REPORT NUMBER: WI 03-02

Evaluation of Lumimark Traffic Safety Marking System

FINAL REPORT

APRIL 2002

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
WI-03-02		

4. Title and Subtitle	5. Report Date
Evaluation of Lumimark Traffic Safety Marking System	Apr-02
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Peter Kemp, Erin Norton	WI-03-02

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Wisconsin Department of Transportation DTID/BHC/Pavements Section/Technology Advancement Unit 3502 Kinsman Blvd. Truax Center Madison, WI. 53704-2507	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Wisconsin Department of Transportation DTID/BHC/Pavements Section/Technology Advancement Unit 3502 Kinsman Blvd. Truax Center Madison, WI. 53704-2507	Final Report 2000 - 2002
	14. Sponsoring Agency Code WisDOT Study WI-00-02

15. Supplementary Notes

16. Abstract

This report contains color, luminance and retroreflectivity data of Masterbuilders Lumimark product. This report details a demonstration installation of the product in Wisconsin on SH 59 in Transportation District 2, Waukesha County. The product is a cementious pavement marking material.

17. Key Words	18. Distribution Statement
Retroreflectivity, color, luminance, pavement marking LTL 2000	Distribution Unlimited Authorized for Public Release

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	16	

Evaluation of Lumimark Traffic Safety Marking System

WisDOT Research Study # WI 00-02

FINAL REPORT
Report # WI-03-02

by:

Erin Norton and Peter Kemp
Wisconsin Department of Transportation

for

WISCONSIN DEPARTMENT OF TRANSPORTATION
DIVISION OF TRANSPORTATION INFRASTRUCTURE DEVELOPMENT
BUREAU OF HIGHWAY CONSTRUCTION
PAVEMENTS SECTION
TECHNOLOGY ADVANCEMENT UNIT
3502 KINSMAN BLVD., MADISON, WI 53704-2507

April 2002

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Background

Conventional pavement marking systems are susceptible to wear from traffic, weather, de-icing chemicals, and snowplows. When markings wear, they become difficult to see at night and during rainfall. Decreased striping visibility increases the chances for accidents resulting in injuries and fatalities. Accidents may also occur during the restriping of conventional markings, despite traffic control efforts. The Wisconsin Department of Transportation currently utilizes a waterborne paint that has a short 1 to 2 year life and an epoxy paint that has a 3 to 5 year life. These systems have glass beads broadcasted over the paint to provide retroreflectivity.

Introduction

A demonstration installation of a pavement marking in Portland Cement Concrete (PCC) pavement was conducted in mid-August 2000 by the Wisconsin Department of Transportation on the STH 59 Waukesha (South) Bypass in Transportation District 2, Waukesha County using the Lumimark Safety Traffic Marking System.

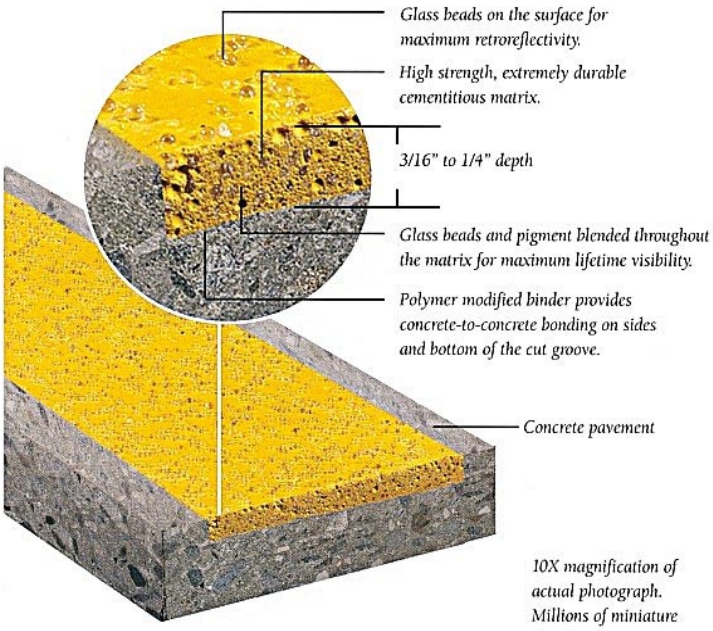

Figure 1: Lumimark Cross Section

The site is located approximately 25 feet from the intersection of STH 59 and Center Road in the West bound lanes. The installation extends West 639 feet from Center Road (Station 119+95 – 126+25), in the lane line and edge line marking areas of the project. Both yellow and white sections of delineation were installed. The Lumimark System is manufactured by Master Builders and installed by Lumimark Systems Inc. (LSI) contractors

