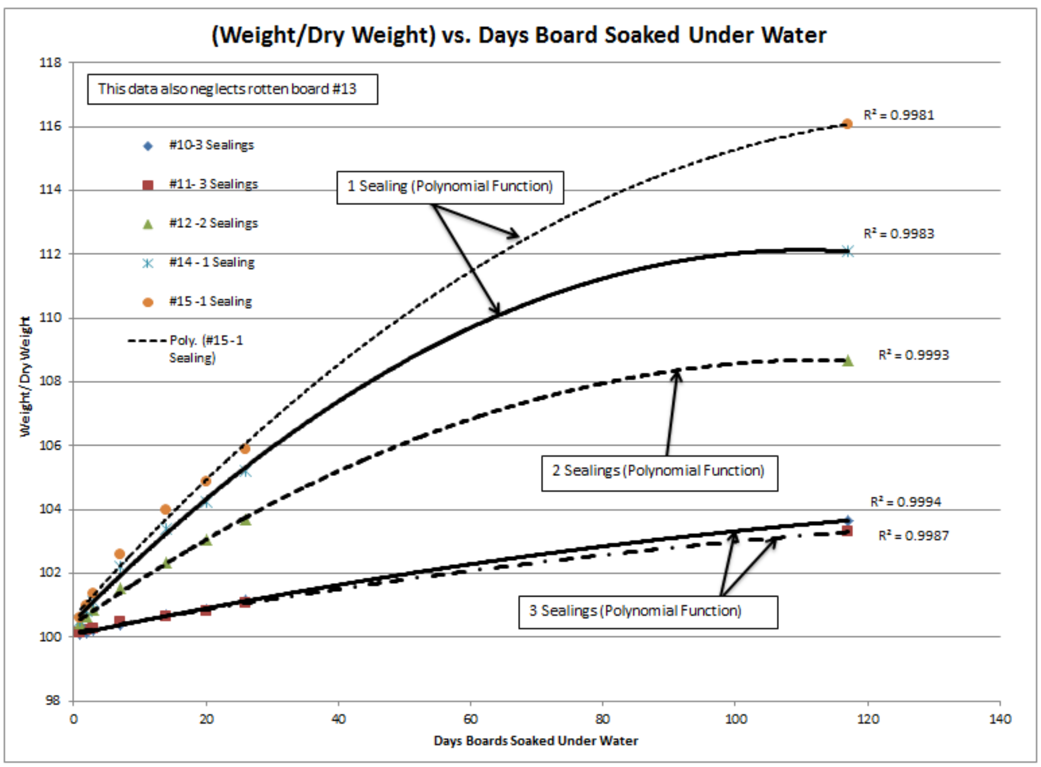


Figure 23: (Weight/dry weight) vs. days boards soaked.

Graph conclusion for Figures 22 and 23: Figure 22 displays all the test sections: 2 with no sealing, 2 with 1 sealing, 2 with 2 sealings, and 2 with 3 sealings. Figure 23 displays all the tests, neglecting the no-sealing samples and the rotten 2-sealings sample. This gave clear data on what was happening as the number of seal coatings was increased.

The results shown in Figures 22 and 23 demonstrate that as the number of seal coatings on the boards is increased, samples weighed less; thus, the samples absorbed less water with an increase in the number of coatings.

