



**EVALUATION OF THIN OVERLAYS
FOR BRIDGE DECKS**

Final Report

SPR 304-431



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by

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16. Abstract Eight thin polymer overlay systems were evaluated in the laboratory and on two bridge decks exposed to trucks and passenger vehicles including those with studded tires. The products were Mark 154, Flex-O-Lith, Safetrack HW, Kwik Bond PPC MLS, Tyregrip, SafeLane HDX, Urefast PF60, and Unitex ProPoxyType III DOT. None of the overlay systems showed superior performance under moderate average daily traffic from the standpoint of maintaining good skid resistance and resisting wear through. Tyregrip and Safetrack HW started to wear through to the concrete after exposure of approximately 1.3 million vehicles, and Urefast PF60 wore through much sooner. For the five products that did not wear through, empirical equations predicted the friction number of the best of these five products would decrease to 40 (equivalent to the friction number of the concrete) within five months at a traffic level of 10,000 vehicles per lane per day. Delamination from the concrete was not a major problem with the products. Laboratory tests were not able to predict performance.					
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
<u>LENGTH</u>					<u>LENGTH</u>				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
<u>AREA</u>					<u>AREA</u>				
in ²	square inches	645.2	millimeters squared	mm ²	mm ²	millimeters squared	0.0016	square inches	in ²
ft ²	square feet	0.093	meters squared	m ²	m ²	meters squared	10.764	square feet	ft ²
yd ²	square yards	0.836	meters squared	m ²	m ²	meters squared	1.196	square yards	yd ²
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	kilometers squared	km ²	km ²	kilometers squared	0.386	square miles	mi ²
<u>VOLUME</u>					<u>VOLUME</u>				
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	meters cubed	m ³	m ³	meters cubed	35.315	cubic feet	ft ³
yd ³	cubic yards	0.765	meters cubed	m ³	m ³	meters cubed	1.308	cubic yards	yd ³
NOTE: Volumes greater than 1000 L shall be shown in m ³ .									
<u>MASS</u>					<u>MASS</u>				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
<u>TEMPERATURE (exact)</u>					<u>TEMPERATURE (exact)</u>				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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EVALUATION OF THIN OVERLAYS FOR BRIDGE DECKS

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1.0 INTRODUCTION

Bridge decks, most of which are comprised primarily of concrete and reinforcing steel, are arguably the most important element in assuring safe passage of vehicles over a bridge. The surface of the deck must provide a balance between smooth ride and good skid resistance. The deck distributes and supports the weight of the traffic thereby contributing to the load capacity of the bridge. To some degree, the deck also protects the underlying bridge elements from environmental exposure. However, in performing its function, a bridge deck is exposed to load and thermally induced stresses, deicing chemicals, rain, and abrasion from traffic. These factors lead to cumulative damage and reduced performance including concrete cracks, missing concrete, delaminations, ruts, reduced skid resistance, and corrosion of the steel reinforcement. Often the interactions of the factors that decks are exposed to result in accelerated damage such as chloride from deicing chemicals infiltrating to the steel reinforcement through load induced cracks and causing accelerated corrosion of the steel.

All bridge decks require repairs and will eventually reach a damage state that requires an expensive deck replacement. Consequently, cost-effective procedures that can postpone deck replacement and maintain safe functionality are very appealing to bridge owners. Applying a thin polymer overlay is one such action that can prolong deck life by sealing cracks and restoring skid resistance. Thin polymer overlays consist of a polymer resin, generally epoxy, methyl methacrylate, or polyurethane, that is applied to the surface of the deck. Aggregate is embedded in the polymer. The polymer effectively seals cracks in the concrete, and the aggregate provides the wear and skid resistance. The overall thickness of thin polymer overlays is generally $\frac{1}{4}$ to $\frac{1}{2}$ inch.

Oregon has had mixed results with thin polymer overlays. In some cases, the overlays have performed well; in other cases, the overlays have delaminated or have been worn to a point where the skid resistance was dangerously low. Compounding the problem of bridge deck preservation is the fact that Oregon allows studded tires, which undoubtedly reduce the life of the thin overlays. Nevertheless, the feeling among Oregon DOT personnel is that thin polymer overlays can provide substantial cost savings and reduce traffic congestion by delaying deck replacements if the products that perform well under Oregon conditions can be identified.

1.1 OBJECTIVE

The objectives of this investigation are to identify specific thin polymer overlay products that will provide good performance on Oregon bridges and to recommend a method for qualifying future products.

1.2 BACKGROUND

Only limited comparative field studies have been conducted to evaluate the performance of thin polymer overlays under operating conditions (*Guthrie et al. 2005; Wilson and Henley 1995; and*

Sprinkel et al. 1993). None of these comparisons were designed to make a direct comparison of the specific overlay products. Wilson and Henley summarized 10 years of experience with epoxy and methyl methacrylate (MMA) overlays in Washington State. According to the investigation, MMA overlays retain skid resistance better than epoxy overlays over time. However, the skid resistance of epoxy overlays starts higher than MMA. This general behavior is illustrated in Figures 1.1 and 1.2 for six different epoxy products and five different MMA products based on the Washington data.

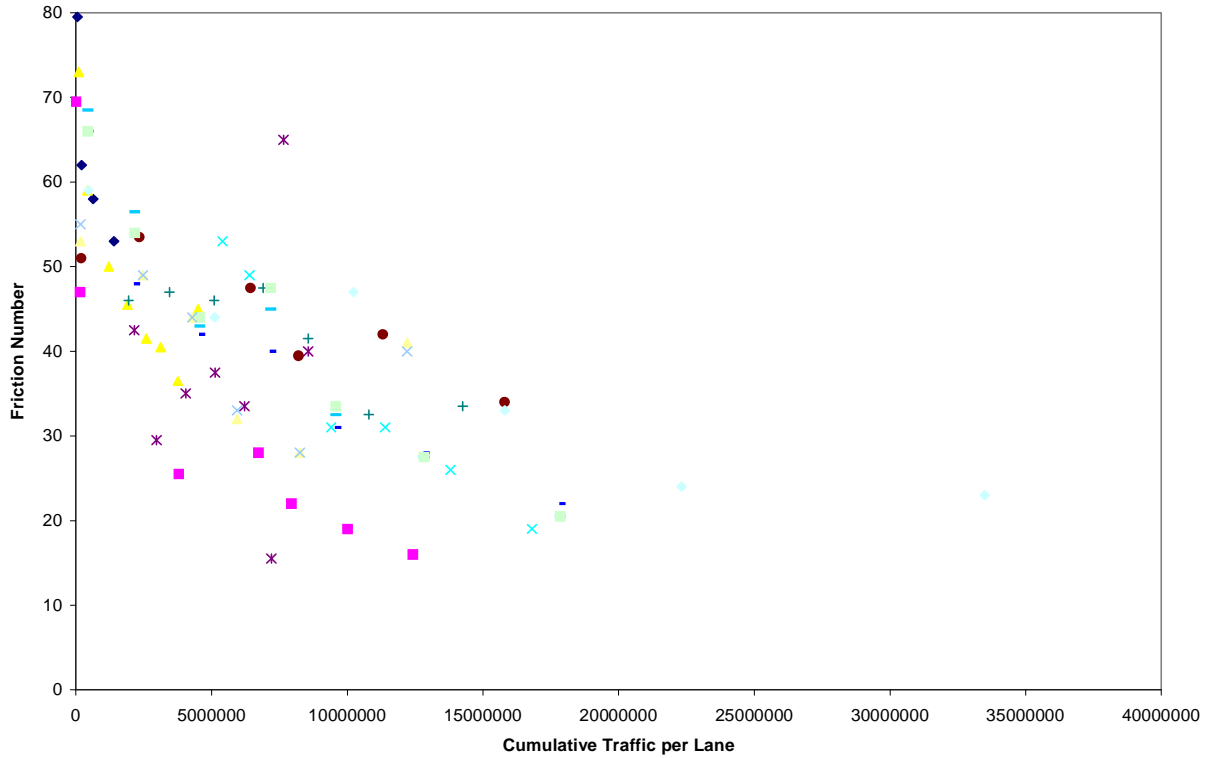
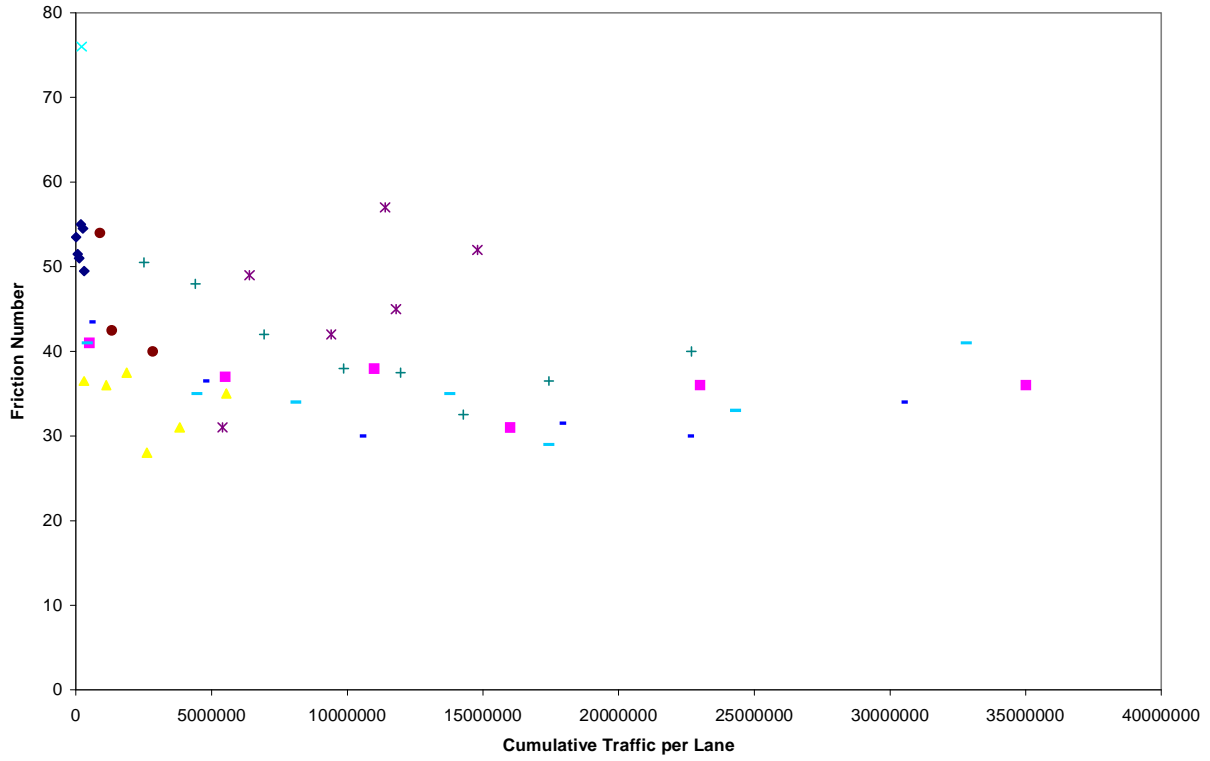