The Lumimark System uses integrated glass beads in the polymer-modified cementious matrix to provide retroreflectivity on dry or wet pavements. These beads also improve nighttime visibility over a standard paint. The product literature describes the Lumimark matrix to be exceptionally durable. Comparable with concrete in strength, thermal expansion, shrinkage, permeability, scaling, and freeze/thaw durability.

Lumimark Pavement Marking System is designed to provide improved retroreflectivity and color during the life of the pavement. Benefits touted by the manufacturer are increased safety due to more consistent retroreflectivity, and less maintenance activity associated with restriping efforts. During the winter season, snowplow blades scrape off the top layer of the Lumimark. This allows fresh reflectivity beads to become exposed on the surface.

Lumimark HW 100 White and Lumimark HW 100 Yellow are cementious polymer-modified products that are designed for use in edge and centerline striping for highways, and all striping needs on runways, taxiways, and aprons at airports in conjunction with PCC pavements.

Construction

A groove approximately ¼ in. was milled into the PCC pavement. The groove was cleared of any debris by the use of a power washer.

The material, Lumimark HW 100 White and Lumimark HW 100 Yellow, was mixed by hand to a consistent, homogeneous and placed manually into the hand operated machine.

Lumimark broadcasts glass beads directly after the finishing operation for initial retroreflectivity. Beads were broadcast on the surface of the material to provide initial retroreflectivity. This is done due to the cementious nature of the material coating the top layer of beads during the placement of the material.

Control joints were then cut to re-establish existing transverse pavement joints. A uniform application of a curing/sealing compound was then applied to the fresh material. This is done immediately after broadcasting of the beads to control moisture loss and help insure the strength and durability of the system.

The machine used to apply the Lumimark in the milled groove, consolidated, struck-off the material, and an applied a broadcasted bead finish on the surface. This machine was not the long line production prototype. The system was a small hand guided machine typically used in shorter work areas not long line applications. The hand held operation was very time consuming and labor intensive. A long line vehicle was in development at the time of this demonstration, but not available for the installation. The use of a long line machine should eliminate a lot of the time and labor concerns along with a more consistent product.

An Initial problem was encountered with the milling operations. The milled groove was within ½ to 1 inch of the edge of the pavement. This left too small of section of the original pavement and subsequently broke off. The milled groove section was then moved in approximately 1 additional inch from the edge of the pavement. No problems were experienced with the milled edge shearing off after the adjustment.

Calibration problems were also experienced in the application of the topical coat of glass beads. The application rate of the beads was corrected as the demonstration proceeded.

Evaluation

The Lumimark marking system was being evaluated with semiannual color and retroreflectivity readings taken by WisDOT. Bond strength pull-tab tests were conducted semiannually by Master Builders on the field installation. Shear strength tests, conducted by WisDOT, were done on cores supplied by Master Builders. Evaluation of appearance will be conducted for two years on a semiannual basis. WisDOT conducted ASTM C666 freeze/thaw tests on block supplied by Master Builders, and the results are listed along with all other test data and readings in Appendix A.

Conclusion / Observations

1. It is concluded that the Lumimark system maintains retroreflectivity readings that exceeds the perceived minimum retroreflectivity readings. Initial trends show that Lumimark increases in retroreflectivity readings from initial placement as the top surface wears from snowplow and traffic activities (see Appendix A).

2. Shear data is in an acceptable range but lower than experienced in PCC overlays from WisDOT Lab Data (see Appendix A and B).