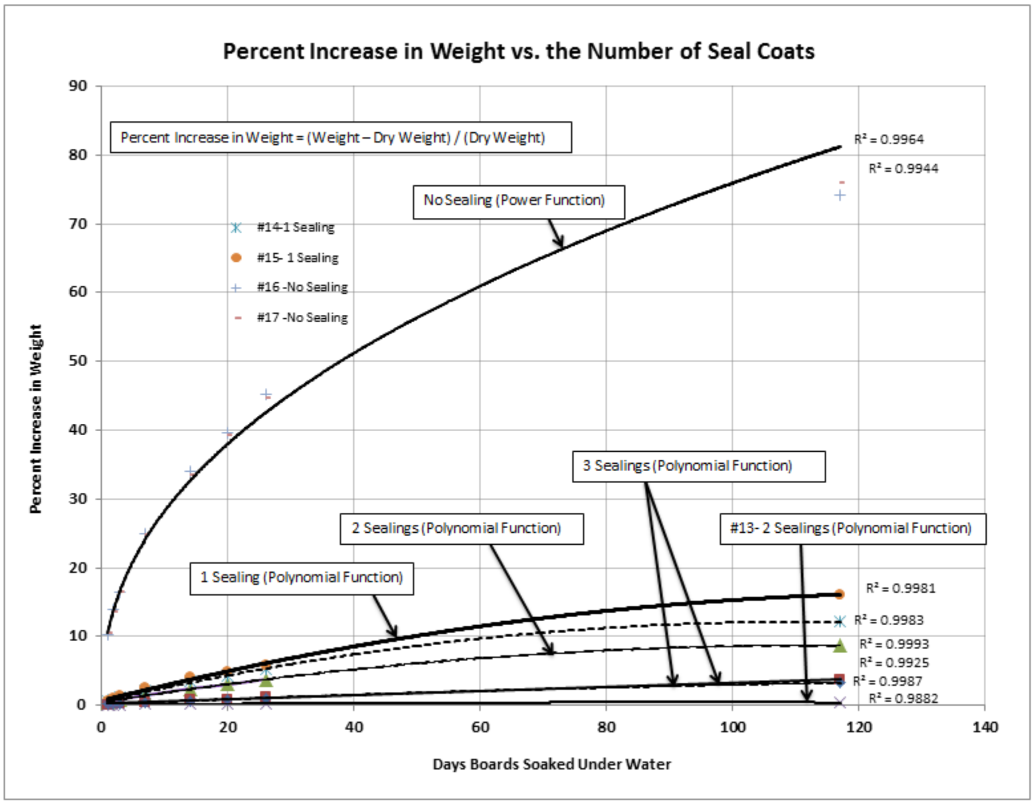


Figure 24: Percent increase in weight vs. number of seal coatings.