Figure 1.1: In-service skid resistance of thin epoxy overlays.



2.0 APPROACH

Eight thin polymer overlay manufacturers agreed to provide and install two test sections of their respective products free-of-charge. The manufacturers were responsible for preparing the test sections and applying their respective overlays. Each section had to be a minimum of 120 feet long in order to conduct skid resistance testing with the ODOT skid trailer. Two bridges were selected, Willamette River Bridge at Newberg (08156) and the South Yamhill River Highway 39 McMinnville Spur Bridge (06758), that were long enough to accommodate four test sections in each travel direction. This arrangement allowed the following:

- a direct comparison of each product to five of its peers,
- a second application for each product in case defects in a test section were a result of the section location and not the overlay product, and
- a test of whether the performance of a product can be repeated.

Prior to installation, ODOT mapped the locations of joints, drains, major cracks, and delaminations for each section. Most sections showed substantial cracking, in which case, the cracks in an area extending across the width of the lane and 5-foot along the lane were highlighted and photographed in order to document the degree of cracking. The pre-installation section maps are shown in Appendix A. The section locations and the respective products are shown in Table 2.1. A photograph of the highlighted cracks from Section E is shown in Figure 2.1. Delaminated areas delineated with paint are also shown in the photograph.

Table 2.1: Overlay product locations.

Section ID	Bridge	Start of Section*	Material
A	08156 - Newberg	167' N	Mark 154 by Polycarb
B	08156 - Newberg	404' N	Flex-O-Lith by Euclid/Tamms
C	08156 - Newberg	587' N	Safetrack HW – 2 Coat System by Stirling Lloyd
D	08156 - Newberg	712' N	Kwik Bond PPC MLS by Kwik Bond Polymers
E	08156 - Newberg	259' S	Tyregrip by Ennis/Prismo
F	08156 - Newberg	384' S	SafeLane HDX by Cargill
G	08156 - Newberg	566' S	Urefast PF60 by LiquidConcrete
H	08156 - Newberg	804' S	Unitex Pro-Poxy Type III DOT by Unitex
I	06758 - McMinnville	182' S	Flex-O-Lith by Euclid/Tamms
J	06758 - McMinnville	313' S	Mark 154 by Polycarb
K	06758 - McMinnville	603' S	Unitex Pro-Poxy Type III DOT by Unitex
L	06758 - McMinnville	741' S	Urefast PF60 by LiquidConcrete
M	06758 - McMinnville	132' N	SafeLane HDX by Cargill
N	06758 - McMinnville	270' N	Tyregrip by Ennis/Prismo
O	06758 - McMinnville	560' N	Kwik Bond PPC MLS by Kwik Bond Polymers
P	06758 - McMinnville	691' N	Safetrack HW – 2 Coat System by Stirling Lloyd

*Distance is from start of bridge in the direction indicated. N – northbound lane, S – southbound lane.



Figure 2.1: Highlighted cracks and marked delaminations.

3.0 RESULTS

3.1 OVERLAY INSTALLATIONS

Most of the eight products were applied to the two bridges in July and August. Two sections were overlaid in September. Approximately half of the sections were overlaid at night. Table 3.1 shows the installation dates, the resin type, and the general application steps for each of the eight products. The table also shows photographs of typical application procedures. After the installations, Kwik Bond informed ODOT that Kwik Bond had used different aggregate types for its two installations contrary to the instructions given to the suppliers. The aggregate used on the Newberg Bridge was a 4:1 ratio of Steilacoom Basalt to #6-10 Oregon Emery; the aggregate used on the McMinnville Bridge was 100% Steilacoom Basalt.

Table 3.1: General application procedure for the overlay products.



Product	Installation Date	Installation Contractor	Deck Preparation
Mark 154	7/23/07 day - Newberg 8/20/07 night - McMinnville	Polycarb	Riding shot blaster
Flex-O-Lith	7/24/07 day - Newberg 7/16/07 day - McMinnville	Tough Stuff	Walk behind shot blaster 
Safetrack HW	7/23/07 day - Newberg 8/22,23/07 night - McMinnville	Pioneer Waterproofing	Walk behind shot blaster
Kwik Bond PPC MLS	7/24/07 day - Newberg 9/24/07 night - McMinnville	Concrete Barrier	Riding shot blaster 
Tyregrip	7/26/07 day - Newberg 8/22/07 night - McMinnville	Apply-A-Line	Walk behind shot blaster
SafeLane HDX	7/25/07 day - Newberg 8/28/07 night - McMinnville	Pioneer Waterproofing	Walk behind shot blaster
Urefast PF60	7/26/07 day - Newberg 8/20/07 night - McMinnville	Sullivan	Walk behind shot blaster
Unitex Pro-Poxy Type III DOT	7/26/07 day - Newberg 7/16/07 day - McMinnville	Pioneer Waterproofing	Walk behind shot blaster

Table 3.1 continued








Product	Resin Type	Primer Application	Number of Lifts	Resin Application
Mark 154	Epoxy	None	2	Resin in bulk. Components mixed at nozzle of applicator. 
Flex-O-Lith	Epoxy	None	2	Resin in buckets. Full buckets combined and mixed with drill mixer.
Safetrack HW	MMA	PAR-1 resin only	1	Primer resin in drum; lift resin in buckets. Resins mixed with activator with drill mixer. Amount of activator depends on concrete temperature. Pre-measured thixotrope added to lift resin to increase viscosity. Inhibitor added to lift resin if concrete temperature too high.
Kwik Bond PPC MLS	Polyester	KBP103/204 polyacrylate resin only	2	Primer mixed in tank and sprayed onto deck from truck. Approximately 4 gallons of lift resin poured into 5 gallon buckets from bulk drum and mixed with 8 oz of activator using drill mixer.
Tyregrip	Epoxy	None	1	Resin in buckets. Full buckets combined and mixed with drill mixer.
SafeLane HDX	Epoxy	None	2	Resin in bulk drums. 4 gallons of resin and hardener were mixed in garbage can with drill mixer.
Urefast PF60	Urethane	R-60 resin and aggregate	2	Resin in bulk. Components mixed at nozzle of applicator.
Unitex Pro-Poxy Type III DOT	Epoxy	None	2	Resin in bulk drums. Approximately 4 gallons of resin and hardener were combined in garbage can and mixed with drill mixer. 

Table 3.1 continued

Product	Aggregate Type	Aggregate Application	Cleanup
Mark 154	Oklahoma Flint #8	Machine broadcast 	Compressed air
Flex-O-Lith	3M Indag Basalt #8	Hand broadcast 	Brooms
Safetrack HW	Steilacoom basalt	Hand broadcast	Brooms
Kwik Bond PPC MLS	4:1 ratio of Steilacoom Basalt + #6-10 Oregon Emery blend on Newberg Bridge; 100% Steilacoom Basalt on McMinnville Bridge	Hand broadcast	Sweeper 
Tyregrip	Calcined bauxite	Hand broadcast from back of truck 	Sweeper
SafeLane HDX	Dolomitic limestone	Hand broadcast	Brooms
Urefast PF60	Steilacoom Basalt	Hand broadcast	Blowers and brooms
Unitex Pro-Poxy Type III DOT	#6-10 Oregon Emery	Hand broadcast	Compressed air and brooms 

3.2 INSTALLATION OBSERVATIONS

All the installers shot blasted the bridge deck prior to applying resin. The degree of bridge deck preparation varied among the field sections. Some crews made sure all paint and residues were completely removed; other crews made only a cursory attempt at removing the paint lines. Very few crews abraded the deck to the curb. Only one crew was observed adjusting their magnetic sweeping to thoroughly remove shot from the tine grooves on the Newberg Bridge. However, most of the surface areas of the decks were abraded and free of foreign matter and laitance prior to resin application.