3. Freeze/thaw data showed that the Lumimark system has an acceptable resistance to freeze/thaw comparable to WisDOT standard PCC mix.

4. Color readings for white marking material are acceptable but are inconclusive at this point for yellow marking material. Some readings fluctuate in and out of the acceptable range of readings as per ASTM D6628

5. Luminance readings as per ASTM D6628 specifies that white should read at a minimum 45 and yellow should read 30 at a minimum. The reading were below the minimum threshold (see Appendix A)

Recommendations

1. Continue monitoring of installation on a biannual basis.
2. Not to approve installation method.
3. Not to approved product.

Implementation

1. No action to be taken by Wisconsin Department of Transportation as a result of this study. The method and product was not found to be an acceptable method for pavement marking. Further refinements must be done to the product and method for Wisconsin to accept as a standard or as a limited practice.

Appendix A WISDOT tests

Lumimark/ Master Builders

Polymer-Modified Cementious Marking

Test Section Hwy 59 Bypass Waukesha August 2000

*Orientation				**Color			Yellow Edgeline				White Edgeline			
Retroreflectivity				Center of skipline			Aligned to center of Skipline				Aligned to center of Skipline			
Skip	Beginning	Middle	End	Y	x	y	Retro	Y	x	y	Retro	Y	x	y
1	148	237	192	43.79	0.3324	0.3507	131	26.90	0.4942	0.4515				
2	210	187	161	41.56	0.3214	0.3474	137	28.01	0.4958	0.4543				
3	165	124	146	38.17	0.3212	0.3474	150	28.72	0.4990	0.4507	224	42.28	0.3526	0.3501
4	132	197	130	40.08	0.3210	0.3400	144	23.25	0.4907	0.4466	312	35.36	0.3199	0.3451
5	167	185	156	39.67	0.3200	0.3445	187	26.48	0.4961	0.4526	213	48.80	0.3190	0.3436
6	171	215	136	42.96	0.3200	0.3461	115	27.72	0.4977	0.4545	193	48.07	0.3197	0.3436
7	265	175	150	40.17	0.3209	0.3479	161	27.01	0.4931	0.4513	111	44.97	0.3186	0.3444
8	131	146	124	40.37	0.3205	0.3464	162	26.93	0.4936	0.4504	212	45.71	0.3196	0.3453
9	177	180	123	43.15	0.3201	0.3411	131	28.22	0.4976	0.4548	124	39.05	0.3212	0.3470
10	171	159	172	40.72	0.3216	0.3482	131	30.10	0.5015	0.4573	282	43.92	0.3202	0.3468
11	127	168	124	42.79	0.3199	0.3456	219	28.82	0.5015	0.4573	75	50.04	0.3199	0.3435
12	122	125	101	44.59	0.3196	0.3475	150	30.16	0.4999	0.4592	168	47.33	0.3203	0.3456
13	110	105	142	36.95	0.3227	0.3507	123	33.86	0.4956	0.4528	81	52.77	0.3194	0.3433
Ave.	**161.23**	**169.46**	**142.85**	**41.15**	**0.32**	**0.35**	**149.31**	**28.17**	**0.4966**	**0.4533**	**181.36**	**45.30**	**0.3228**	**0.3453**