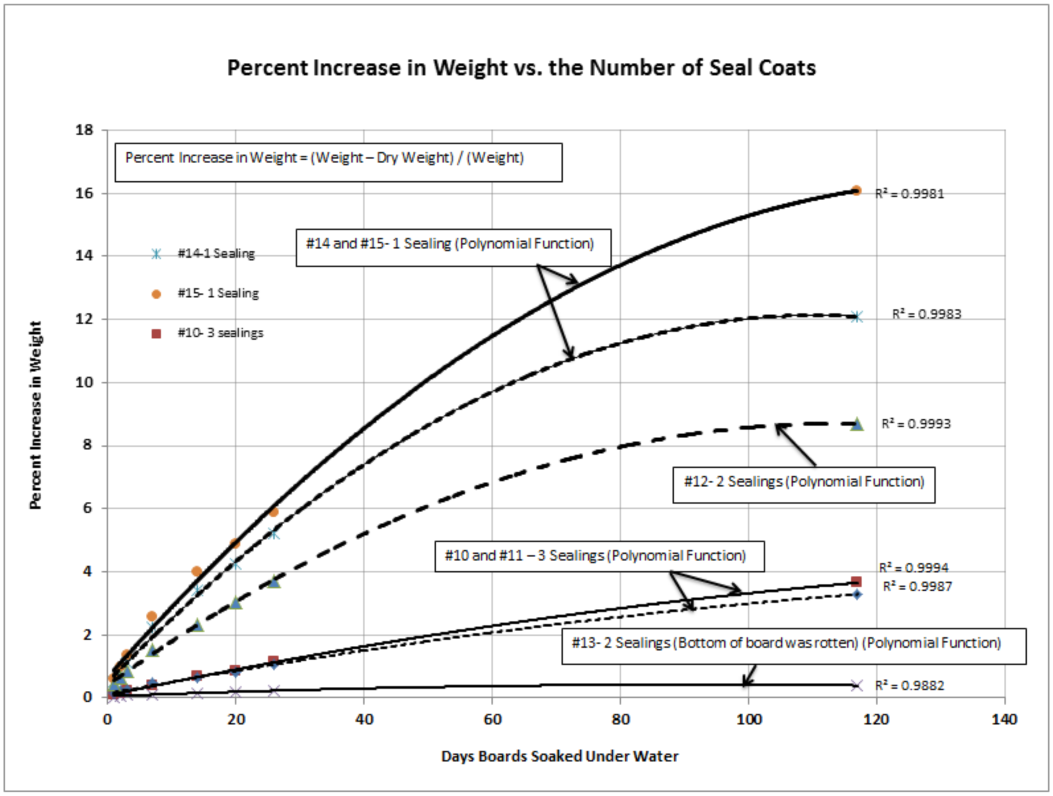


Figure 25: Percent increase in weight vs. number of seal coatings.

Graph conclusion for Figures 24 and 25: Figure 24 displays all the test sections: 2 with no sealing, 2 with 1 sealing, 2 with 2 sealings, and 2 with 3 sealings. Figure 25 displays all the tests, neglecting the no sealing. This gave clear data on what was happening as the number of seal coatings was increased.

The results shown in Figures 24 and 25 demonstrate that as the number of seal coatings on the boards is increased, samples weighed less; thus, the samples absorbed less water with an increase in the number of coatings.

3.7.3 Wear testing

After collecting test sample data on the isopropyl alcohol percentage and the test mixture, a traction wear test was conducted on the samples. This test was conducted by using the machine shown in Figure 26. The tire was loaded onto the sample panel in the tray with a force of 4,500 N, which was determined as an average value for the weight of trucks that pass over the Yukon River Bridge. With the tire locked at its axle, the hydraulic ram moves the tray back and forth, resulting in traction between the tire and the sample panel. This test demonstrates long-term wear to determine how the epoxy mixture would be affected by trucks driving across the surface of this material. Following this test, the epoxy coating showed little deformation (Figure 27), thus passing the traction wear test.

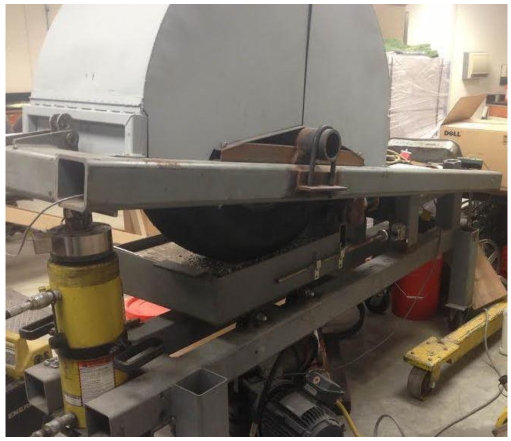


Figure 26: Traction and wear test equipment.

Figure 27: Epoxy sample after the wear test.

3.7.4 Application process on test planks

The test mixture application process requires the following Items:

- Type III dot epoxy
- Isopropyl alcohol
- Moisture content gauge
- Tacking cloth
- Plastic paper or visqueen
- A 7/8 in. hole bit
- 1-3/8 in. pieces of 13/16 in. PVC pipe
- Masking tape

- 1/8 in. metal strips, 3 in. tall x 8.ft long
- #50–#60 grade silica sand
- #6–#10 local aggregate (mostly 6–8, but #10 separated out)
- Mixing cans
- Low-speed drill
- Acetone (for cleanup)

Preparation process prior to coating planks:

1. Check the moisture content (MC) of boards with the MC gauge to ensure that MC is below 9%.
2. Set the boards on sawhorses, with the grain pointing up; label to ensure that the application is applied to the correct side (Figure 28).
3. Given the dot bolt pattern, mark where all the bolt holes will be drilled.


Figure 28: Laying out bolt pattern.

4. Countersink 1½ in. diameter hole at 1 in. depth. Be sure to use a jig or a drill press to obtain a hole that is perpendicular to the plane of the board (Figure 29).
5. Using a 3/8 in. drill bit, drill in the center of the countersunk holes (Figure 30) to bore a hole all the way through the board (this hole prevents cracking when bolts are inserted).