The degree of crew experience was obvious during the installations. Some crews did not place the resin and aggregate consistently, which resulted in thin spots in individual lifts and subtle waves in the overlay. The waves are unlikely to affect performance, but the thin areas could wear through prematurely. In some cases, the crews opened the bags of aggregate in such a way that paper and plastic fell into the aggregate and ended up in the overlay. In one case, several steel nuts were found in the overlay.

The installation of the Urefast PF60 overlay on the Newberg Bridge was compromised when the equipment that applies the resin malfunctioned and did not mix the resin components at the correct ratio. Unfortunately, the problem was not detected by the operator, and much of the section was laid down with a resin that did not set up. The crew scraped off the soft layers resulting in a section with many thin and bare areas. The other Urefast PF60 section on the McMinnville Bridge was installed correctly, but after two months, patches of the top lift in the wheel tracks were coming off. Test results for the Urefast PF60 are shown in this report, but the product is not included in the comparative performance analysis.

Kwik Bond informed ODOT that one batch of its resin on the McMinnville Bridge did not receive the correct amount of accelerator. Inspection of the section shortly after this notification showed a 2 ft x 10 ft area with patches of deformed or missing top lift.

3.3 SKID RESISTANCE

Skid testing was conducted according to ASTM E 274 for a locked wheel dragged over a wetted pavement surface. Testing was conducted on the overlay sections and bare concrete for each bridge. The data are shown in Table 3.2.

Table 3.2: Skid testing results.

Product	Location	Date	Cumulative Traffic	Pass 1	Pass 2	Pass 3	Pass 4	Average
Concrete	Newberg	9/5/2007	Initial FN	36	34	35		35
		2/4/2008	281,000	58	34	47	48	47
		6/2/2008	501,000	37	38	36		37
		10/15/2008	751,000	32	38			35
		6/30/2009	1,228,000	36	41	40	40	40
		5/11/2010	1,811,000	39	42			41
		9/20/2010	2,055,000	40	41			41
		9/5/2007	Initial FN	32	34	35	36	34
		2/4/2008	1,160,000	47	45			46
		10/15/2008	3,090,000	32	29			31
Mark 154	Newberg	6/30/2009	5,046,000	26	29			28
		5/11/2010	7,440,000	40	30			35
		9/20/2010	8,444,000	38	32			35
		9/5/2007	81,400	69	57	66	70	66
		10/30/2007	183,000	61	64	77	67	67
		2/4/2008	363,000	70	64	72	60	67
		6/2/2008	583,000	43	44	45	43	44
		10/15/2008	832,000	39	40	40	40	40
		6/30/2009	1,310,000	32	32	34	36	33
		5/11/2010	1,893,000	33	35	31		33
Mark 154	McMinnville	9/20/2010	2,137,000	29	27	25		27
		9/5/2007	114,000	70	67	69	67	68
		10/30/2007	532,000	61	56	59	59	59
		2/4/2008	1,270,000	54	59	54	59	56
		6/2/2008	2,170,000	34	35	35	36	35
		10/15/2008	3,200,000	32	33	33	32	33
		6/30/2009	5,160,000	25	21	22	25	23
		5/11/2010	7,554,000	29	27	25		27
		9/20/2010	8,558,000	26	25	25		25
		Flex-O-Lith	Newberg	9/5/2007	79,600	61	64	65
10/30/2007	181,000			61	56	59	59	59
2/4/2008	361,000			65	70	56	63	64
6/2/2008	581,000			41	41	40	37	40
10/15/2008	831,000			35	34	32	35	34
6/30/2009	1,308,000			27	28	30	33	30
5/11/2010	1,891,000			20	21	19		20
9/20/2010	2,135,000			29	38	18		28
9/5/2007	388,000			63	64	64	64	64
10/30/2007	806,000			61	64	77	67	67
Flex-O-Lith	McMinnville	2/4/2008	1,540,000	44	55	57	54	52
		6/2/2008	2,450,000	30	31	32	32	31
		10/15/2008	3,470,000	30	30	31	30	30

Table 3.2 continued

		6/30/2009	5,434,000	19	18	20	18	19
		5/11/2010	7,828,000	22	17	16		18
		9/20/2010	8,831,000	18	19	21		19
Safetrack HW	Newberg	9/5/2007	81,400	62	64	64	62	63
		10/30/2007	183,000	57	59	63	60	60
		2/4/2008	363,000	61	60	60	59	60
		6/2/2008	583,000	41	41	40	47	42
		10/15/2008	832,000	36	38	37	38	37
		6/30/2009	1,310,000	32	32	28	33	31
		5/11/2010	1,893,000	23	28	24		25
		9/20/2010	2,137,000	24	22	21		22
	McMinnville	9/5/2007	106,000	67	67	66	66	67
		10/30/2007	524,000	64	61	62	70	64
		2/4/2008	1,260,000	68	58	57	57	60
		6/2/2008	2,170,000	38	39	37	36	38
		10/15/2008	3,190,000	34	35	35	33	34
		6/30/2009	5,153,000	28	28	17	18	23
		5/11/2009	7,547,000	23	24	21		23
		9/20/2010	8,550,000	35	28	27		30
Kwik Bond PPC MLS*	Newberg	9/5/2007	79,600	62	63	64	58	62
		10/30/2007	181,000	60	60	59	58	59
		2/4/2008	361,000	62	64	62	62	63
		6/2/2008	581,000	48	48	47	48	48
		10/15/2008	831,000	42	41	41	38	41
		6/30/2009	1,308,000	46	44	45	50	46
		5/11/2010	1,891,000	23	37	36		32
		9/20/2010	2,135,000	35	33	32		33
	McMinnville	10/10/2007	122,000	72	69	64	61	67
		10/30/2007	274,000	38	47	51	51	46
		2/4/2008	1,010,000	57	62	62	62	61
		6/2/2008	1,920,000	37	38	40	41	39
		10/15/2008	2,940,000	35	36	39	36	36
		6/30/2009	4,902,000	27	31	31	28	29
		5/11/2010	7,296,000	29	27	27		28
		9/20/2010	8,299,000	28	28	37		31
Tyregrip	Newberg	9/5/2007	75,800	73	51	69	69	66
		10/30/2007	178,000	72	74	78	76	75
		2/4/2008	357,000	74	75	76	71	74
		6/2/2008	577,000	60	61	63	59	61
		10/15/2008	827,000	49	50	40	34	43
		6/30/2009	1,304,000	53	60	60	53	56
		5/11/2010	1,887,000	49	47	47		47
		9/20/2010	2,131,000	47	49	53		50

Table 3.2 continued

	McMinnville	9/5/2007	106,000	79	75	75	77	77
		10/30/2007	524,000	47	54	50	62	53
		2/4/2008	1,260,000	60	77	72	69	69
		6/2/2008	2,170,000	40	38	42	44	41
		10/15/2008	3,190,000	44	48	46	48	46
		6/30/2009	5,153,000	41	45	42	44	43
		5/11/2010	7,547,000	47	47	47		47
		9/20/2010	8,550,000	55	55	52		54
SafeLane HDX	Newberg	9/5/2007	77,700	55	54	58	56	56
		10/30/2007	179,000	47	54	46	62	52
		2/4/2008	359,000	54	50	57	53	53
		6/2/2008	579,000	36	37	35	38	37
		10/15/2008	829,000	35	27	29	30	30
		6/30/2009	1,306,000	27	29	25	30	28
		5/11/2010	1,889,000	25	23	21		23
		9/20/2010	2,133,000	29	20	18		22
	McMinnville	9/5/2007	60,800	70	69	66	67	68
		10/30/2007	479,000	72	74	78	76	75
		2/4/2008	1,220,000	52	53	51	50	51
		6/2/2008	2,120,000	33	31	36	29	32
		10/15/2008	3,150,000	23	26	26	25	25
		6/30/2009	5,107,000	18	18	18	20	19
		5/11/2010	7,501,000	18	18	23		20
		9/20/2010	8,504,000	20	23	22		22
Urefast PF60	Newberg	9/5/2007	75,800	54	55	51	48	52
		10/30/2007	178,000	38	47	51	51	46
		2/4/2008	357,000	48	46	43	43	45
		6/2/2008	577,000	34	32	32	33	33
		10/15/2008	827,000	29	31	26	29	29
		6/30/2009	1,304,000	32	32	29	31	31
		5/11/2010	1,887,000	27	24	26		25
		9/20/2010	2,131,000	25	23	23		24
	McMinnville	9/5/2007	114,000	51	47	48	48	49
		10/30/2007	532,000	60	60	59	58	59
		2/4/2008	1,270,000	48	49	46	48	48
		6/2/2008	2,170,000	32	30	32	42	34
		10/15/2008	3,200,000	27	26	28	27	27
		6/30/2009	5,160,000	32	26	26	27	28
		5/11/2010	7,554,000	38	40	40		39
		9/20/2010	8,558,000	39	39	38		39
Unitex Pro-Poxy Type	Newberg	9/5/2007	75,800	73	36	75	77	65
		10/30/2007	178,000	64	61	63	70	64
		2/4/2008	357,000	63	62	64	60	62

Table 3.2 continued

		6/2/2008	577,000	47	46	39	50	45
		10/15/2008	827,000	40	42	41	41	41
		6/30/2009	1,304,000	43	42	38	50	43
		5/11/2010	1,887,000	32	32	31		32
		9/20/2010	2,131,000	33	31	36		33
	McMinnville	9/5/2007	388,000	67	67	66	66	67
		10/30/2007	806,000	64	61	62	70	64
		2/4/2008	1,540,000	68	58	57	57	60
		6/2/2008	2,450,000	38	39	37	36	38
		10/15/2008	3,470,000	34	35	35	33	34
		6/30/2009	5,434,000	28	30	37	31	32
		5/11/2010	7,828,000	48	30	27		35
		9/20/2010	8,831,000	37	32	31		33

*For Kwik Bond, Newberg aggregate was 4:1 Steilacoom Basalt to Oregon Emery; McMinnville aggregate was 100% Steilacoom Basalt.