Lumimark/ Master Builders

Polymer-Modified Cementious Marking

Test Section Hwy 59 Bypass Waukesha October 2000

	*Orientation			**Color			Yellow Edgeline					White Edgeline		
	Retroreflectivity			Center of skipline			Aligned to center of Skipline				Aligned to center of Skipline			
Skip	Beginning	Middle	End	Y	x	y	Retro	Y	x	y	Retro	Y	x	y
1	193	279	281	45.77	0.3215	0.3477	136	29.85	0.4508	0.4329	*219	*39.66	*0.3339	*0.3425
2	342	256	200	43.98	0.3201	0.3466	259	35.01	0.4513	0.4339	*167	*29.39	*0.3451	*0.4329
3	271	173	114	36.99	0.3217	0.3479	236	34.77	0.4641	0.4388	201	35.01	0.4513	0.4339
4	222	223	202	41.42	0.3224	0.3482	173	27.14	0.4600	0.4370	276	34.77	0.4641	0.4388
5	153	253	185	40.37	0.3224	0.3487	122	33.18	0.4548	0.4336	199	27.14	0.4600	0.4370
6	247	307	200	46.05	0.3195	0.3443	156	31.20	0.4802	0.4508	170	46.05	0.3195	0.3443
7	265	226	174	45.35	0.3205	0.3466	153	29.44	0.4684	0.4416	142	46.85	0.3185	0.3443
8	208	208	211	41.40	0.3216	0.3481	121	33.18	0.4743	0.4462	144	46.57	0.3206	0.3459
9	248	230	160	42.36	0.3194	0.3460	148	28.56	0.4738	0.4467	156	42.96	0.3211	0.3477
10	204	219	208	43.67	0.3207	0.3469	119	34.26	0.4813	0.4521	258	50.50	0.3203	0.3436
11	147	231	154	44.05	0.3204	0.3480	157	35.17	0.4629	0.4388	253	34.26	0.4813	0.4521
12	142	171	122	45.34	0.3195	0.3451	137	34.98	0.4840	0.4541	247	51.61	0.3195	0.3424
13	130	153	168	41.82	0.3219	0.3477	91	25.45	0.4483	0.4281	82	62.07	0.3192	0.3424
Ave.	**213.23**	**225.31**	**183.00**	**42.97**	**0.32**	**0.35**	**154.46**	**31.71**	**0.47**	**0.44**	**193.45**	**43.44**	**0.3723**	**0.38**
Epoxy Edge Line west of Lumimark														
Epoxy	171	243	246	60.17	0.3166	0.3440					193	60.26	0.3166	0.3436
											219	39.66	0.0334	0.3425
	* epoxy edge line corresponding with the adjacent skip										167	29.385	34.0000	0.4329

Lumimark/ Master Builders

Polymer-Modified Cementitious Marking

Test Section Hwy 59 Bypass Waukesha June 01

	Orientation			Color			Yellow Edgeline				White Edgeline			
	Retroreflectivity			Center of skipline			Aligned to center of Skipline				Aligned to center of Skipline			
Skip	Beginning	Middle	End	Y	x	y	Retro	Y	x	y	Retro	Y	x	y
1	164	113	111	34.74	0.3382	0.3569	106	25.28	0.4283	0.4093	310*	47.96*	0.3382*	0.3620*
2	260	172	202	32.69	0.3398	0.359	205	27.47	0.4204	0.4055	165*			
3	220	177	162	31.56	0.3342	0.357	140	29.45	0.4169	0.4043	99	33.15	0.3324	0.3546
4	245	223	165	35.89	0.3313	0.3554	132	25.87	0.4123	0.3989	106	36.86	0.3372	0.3559
5	250	260	314	35.68	0.3325	0.3554	135	28.91	0.4216	0.4091	135	31.57	0.3375	0.3560
6	261	315	272	35.59	0.3324	0.3562	172	28.21	0.4391	0.4146	274	35.69	0.3333	0.3545
7	337	308	283	36.7	0.3315	0.3551	106	26.54	0.4611	0.4277	163	32.68	0.3334	0.3539
8	271	253	326	35.37	0.3307	0.3550	199	26.89	0.4505	0.4208	154	24.83	0.3393	0.3572
9	287	283	277	33.71	0.3292	0.3545	157	30.13	0.4275	0.4092	113	29.32	0.3341	0.3568
10	274	296	291	33.47	0.3311	0.3568	249	30.65	0.4447	0.4179	102	38.32	0.3403	0.3586
11	141	273	285	35.26	0.3324	0.3534	288	31.23	0.4597	0.4285	147	33.68	0.3354	0.3549
12	213	232	246	35.86	0.3319	0.3559	212	30.87	0.4691	0.4328	220	34.99	0.3378	0.3549
13	184	328	177	39.60	0.3304	0.3538	208	21.52	0.4292	0.4089	126	46.38	0.3277	0.3474
Ave.	**239.00**	**248.69**	**239.31**	**35.09**	**0.3327**	**0.3557**	**177.615**	**27.925**	**0.4370**	**0.4144**	**149.00**	**34.32**	**0.3353**	**0.3550**