Figure 29: Drilling countersunk holes.

Figure 30: Completed board though application process.

6. Inspect the holes looking for any slivers; remove with pliers or sandpaper.
7. Sand the surface of the boards.
8. Tack the boards with tacking cloth, to get rid of the impurities and loose wood dust.
9. Cut 1½ in. PVC pipe to 1-5/8 in. lengths. This length is determined by the depth of the countersunk holes plus the thickness of the aggregate coating to meet the desired overall thickness of the planks.
10. De-bur the PVC cut pipe (Figures 31 and 32).

Figure 31: Bur on PVC pipe

Figure 32: De-burred PVC pipe

Final mixing procedure for application of seal coating:

11. Set out even amounts of epoxy and hardener.
12. Set out a 3–5% by volume amount of isopropyl alcohol.
13. Mix the epoxy and hardener with a low-speed drill; be careful not to mix too fast to avoid unnecessary air formation. Mix for 1 min.
14. Add the isopropyl alcohol, and continue to mix for 2 min.
15. When mixture is well mixed, apply to the boards on 5 of the sides (not the bottom) with a 3/16 in. notched squeegee or a paintbrush. When mixture has been well applied, allow to dry for at least 5–6 hr (Figure 33). Be sure that the coating on the boards is not tacky.

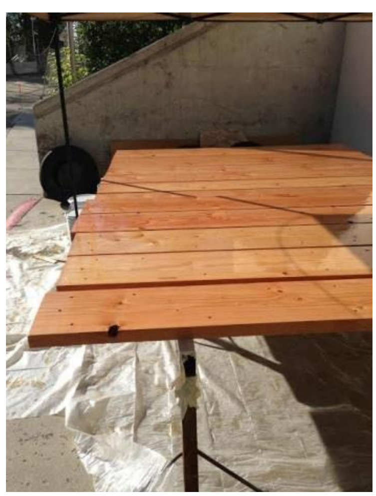


Figure 33: Planks drying after sealing

Final aggregate application preparation:

1. Be sure that the boards are completely dry and are not tacky.
2. Apply tape around the top perimeter of the boards to make up the overall thickness of the planks. This acts as a coating barrier. In this case, the boards were 1-7/8 in.; therefore, a 5/8 in. overhang of tape was applied to meet the overall height of the boards of 2½ in.
3. Place cut and de-burred PVC pipe into the countersunk holes of the planks.
4. Fill the inside of the PVC pipe with cotton balls to enable the coating to get inside the holes during the application process.
5. Lay out the planks on sawhorses to apply the coating (Figure 34).

Figure 34. Plank preparation before aggregate application.

Final aggregate application:

6. Set out even amounts of epoxy and hardener.
7. Set out a 3% by volume amount of the isopropyl alcohol.
8. Set out 2.5 times the amount of the total epoxy mixture of the fine-grained silica sand, and 2.5 times of the coarse-grained local aggregate.
9. Set the boards on sawhorses in a well-ventilated area (preferably outside).
10. Mix the epoxy and hardener with a low-speed drill; be careful not to mix too fast to avoid unnecessary air formation. Mix for 1 min.
11. Add the isopropyl alcohol, and continue to mix for 1 min.
12. Slowly, add in the fine-grained silica sand and the local aggregate. Allow enough mixing until all the sand is well saturated within the epoxy (2–3 min).
13. Apply the mixture to the boards, using your hands to spread the epoxy as evenly as possible. Gauge the thickness of the aggregate coating by the height of the tape and the height of the PVC pipe sticking out of the countersunk holes. Be careful not to cover the tops of the countersunk holes.

14. Once the mixture is in place, liberally apply the local aggregate by broadcasting it across the top of the boards. The top of the boards should look like they are covered with evenly dispersed dry aggregate.
15. Allow the mixture to dry on a level surface for at least 6 hr (Figure 35).

Figure 35: Planks drying.

Cleanup and disposal:

16. When the mixture has completely dried, remove the tape from the edges of the planks as well as the cotton balls inside the PVC pipe (Figure 36).

Figure 36: Removing tape and cotton balls.