3.4 LABORATORY TESTS

Laboratory tests were conducted to characterize the resins, aggregates, and the overlay systems. The intent was to investigate whether a set of common tests could be used to predict field performance. Except for the ultraviolet light exposure, tests were selected that could be conducted easily in most transportation laboratories. The laboratory tests performed on the Kwik Bond PPC MLS system were done only for specimens containing the 4:1 Steilacoom Basalt to Oregon Emery.

The aggregate for each product was characterized. Because Safetrack HW, Urefast PF60, and Kwik Bond at McMinnville used the same aggregate, the same aggregate sample was used to represent these three systems. The results of the aggregate testing are shown in Table 3.3 with details in Appendix B-1.

Table 3.3: Aggregate characteristics.

Product	Aggregate Type	Average Size* (in)	Bulk Specific Gravity	Absorption (%)	Soundness (Total % Loss)	Microdeval (% Loss)
Mark 154	Oklahoma Flint #8	0.13	2.572	1.16	2.6	9.2
Flex-O-Lith	3M Indag Basalt #8	0.08	3.079	0.32	1.2	7.4
Safetrack HW; Urefast PF60; Kwik Bond PPC (McMinnville)	Steilacoom Basalt	0.10	2.670	1.07	1.4	8.1
Kwik Bond PPC MLS (Newberg)	Steilacoom Basalt + #6-10 Oregon Emery	0.10	2.690	0.87	1.2	8.0
Tyregrip	Calcined bauxite	0.10	3.176	1.60	0.2	5.1
SafeLane HDX	Dolomitic limestone	0.16	2.720	1.29	1.0	12.9
Unitex Pro-Poxy Type III DOT	#6-10 Oregon Emery	0.08	2.875	1.23	0.6	5.3

*Based on the weighted average of the sieve analysis.

Abrasion testing was conducted on panels made on-site when the overlay sections were installed. Two areas on the panels were tested. The abrasion test was based on the rotating cutter method described in ASTM C 944. The rotating cutter samples were conditioned prior to testing by dragging a crowbar across the surface for three minutes. This procedure knocked off the aggregate that were weakly bonded to the overlay. A force of 22 pounds was exerted on the cutter, and a rotation speed of 250 rpm was used. Each test location was abraded for five 2-minute intervals, and the weight loss was measured after each interval. By the last interval, the rate of weight loss had leveled off. Table 3.4 reports the average weight loss for the last interval for each of the overlay systems with details provided in Appendix B-2.

Table 3.4: Abrasion test results.

Product	Aggregate Type	Sample 1	Sample 2	Average
Mark 154	Oklahoma Flint #8	0.7	0.8	0.8
Flex-O-Lith	3M Indag Basalt #8	0.7	0.5	0.6
Safetrack HW	Steilacoom Basalt	0.4	0.5	0.4
Kwik Bond PPC MLS (Newberg)	Steilacoom Basalt + #6-10 Oregon Emery	0.8	0.6	0.7
Tyregrip	Calcined bauxite	0.5	0.6	0.5
SafeLane HDX	Dolomitic limestone	1.3	1.1	1.2
Urefast PF60	Steilacoom Basalt	0.2	0.5	0.3
Unitex Pro-Poxy Type III DOT	#6-10 Oregon Emery	0.4	0.4	0.4

Note: Values are the weight loss in grams during the last two minutes of ten minutes of grinding.

Water absorption tests were conducted on the resins according to ASTM D-570. The tests were run for five weeks at which time the specimens showed little or no additional water absorption. Table 3.5 shows the percent increase in weight due to water absorption after the five weeks.

Table 3.5: Water absorption results of the resins.

Product	Sample 1	Sample 2	Sample 3	Average
Mark 154	5.8	2.9	4.8	4.5
Flex-O-Lith	2.3	2.3	2.1	2.3
Safetrack HW	2.0	1.4	1.3	1.6
Kwik Bond PPC MLS	1.9	1.7	2.0	1.9
Tyregrip	0.9	1.1	1.0	1.0
SafeLane HDX	1.4	1.5	1.3	1.4
Urefast PF60	5.0	5.1	5.0	5.0
Unitex Pro-Poxy Type III DOT	1.3	1.3	1.4	1.3

Note: Values are the percentage increase in weight.

Tensile strength tests were conducted on the resins according to ASTM D 638. Specimens were tested at 0, 70, and 140°F in order to cover the range of expected operating temperatures. In addition, sets of tensile specimens were exposed to ultraviolet light based on ASTM G 155 in a Weatherometer to simulate sunshine prior to testing at 70°F. The results are shown in Tables 3.6, 3.7, and 3.8.

Table 3.6: Tensile strength results of the resins at various temperatures.

Temperature	Product	Sample 1 (psi)	Sample 2 (psi)	Sample 3 (psi)	Sample 4 (psi)	Average (psi)
0°F	Mark 154	4596	2147	5330	5555	4407
	Flex-O-Lith	4958	5952*	6458	5147	>5629
	Safetrack HW	2667	2484	1916	1489	2139
	Kwik Bond PPC MLS	12500*	6396	8333*	13158*	>10097
	Tyregrip	6662	8621*	5762	2996	>6010
	SafeLane HDX	8200	3598	5281	7576*	>6164
	Urefast PF60	6461	6890	5547	7152	6513
	Unitex Pro-Poxy Type III DOT	8265	7353*	7671	9615*	>8226
70°F	Mark 154	3620	2730	2643	2896	2972
	Flex-O-Lith	1938	2314	2580	1825	2164
	Safetrack HW	3272	2523	2178	2936	2727
	Kwik Bond PPC MLS	3020	1626	2178	2936	2440
	Tyregrip	5330	5366	4848	5036	5138
	SafeLane HDX	2659	2447	2636	2516	2565
	Urefast PF60	3368	2304	1924	2590	2547
Unitex Pro-Poxy Type III DOT	4366	5251	2708	3802	4032	
140°F	Mark 154	243	328	340	296	302
	Flex-O-Lith	201	250	219	283	238
	Safetrack HW	975	1457	1295	1247	1244
	Kwik Bond PPC MLS	1154	880	740	449	806
	Tyregrip	518	486	1480	181	666
	SafeLane HDX	144	215	123	221	176
	Urefast PF60	873	599	378	608	615
	Unitex Pro-Poxy Type III DOT	268	281	405	430	346

*Exceeded load cell range of 250 pounds, so specimen strength was greater than reported value.

Table 3.7: Tensile elongation results of the resins at various temperatures.

Temperature	Product	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Sample 4 (%)	Average (%)
0°F	Mark 154	25	20	30	30	26
	Flex-O-Lith	35	25	25	20	26
	Safetrack HW	20	15	20	10	16
	Kwik Bond PPC MLS	35	30	30	30	31
	Tyregrip	30	30	35	20	29
	SafeLane HDX	30	15	20	30	24
	Urefast PF60	30	50	40	40	40
	Unitex Pro-Poxy Type III DOT	50	20	35	35	35
70°F	Mark 154	60	70	80	90	75
	Flex-O-Lith	70	80	90	65	76
	Safetrack HW	20	20	15	30	21
	Kwik Bond PPC MLS	40	40	45	30	39
	Tyregrip	30	30	30	40	33
	SafeLane HDX	65	80	50	65	65

Table 3.7 continued

	Urefast PF60	115	105	105	130	114
	Unitex Pro-Poxy Type III DOT	35	55	40	45	44
	Mark 154	110	115	120	145	123
140°F	Flex-O-Lith	80	80	55	70	71
	Safetrack HW	15	35	65	20	34
	Kwik Bond PPC MLS	70	60	65	55	63
	Tyregrip	55	45	40	30	43
	SafeLane HDX	60	70	45	60	59
	Urefast PF60	140	145	90	120	124
	Unitex Pro-Poxy Type III DOT	80	85	90	70	81

Table 3.8: 70°F tensile results of the resins after exposure to simulated terrestrial sunlight.