* Epoxy Edge Line Corresponding with the Adjacent Skip Line

Lumimark/ Master Builders

Polimer-Modified Cementitious Marking

Test Section Hwy 59 Bypass Waukseha November 01

	*Orientation			**Color			Yellow Edgeline				White Edgeline			
	Retroreflectivity			Center of skipline			Alligned to center of Skipline				Alligned to center of Skipline			
Skip	Beginning	Middle	End	Y	x	y	Retro	Y	x	y	Retro	Y	x	y
1	135	195	182	33.86	0.3356	0.3542	222	33.10	0.3866	0.3894	*256	*47.87	*0.336	*0.362
2	288	256	343	40.83	0.3401	0.3594	233	27.01	0.4206	0.4071	*151	*40.46	*0.3376	*0.364
3	310	283	212	31.09	0.3335	0.3567	170	26.66	0.4351	0.4132	297	34.25	0.3408	0.3594
4	280	223	292	31.55	0.3336	0.3557	147	28.16	0.4108	0.4020	139	35.68	0.3387	0.3583
5	209	378	350	31.73	0.3323	0.3568	145	.29.23	0.4242	0.4080	169	36.21	0.3370	0.3564
6	376	388	358	35.68	0.3311	0.3554	124	28.42	0.4369	0.4140	305	29.22	0.3355	0.3585
7	384	409	377	34.33	0.3323	0.3555	187	26.42	0.4128	0.4025	189	35.05	0.3353	0.3540
8	332	278	286	33.05	0.3342	0.3568	205	28.88	0.4356	0.4155	279	35.12	0.3371	0.3564
9	260	355	329	32.63	0.3335	0.3580	127	27.38	0.4392	0.4155	280	27.57	0.3357	0.3596
10	259	309	258	37.16	0.3375	0.3574	210	26.50	0.4374	0.4156	159	38.07	0.3330	0.3562
11	312	302	259	37.21	0.3345	0.3562	269	27.56	0.4409	0.4181	247	37.10	0.3327	0.3543
12	286	285	278	32.19	0.3339	0.3587	233	27.1	0.4590	0.4295	273	32.23	0.3356	0.3588
13	269	319	277	38.33	0.3331	0.3559	**0	32.37	0.401	0.3951	237	53.03	0.3257	0.3467
Ave.	**284.62**	**306.15**	**292.38**	**34.59**	**0.3342**	**0.3567**	**189.333**	**28.2967**	**0.4262**	**0.4097**	**234.00**	**35.78**	**0.3352**	**0.3562**

** line painted over not included in average. * Epoxy Edge Line Corresponding with the Adjacent Skip Line, not included in average

LUMIMARK Bead Gradation Analysis

	Individual Sieves		Cumulative Sieves		
Size	Ret., g.	% Ret.	Ret., g.	% Ret.	% Pass
10	0.000	0.00	0.000	0.00	100.00

SHEAR STRENGTH

Master Builders - Lumimark

		YELLOW				WHITE		
	CORE #	LOAD	AREA	PSI	CORE #	LOAD	AREA	PSI
7 DAY	1	831	5.768	144.1	1	2218	5.768	384.5
	3	2408	5.768	417.5	3	1578	5.768	273.6
	5	1323	5.768	229.4	5	1914	5.768	331.8
7 DAY AVERAGE		1521	5.768	**263.6**		1903	5.768	**330.0**
28 DAY	2	1224	5.768	212.2	2	1678	5.768	290.9
	4	1382	5.768	239.6	4	3181	5.768	551.5
	6	1620	5.768	280.9	6	1657	5.768	287.3
28 DAY AVERAGE		1409	5.768	**244.2**		2172	5.768	**376.6**
TOTAL AVERAGE				**253.9**				**353.3**
OVERALL AVERAGE								**303.6**

NOTE: There was no significant difference in the 7 & 28 day averages, but there was a significant difference in the two batches. I would deduct from this that it was more due to the production of the batches that made the difference. Also that the overall average is comparable to the overall average of the Lumimark testing.