17. Inspect each board to ensure that no aggregate has slipped onto the sides of the boards causing issues with spacing when the planks are applied to the surface of the bridge.
18. Properly dispose of the leftover material.

3.7.5 Conclusions from data collected

After gathering data on the sample test boards, Dr. Hulsey and Elliott determined that 3% isopropyl alcohol was the best choice for the solvent. The results showed that as the number of seal coatings increased, the boards performed better against moisture migration. We decided on the application of two coats to seal the boards adequately while still providing practicality in the application process. With the percentage of isopropyl alcohol and the number of seal coatings determined, Elliott began to apply the coating to seal the final wooden planks that would be installed on the Yukon River Bridge.

3.8 Modification Made to the Planks

During the mixture application process, the decision to use two sealings was reconsidered. The amount of time required to apply the first sealing to all the wooden planks revealed that the application of two seal coats was unpractical. An analysis of the data previously collected on test sections showed that using only one coat would be sufficient and would minimize the time required for the application process. Any improvement with the use of two sealings was not great enough to overcome the impracticality of applying two coats. Additionally, we were uncertain as to how much moisture would migrate into the boards through the holes where the lag bolts would be inserted to fasten the boards to the bridge surface; this is an area that was not sealed.

4 What Went Wrong in the Experiment

After the final planks were completed, they were stacked on top of each other while awaiting transport to ADOT&PF. During the plank-moving process, aggregate sealing was chipped on 2 of the 28 planks (Figure 37). The chipping occurred when some planks hit against each other. The chips were patched (Figures 38 and 39), but chipping is still an issue because it demonstrates that the planks are not as durable as they were originally thought to be. It is possible that chipping occurred because of moisture in the sand used during the mixture application process. Moisture in the sand would have prevented the epoxy from properly bonding to the wood, resulting in a pore bond connection.

Figure 37: Chip in plank. Figure 38: Chip patched. Figure 39: Additional chip patched.

5 What Could Be Changed, Future Modifications

After the application process, the final decision was made to use 3% isopropyl alcohol and one seal coating. Before the application process, we had decided to apply two seal coatings, but the practicality of this decision was called into question after one seal coat had been applied. Even with modifying the application process to one seal coating, the time required to coat the planks was still unreasonable. Rather than applying the epoxy and aggregate mix to the planks while they are on the bridge, a better method would be to find a way to pore the epoxy mix over the planks on the decking surface. This method would simplify the application process and ultimately reduce the price of installation, making this idea plausible.

References

"A Full Complement of High-Temperature Grips." MTS. N.p., n.d. <http://www.mts.com/en/forceandmotion/materialstesting/MTS_006136?article=3>, 5 Mar 2014.

"Composites | 3 and 4 Point Flexural Bend Test Equipment." N.p., n.d. <http://www.testresources.net/material-type/composites-test-equipment/4-3-point-flexural-bend-testing-composites-astm-d6272/>, 2 May 2014.

Hulsey, J.L. "Wearing Surface Testing." Alaska University Transportation Center. State of Alaska, Alaska Dept. of Transportation and Public Facilities, Dec. 2012. <http://ine.uaf.edu/autc/files/2013/04/YRB-Final-Report-FINAL_fp-jlh.pdf>, 5 Feb 2014.

"Plastics Tensile Strength Test." Plastics Tensile Strength Test. N.p., n.d. <http://www.yl-tester.com/timemodel/article/2012-08-29/655775.html>, 2 May 2014.

"Report: Repairing U.S. Bridges Would Cost $140 Billion." CNN – Cable News Network, 28 July 2008. <http://www.cnn.com/2008/US/07/28/bridge.report/index.html?iref=nextin>, 5 Feb. 2014.

"Standard Test Methods and Definitions for Mechanical Testing of Steel Products." N.p., n.d. <https://law.resource.org/pub/us/cfr/ibr/003>, 2 May 2014.

Thomasnet,.N.p. <http://news.thomasnet.com/fullstory/Wedge-Grip-is-designed-for-tensile-testing-applications-825276>, 4 Mar 2014.