Exposure (hours)	Product	Strength			Elongation		
		Sample 1 (psi)	Sample 2 (psi)	Average (psi)	Sample 1 (%)	Sample 2 (%)	Average (%)
500	Mark 154	599	1426	1013	25	19	22
	Flex-O-Lith	1029	959	994	22	19	21
	Safetrack HW	1933	2140	2037	22	25	24
	Kwik Bond PPC MLS	4911	2588	3750	47	25	36
	Tyregrip	1950	2888	2419	22	28	25
	SafeLane HDX	1185	1133	1159	9	19	14
	Urefast PF60	2242	2505	2374	88	94	91
	Unitex Pro-Poxy Type III DOT	1891	2451	2171	28	19	24
1000	Mark 154	1481	2025	1753	25	19	22
	Flex-O-Lith	1245	1217	1231	19	-	19
	Safetrack HW	579	2056	1318	6	19	13
	Kwik Bond PPC MLS	3714	4051	3883	31	38	35
	Tyregrip	2914	1133	2024	19	19	19
	SafeLane HDX	1930	1667	1799	13	19	16
	Urefast PF60	2000	2050	2025	113	94	104
	Unitex Pro-Poxy Type III DOT	1694	1000	1347	19	19	19
1500	Mark 154	1395	1295	1345	13	13	13
	Flex-O-Lith	-	1105	1105	19	16	18
	Safetrack HW	1829	1250	1540	19	13	16
	Kwik Bond PPC MLS	2444	4618	3531	19	22	21
	Tyregrip	391	645	518	9	-	9
	SafeLane HDX	1417	1143	1280	16	-	16
	Urefast PF60	2125	2081	2103	103	78	91
	Unitex Pro-Poxy Type III DOT	1588	1568	1578	16	16	16

Flexural strength and compressive strength tests were conducted on the overlay systems according to ASTM C 580 and ASTM C 579 respectively. Specimens were tested at 0, 70, and 140°F in order to cover the range of expected operating temperatures. The results are shown in Tables 3.9 and 3.10.

Table 3.9: Flexural strength results of the overlay systems at various temperatures.

Temperature	Product	Sample 1 (psi)	Sample 2 (psi)	Sample 3 (psi)	Sample 4 (psi)	Average (psi)
0°F	Mark 154	2564	3839	4154	4048	3651
	Flex-O-Lith	3494	3902	4169	3468	3758
	Safetrack HW	3520	3730	3791	3616	3664
	Kwik Bond PPC MLS	3978	4162	3696	3806	3911
	Tyregrip	4444	4679	4391	4966	4620
	SafeLane HDX	3337	3100	3043	2937	3104
	Urefast PF60	2737	2776	2752	2689	2739
	Unitex Pro-Poxy Type III DOT	4908	5114	5109	5304	5109
70°F	Mark 154	1611	2436	1937	1159	1786
	Flex-O-Lith	2346	2237	2362	2243	2297
	Safetrack HW	3031	3082	3184	2275	2893
	Kwik Bond PPC MLS	2223	2055	2217	2150	2161
	Tyregrip	2770	2933	2762	2745	2803
	SafeLane HDX	1676	1783	1725	2260	1861
	Urefast PF60	1100	1725	1038	1320	1296
	Unitex Pro-Poxy Type III DOT	4100	4442	4480	4091	4278
140°F	Mark 154	259	332	211	245	262
	Flex-O-Lith	384	297	242	225	287
	Safetrack HW	1402	1444	1418	1079	1336
	Kwik Bond PPC MLS	585	449	404	392	458
	Tyregrip	344	264	351	428	347
	SafeLane HDX	282	288	305	281	289
	Urefast PF60	458	194	332	273	314
	Unitex Pro-Poxy Type III DOT	314	339	325	365	336

Table 3.10: Compressive strength results of the overlay systems at various temperatures

Temperature	Product	Sample 1 (psi)	Sample 2 (psi)	Sample 3 (psi)	Sample 4 (psi)	Average (psi)
0°F	Mark 154	10648	9825	11901	11500	10968
	Flex-O-Lith	10865	9697	10586	11902	10762
	Safetrack HW	7118	9049	8498	9520	8546
	Kwik Bond PPC MLS	11703	12660	12263	11014	11910
	Tyregrip	12486	10806	10418	13143	11713
	SafeLane HDX	12952	9357	11547	7704	10390
	Urefast PF60	4047	4342	3964	3549	3976
	Unitex Pro-Poxy Type III DOT	14619	13646	11973	13707	13486
70°F	Mark 154	4429	4779	4452	3976	4409
	Flex-O-Lith	4515	4706	6171	4808	5050
	Safetrack HW	6359	8155	4666	5866	6262
	Kwik Bond PPC MLS	5150	5230	5256	5294	5233
	Tyregrip	7927	7722	7352	-	7667
	SafeLane HDX	5076	4129	4073	3696	4243
	Urefast PF60	3371	2108	2251	2484	2554
	Unitex Pro-Poxy Type III DOT	5905	7726	7917	6949	7124

Table 3.10 continued

140°F	Mark 154	482	329	304	464	395
	Flex-O-Lith	550	543	734	669	624
	Safetrack HW	2299	1929	2146	1922	2074
	Kwik Bond PPC MLS	989	1216	1084	1273	1140
	Tyregrip	1035	1225	1190	1147	1149
	SafeLane HDX	449	629	545	576	550
	Urefast PF60	468	394	467	569	474
	Unitex Pro-Poxy Type III DOT	710	730	558	708	676

3.5 INSPECTION

Visual and delamination inspections were conducted in June of 2009 and 2010. By June 2010 the overlays were in service for 33 to 35 months, depending on the installation date for a particular section. The mapped delaminations are included on the surveys in Appendix A and summarized in Table 3.10. Close-up photographs of the overlays are shown in Figure 3.1.

Most indications of delaminations were associated with known delaminations in the underlying concrete and were not included in Table 3.11. However, the delaminations that were reported in the Table may still be due to the concrete substrate if new concrete delaminations developed between the time of the pre-installation and overlay surveys - a period of three to four years. This could be the case especially for the McMinnville bridge, which was showing signs of deck deterioration. Most of the delaminations recorded in Table 3.10 were for the bridge at McMinnville. Due to the possibility of detecting concrete delamination instead of actual overlay delamination, a delamination survey was not conducted at the McMinnville Bridge for June 2010.

Safetrack HW and Tyregrip showed evidence of wearing through to the concrete. Flex-O-Lith also showed wear-through in one part of one section, but this was attributed to insufficient overlay thickness due to the contractor running out of resin during installation. Subsequent comparisons in this report do not show Flex-O-Lith exhibiting wear-through.

A common feature shown in the photographs of Figure 3.1 was voids in the overlays presumably from missing aggregate. No attempt was made to investigate the mechanism for the void formation (e.g., aggregate pull-out, aggregate crushing); however, some photographs showed aggregate that appeared highly fractured. The presence of fractured aggregate indicates that aggregate crushing may be one cause of the voids.

Table 3.11: Inspection results.

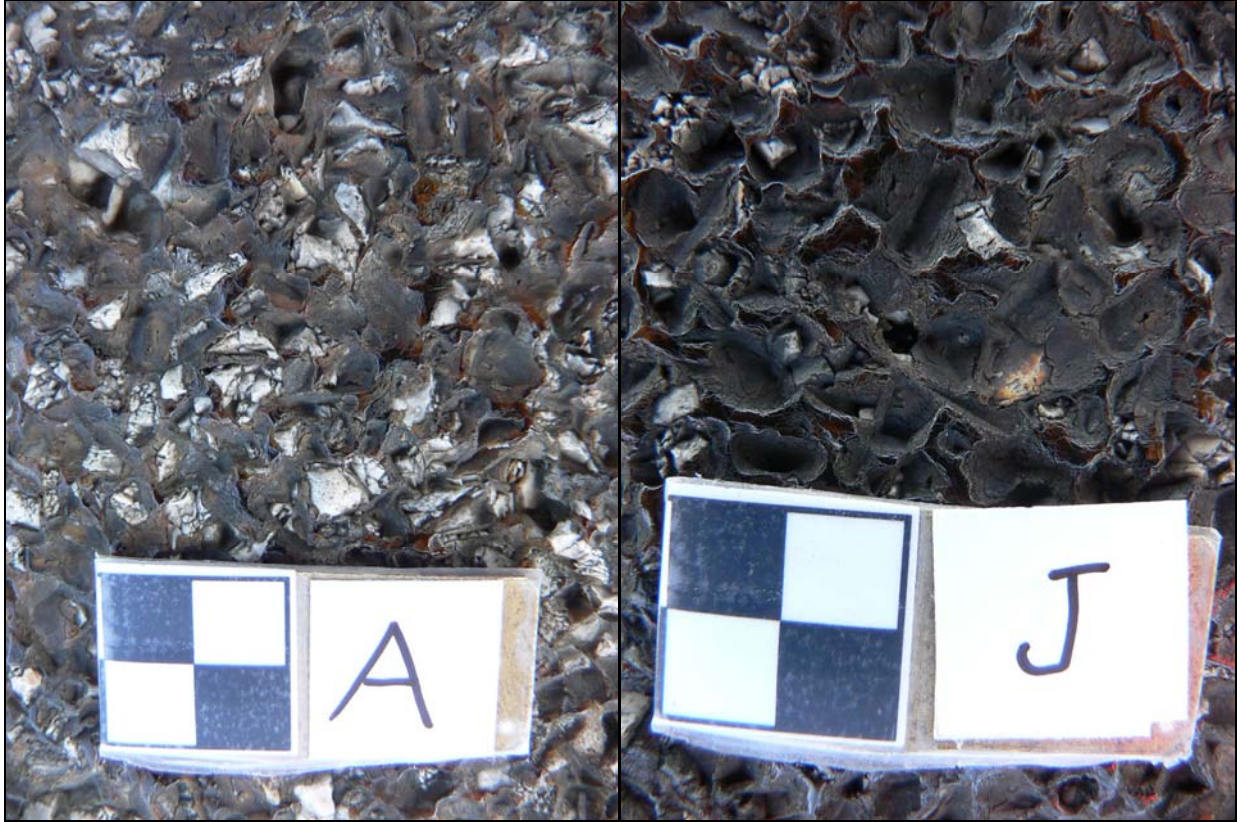
Product	Installation Date	Traffic Exposure	Truck Exposure	Number of Delaminations *	Comments
Mark 154	7/23/07 Newberg	1,300,000	112,000	0	
	8/20/07 McMinnville	5,110,000	240,000	1	
Flex-O-Lith	7/24/07 Newberg	1,300,000	112,000	1	During installation, the contractor ran out of resin before completing the last 25' of the section. The overlay was wearing through to the concrete in this part of the section in June 2009
	7/16/07 McMinnville	5,390,000	253,000	0	
Safetrack HW	7/23/07 Newberg	1,300,000	112,000	7	Started to wear through to concrete by June 2009. ~10% of wheel paths had worn through by June 2010
	8/22/07 McMinnville	5,110,000	240,000	4	~10% of wheel paths had worn through to concrete by June 2009. ~15% of wheel paths had worn through by June 2010
Kwik Bond PPC MLS**	7/24/07 Newberg	1,300,000	112,000	2	
	9/24/07 McMinnville	4,860,000	228,000	3	
Tyregrip	7/26/07 Newberg	1,290,000	111,000	0	Beginning to wear through to concrete by June 2009. ~5% of wheel paths had worn through by June 2010.
	8/22/07 McMinnville	5,110,000	240,000	10	Beginning to wear through to concrete.
SafeLane HDX	7/25/07 Newberg	1,290,000	111,000	2	
	8/28/07 McMinnville	5,060,000	238,000	2	
Urefast PF60	7/26/07 Newberg	1,290,000	111,000	Not surveyed	
	8/20/07 McMinnville	5,110,000	240,000	Not surveyed	
Unitex Pro-Poxy Type III DOT	7/26/07 Newberg	1,290,000	111,000	4	
	7/16/07 McMinnville	5,390,000	253,000	11	