All cores were frozen after curing for 7 & 28 days respectively and testing was completed on 01/11/01by David S. Hutchinson Engineering Specialist Transportation (Senior).

Appendix B: Shear Test Background Letter

CORRESPONDENCE/MEMORANDUM State of Wisconsin

DATE: 11/06/90

TO: John J. Steinhauer

FROM: James M. Parry

SUBJECT: Shear Strength Testing of CRCP Overlay Cores

We have received and tested the cores which you sent from the bonded PCC overlay on USH 41/141 in Brown County. Shear testing was performed on these cores at the interface of the PCC overlay and the underlying CRCP. A summary of these data by lane and by surface preparation type is given below:

LANE	SURFACE PREPARATION TYPE	SHEAR STRENGTH (psi)
Driving	Shotblasted	760
Driving	Milled	850
Passing	Shotblasted	990
Passing	Milled	690

For comparison, the average shear strength of the similar PCC overlay on I-90/94 in Dane County, at two years age, was 720 psi (minimum was 510 psi). The Dane County pavement has performed well for 6 years with only isolated distress, under greater truck volume than USH 41/141. The Iowa specification for opening a bonded overlay to traffic is 200 psi shear strength.

Thus, it does not appear that shear strength was the principal cause of the overlay failure on USH 41/141. Although the shear strength of the shotblasted surface in the passing lane was greater than that in the driving lane, the driving lane value is still not deficient when compared with the Dane County pavement. The lower shear strength value in the driving lane may be due to a greater buildup or penetration of oil and contaminants on the original CRCP in the driving lane during its service life, which may not have been completely removed during shotblasting. Another possibility is that since the lanes were placed at different times, the mix proportions or application conditions or procedures may have been different.

The variation in shear strengths in the milled transition sections at the ends of the overlay appears to be due to statistical scatter. The shear fracture plane of the milled cores was very uneven, and involved coarse aggregate fracture (whereas the shear fracture plane of the shotblasted cores followed the flat interface very closely). This uneven type of fracture generated much wider data scatter, which was also the case when shear tests were attempted on the cores at depths other than at the interface.

While the rougher surface attained by milling did not improve the bonding shear strength between the pavement layers, it did make a big difference in the pavement performance in the driving lane. This shows that the shear strength property may not be a good performance indicator in this application.

At this point in time, the cause for the premature failure of the overlay has still not been clearly established.

A detailed summary of the shear test data is given below:

LOCATION*	SURFACE TYPE	SHEAR STRENGTH (PSI) DRIVING LANE	PASSING LANE
0 + 39	Milled	853	624
1 + 90	Shotblasted	794	1072
7 + 73	Shotblasted	739	927
15 + 42	Shotblasted	**	**
25 + 11	Shotblasted	748	973
30 + 77	Milled	845	751

* Location reference starts at 0+00 at north end of overlay, and increases in the direction of traffic. Overlay ends at 32+00.

** These cores were broken at the overlay/CRCP interface when received at the lab, and could not be tested.

Appendix C:
Master Builders Inc. Lumimark Inspection Data

Project Location: Highway 59, Waukesha, Wisconsin

Products: Lumimark HW White & Yellow

Inspection Date: 10/09/2000

Inspected By: John Neeson , Tate Coverdale

Site Information

D.O.T Representative: Dennis Schmunk

Route, Highway ID: Highway 59 (West bound)

Total LF Solid Lines: Approx. 1000 LF

Total LF Skip Lines: Approx. <500 LF

Retroreflectivity Readings (MX-30 Meter)

Lumimark / Master Builders readings

Note: Take measurements every 25 linear feet. readings where taken East to West uphill.

White Solid Line		Yellow Solid Line		White Skip Lines	
248	184	461	266	1. 580	
380	673	303	246	2. 533	
479	403	262	236	3. 290	
515	445	454	229	4. 488	
465	552	502	211	5. 441	
314	507	473	320	6. 626	
399	315	380	283	7. 480	
326	215	322	216	8. 378	
345	198	266	327	9. 350	
192		397	293	10. 449	
242		291	326	11. 366	
240		204	151	12. 332	
512		339	207	13. 297	
351		278	290		
339		328	258		
			336		

Comments: Results reported in [(mcd / square meter) / lux]

Tensile Bond Data (ASTM D 4541)

Lumimark / Master Builders readings

Note: Test every 100 linear feet. Indicate failure mode (*C*: cohesive-within the product, *S*: substrate-in the concrete, *B*: bond line-at bond interface) for each value recorded.

White Solid Line	Failure	Yellow Solid Line	Failure	White Skip Lines	Failure
1. *		1. 300	S & B	1. 350	S
2. *		2. 350	S & B	2. 400	S & B
3. *		3. 300	S & B	3. 500	B
4. *		4. 300	B	4. 350	B
5. *		5. 300	C & S		

Comments:
Adhesive failure between the button and the surface of the stripe (bonding agent failure) Results reported in psi (pounds per square inch)

Date: August 21-22, 2000
Material: Lumimark HW 100 White and Yellow
Lot No.: White-M10 88188 V0, Yellow- M10 88192 V0
Weather Conditions: Sunny and clear
Tested by: Alan Krupa Lumimark/Master Builders

Start Time	Line Type	Ambient °F	Substrate °F	Material °F	Water °F	Batch Size (lbs)	Mix Water (lbs)	Mix °F	Flow (inch)	Final Set (hr:min)
August 21										
White										
2:10	Solid	79	95-100	72	70	55	6.3	83	7	0:55
2:20	Solid	79	95-100	72	70	55	6.3	83	7	NA
2:45	Solid	80	95-100	72	70	55	6.0	83	6.5	0:55
3:10	Solid	79	95-100	72	70	55	6.1	80	6.5	1:10
3:50	Skips	78	95-100	72	70	55	6.1	80	6.5	1:00
August 22										
Yellow										
9:40	Solid	77	88-90	76	72	55	6.0	79	6	1:15
10:10	Solid	80	88-90	76	72	55	6.0	80	6.5	0:55
10:45	Solid	80	88-90	76	72	55	6.0	80	6.5	1:00

Note: The total mix time of 3 minutes.

APPENDIX D: Lumimark Manufactures Data

	Lumimark HW 100 White	***Lumimark HW 100 Yellow***
Split Tensile Strength *(ASTM C-496) modified*	**Psi Mpa**	**Psi Mpa**
1-Day	387 2.7	376 2.6
7-Day	462 3.2	353 2.4
28-Day	499 3.4	628 4.3
Flexural Strength *(ASTM C-348) modified*	**Psi Mpa**	**Psi Mpa**
1-Day	669 4.6	726 5.0
7-Day	798 5.5	693 4.8
28-Day	756 5.2	876 6.0
Direct Tensile Bond *(MBT Method) modified*	*(Material worked into surface)* **Psi Mpa**	**Psi Mpa**
3-Day	197 1.4	123 0.8
7-Day	181 1.2	131 0.9
28-Day	200 1.4	184 1.3
Direct Sheer Bond *(Michigan DOT) modified*	*(Material worked into surface)* **Psi Mpa**	**Psi Mpa**
1-Day	286 2.0	326 2.2
3-Day	479 3.3	322 2.2
7-Day	505 3.5	438 3.0
28-Day	554 3.8	404 2.8
Length Change *(ASTM C-157) modified*	**% Change**	**% Change**
3-Day	-0.018	-0.04
7-Day	-0.041	-0.042
14-Day	-0.061	-0.054
21-Day	-0.07	-0.047
28-Day	-0.076	-0.056
Coefficient of Thermal Expansion *(CRD-39)~56 days*	**Coefficient**	**Coefficient**
70 to 140 F	3.9×10^{-6}	3.9×10^{-6}
140 to 40 F	4.1×10^{-6}	4.2×10^{-6}
40 to 70 F	6.8×10^{-6}	6.7×10^{-6}

Material Test Report

Lumimark HW 100 White

Lumimark HW 100 Yellow

* The tests were performed in the Technical Services Laboratories of Master Builders, Inc. and witnessed by Mr. Sam R. Jakaboio, Director of Technical Services for Solar Testing, Laboratories, Inc. located in Brooklyn Heights, Ohio.