*Delamination indications that coincided with pre-installation indications are not included in the counts shown.

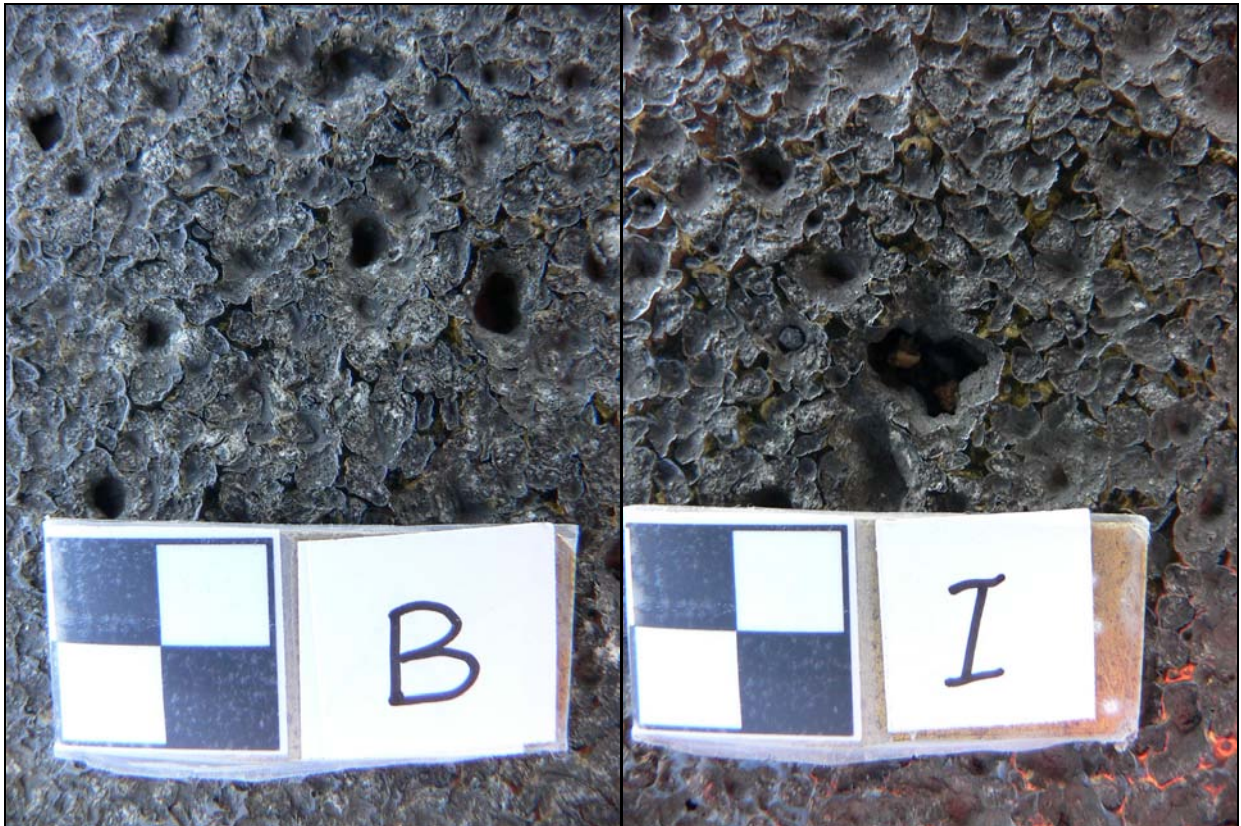
Newberg values are from the June 2010 survey and the McMinnville values are from the June 2009 survey.

**For Kwik Bond, Newberg aggregate was 4:1 Steilacoom Basalt to Oregon Emery; McMinnville aggregate was 100% Steilacoom Basalt.