* Description: Lumimark HW 100 White and Lumimark HW 100 Yellow, Solar Certification

	Lumimark HW 100 White	***Lumimark HW 100 Yellow***
Mix Data		
Ambient Temperature (F)	70	70
Mix Time	4 minutes	4 minutes
% Mix water, by weight	11.5	9.44
Unit weight, lb/ft^3	125	123
Initial flow, inches	6.00	6.00
20-Minute flow, inches	5.75	5.5
30-Minute flow, inches	5.5	N/A
Stiffening rate, hrs:min	1:25	0:43
Setting Time (*ASTM C-266)*		
Initial set, hrs:min	1:38	0:56
Final set, hrs:min	2:18	1:44
Compressive Strength *(ASTM C-109) modified*	**Psi Mpa**	**Psi Mpa**
1-Day	3022 20.8	3094 21.3
7-Day	6325 43.6	6185 42.6
28-Day	8009 55.2	6562 45.2

LUMIMARK PERFORMED TESTS

	Lumimark HW 100 White		***Lumimark HW 100 Yellow***	
Rapid Chloride Permeability (ASTM C-1202) modified	**Coulombs**	**Rating**	**Coulombs**	**Rating**
28-Day	2248	Moderate	1617	Low
UV Resistance ***(ASTM D-822)***	**Color Change**		**Color Change**	
1,000 Cycles, sealed	Unchanged, no yellowing		Color deepened	
Pull-Off Adhesion ***(ASTM D-4541) modified***	*2'x2' concrete slab (1/4" overlay, material worked into surface)*			
	Psi	**Mpa**	**Psi**	**Mpa**
3-Day	208	1.4	217	1.5
7-Day	287	2.0	300	2.1
28-Day	275	1.9	250	1.7
Pull-Off Adhesion ***(ASTM D-4541) sealed***	*1'x1' concrete slab (Material placed into saw-cut 1/4"-deep groove, no scrub coat)*			
	Psi	**Mpa**	**Psi**	**Mpa**
3-Day	117	0.8	167	1.2
7-Day	150	1.0	192	1.3
28-Day	200	1.4	200	1.4
Freeze-Thaw Resistance ***(ASTM C-666-A) 300 cycles***	**Relative Durability Factor (RDF)**			
No. 1 Sealed, 1/4" composit	94.27%		95.64%	
No. 2 Plain, 1/4" composite	96.14%		97.28%	
No. 3 Plain, Solid Beam	100.00%		95.45%	
Scaling Resistance-50 Cycles ***(ASTM C-672)***	**Rating**		**Rating**	
No. 1 Sealed, 1/4"	1 Very slight scaling		1 Very slight scaling	
No. 2 Sealed, 1/8"	1 Very slight scaling		0 No scaling	
No. 3 Plain, 1/4"	1 Very slight scaling		0 No scaling	

Note: Modified specimens were moist-cured for 2 days, then 26 days in air. Sealed specimens were coated with CS-388 water-based acrylic sealer.

APPENDIX E: Photographs

Fig.2: Milling Operation

Fig.3: Hand Mixing

Fig. 4: Placement in Hand Controlled Machine

Fig.5: Placement of White Line

Fig. 6: Spray Cure Application

Fig. 7: Cutting of Control Joints

Fig. 8: Lumimark Yellow Edge Line Installation

Fig. 9: October 2001 Lumimark White Edge Line

Fig. 10 October 2001 Epoxy Taper Line in Fore Ground Adjoining a White Lumimark Edge Line

Fig. 11: Epoxy Taper Line in Back Ground Adjoining a White Lumimark Edge Line

Fig. 12: October 2001,Yellow Lumimark Edge Line

Fig. 13: October 2001, Yellow Lumimark Edge Line