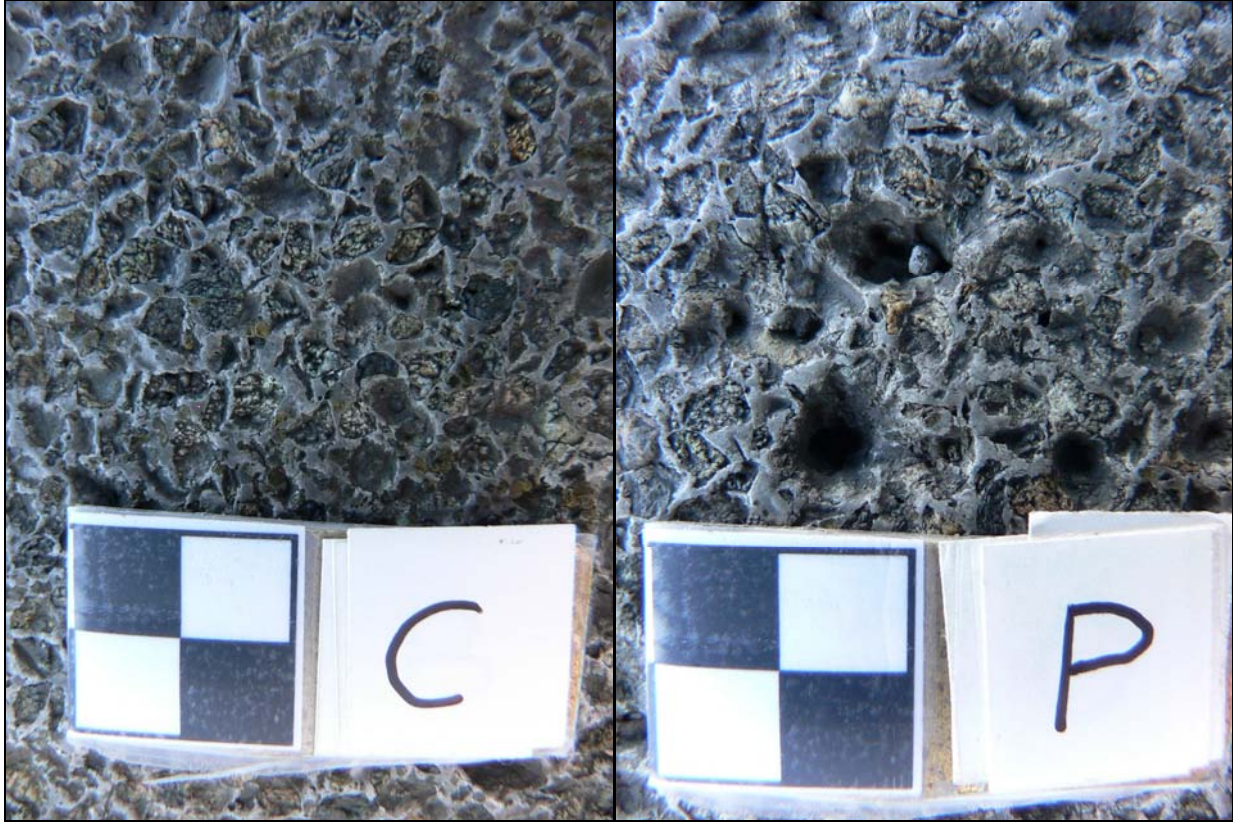
Mark 154



Flex-O-Lith

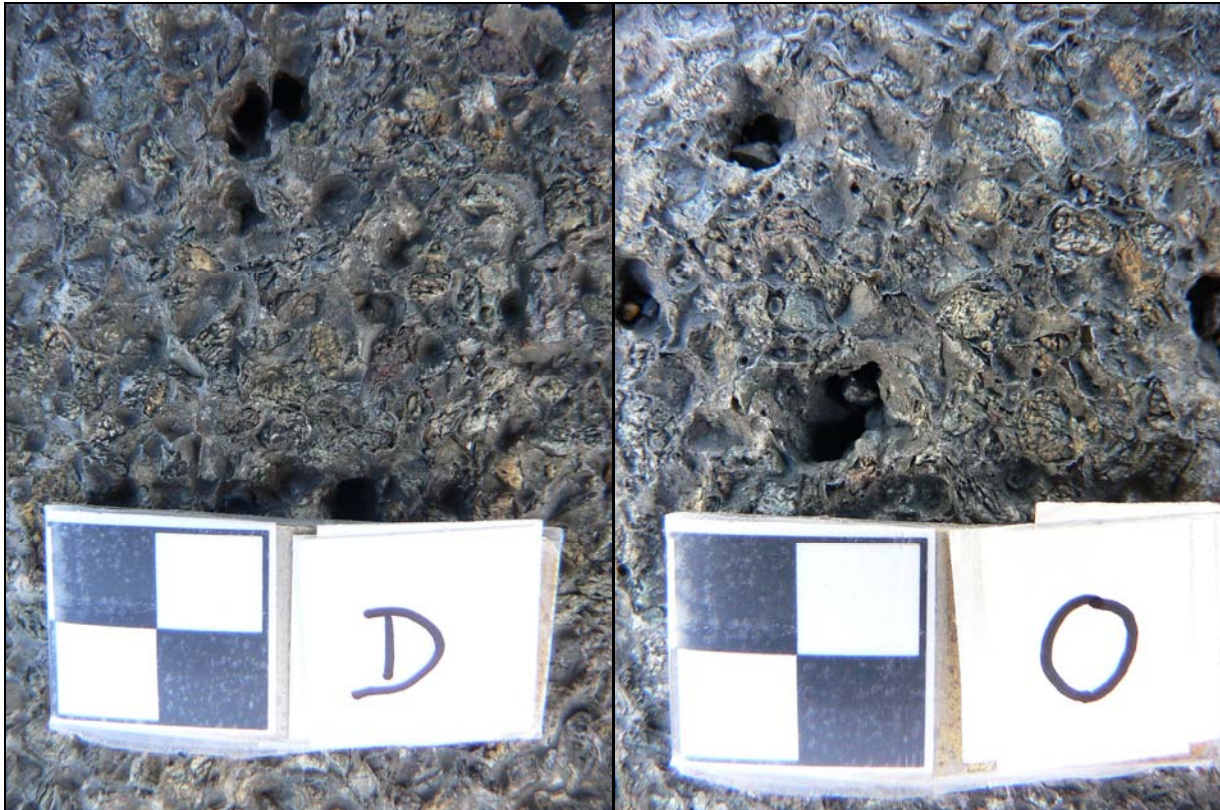


Safetrack HW

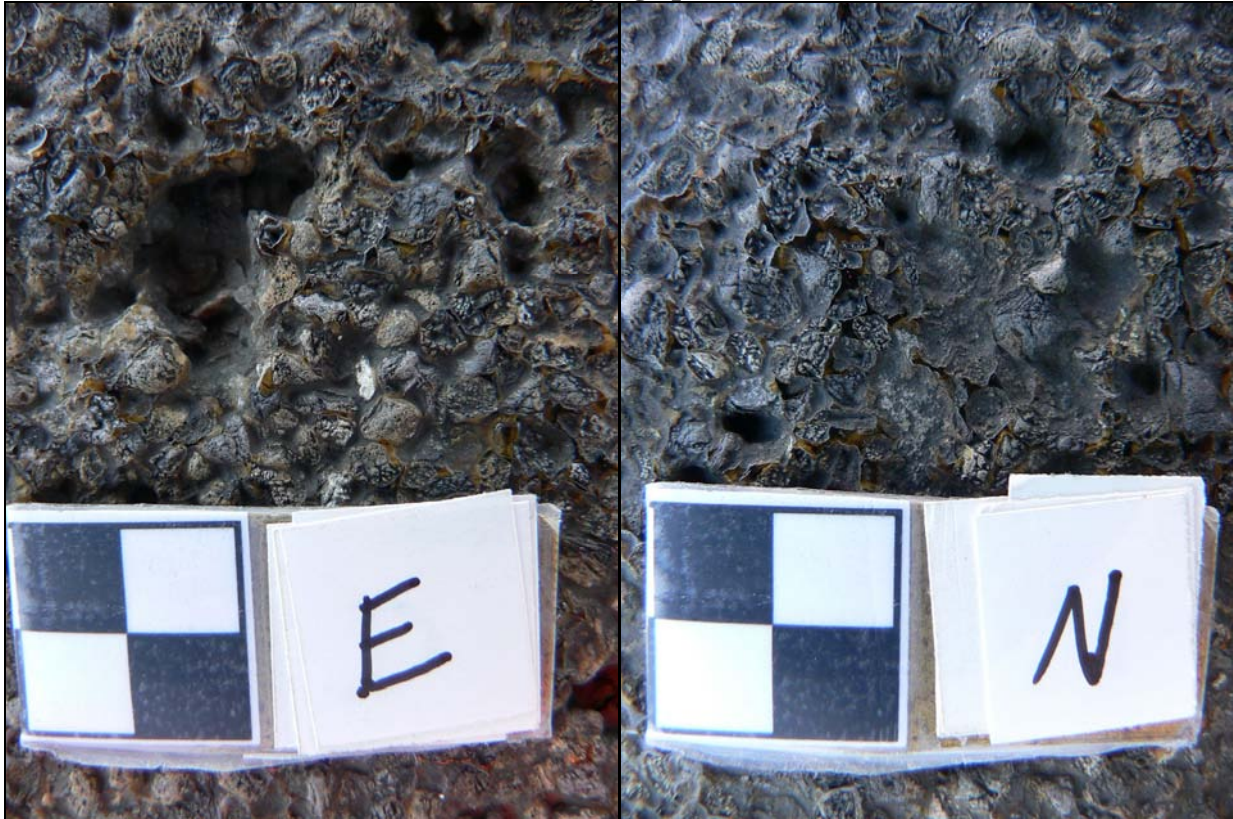


Kwik Bond PPC MLS

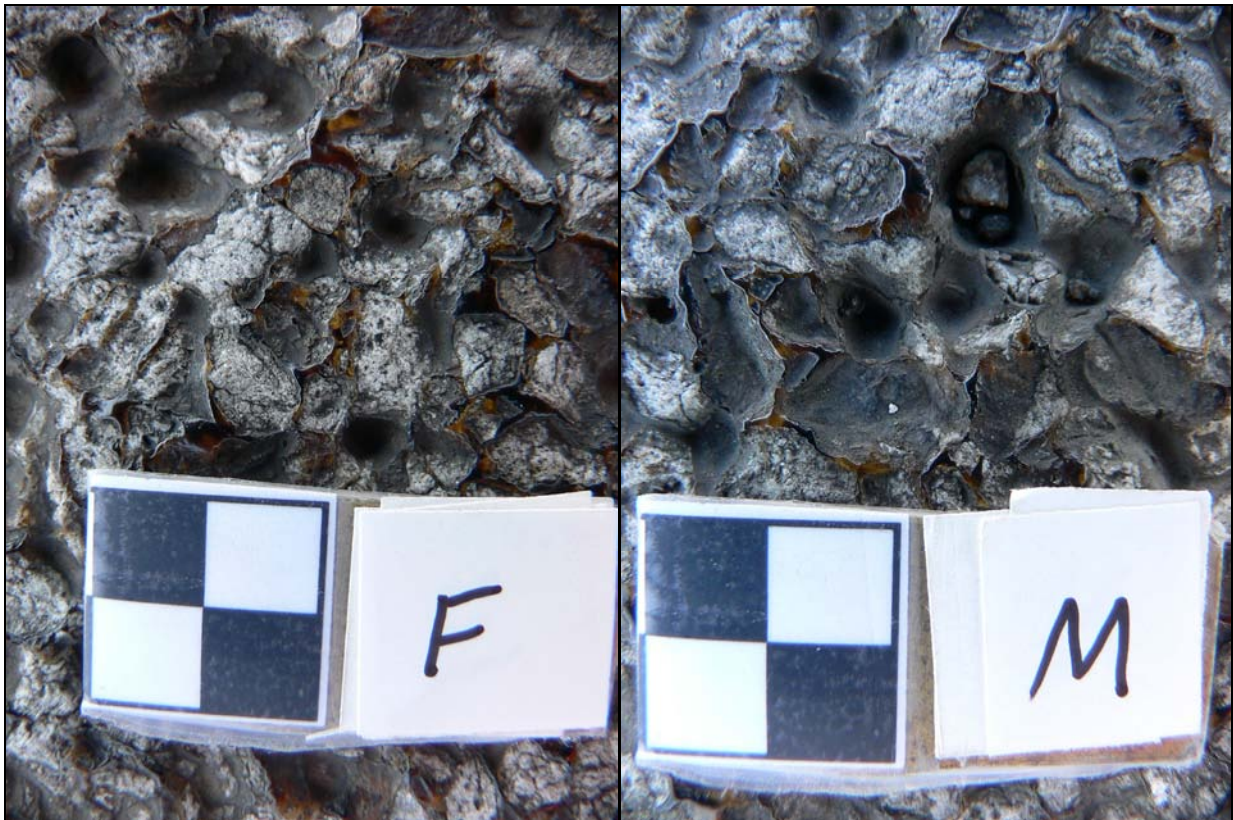
Newberg (left) aggregate was 4:1 Steilacoom Basalt to Oregon Emery; McMinnville (right) aggregate was 100% Steilacoom Basalt



Tyregrip



SafeLane HDX



Unitex ProPoxy Type III DOT

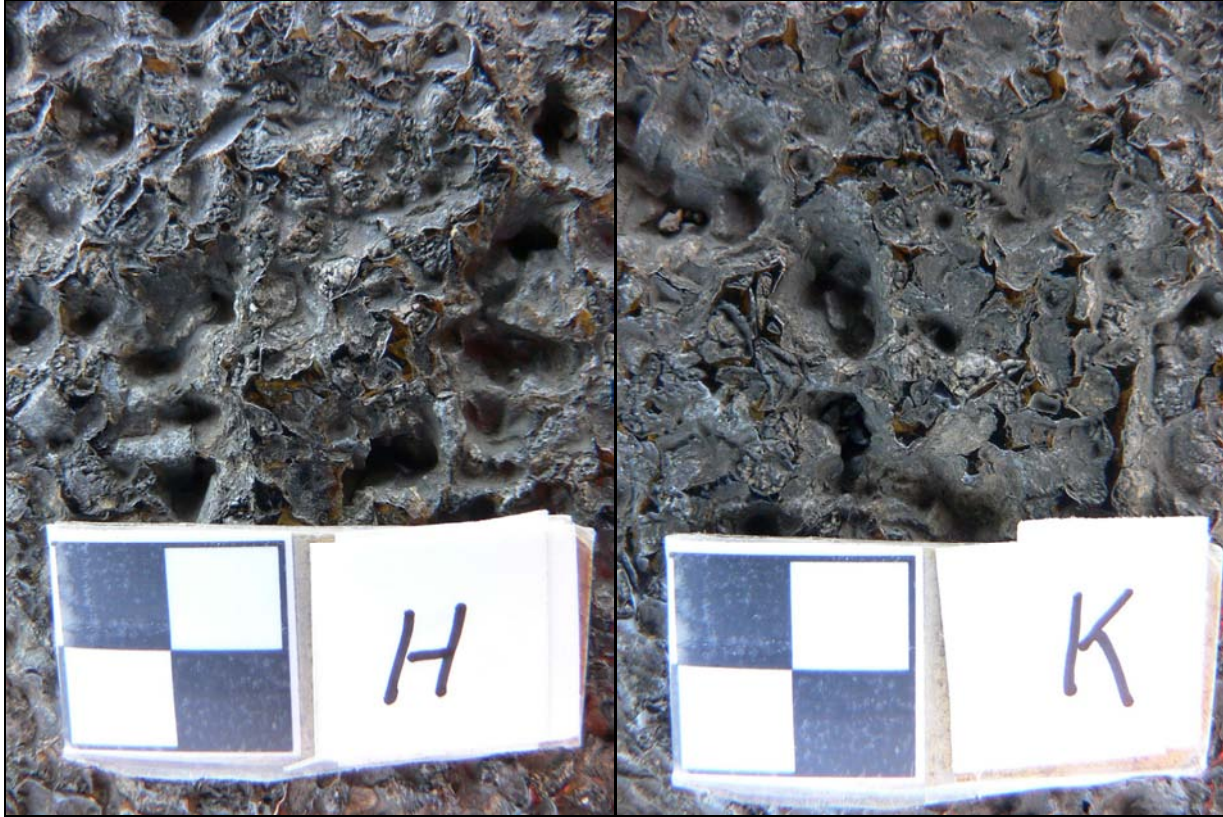


Figure 3.1: Surface condition of overlays at interim inspection. The small squares in the scale are 0.25 in. The left photos are from the bridge at Newberg and the right photos are from the bridge at McMinnville.

4.0 DISCUSSION

4.1 SKID TESTING

The overlays at Newberg were prone to more rapid decrease in friction number than those at McMinnville as shown in Figure 4.1. However, trucks made up a higher fraction of the traffic at Newberg (0.086) than at McMinnville (0.047). Also, the posted speed at Newberg was 55 mph compared to 35 mph at McMinnville. The effects of speed and fraction of trucks on friction number could not be extracted from the data.

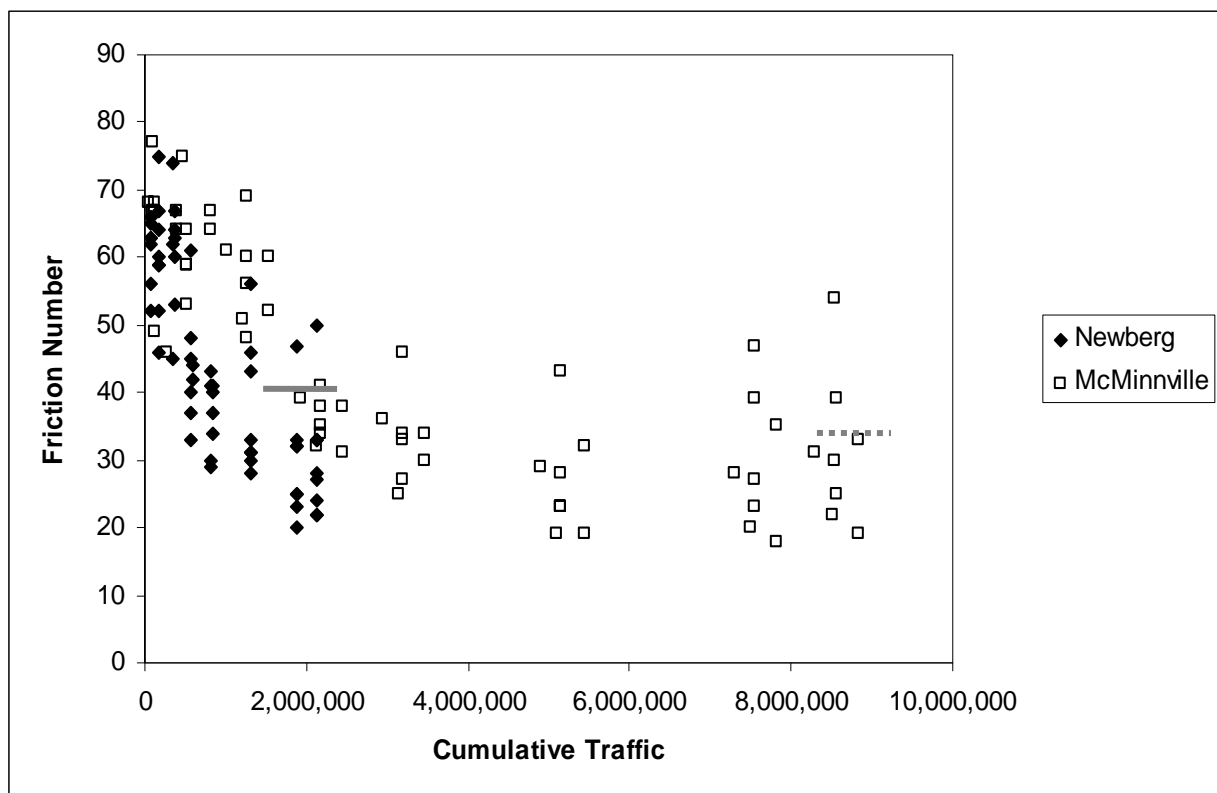


Figure 4.1: Combined skid testing results for all overlay systems. The solid and dashed horizontal lines show the friction number of the concrete for the last set of measurements at Newberg and McMinnville, respectively.

The friction number data for each product were used to develop predictive equations relating cumulative traffic exposure to friction number. Generally, a power curve provided the best fit to the data as shown in Appendix C. The equations and corresponding R^2 values for the conservative exposure conditions of the Newberg Bridge (highway speeds and larger fraction of truck traffic) are given in Table 4.1 along with calculated traffic exposure for corresponding friction numbers of 40 and 30. Due to the low R^2 value for Tyregrip, the equation for this product should not be used for predicting performance.

No product type showed a definitive advantage over other product types. Tyregrip maintained higher friction numbers over time compared to the other products, but Tyregrip also started to wear through to the concrete within two years. Except for Tyregrip, the skid resistance results for the products would be on the low side of the ranges reported in Section 1.2. Neglecting the two products that wore through, no product would be expected to last more than approximately four to five months under moderate average daily traffic per lane of 10,000 vehicles before reaching a friction number of 40. For comparison, the average friction number for the concrete on the Newberg Bridge over the time period of the study was 39 based on the values reported in Table 3.2.

Table 4.1: Calculated traffic exposure to reduce friction number based on results from the Newberg Bridge.

Product	Product Type	Equation*	R ²	Calculated Cumulative Traffic at FN=40	Calculated Cumulative Traffic at FN=30	Comments
Mark 154	Epoxy	$y=2031x^{-.2878}$	0.82	840,000	2,200,000	
Flex-O-Lith	Epoxy	$y=3283x^{-.3341}$	0.76	540,000	1,300,000	
Tyregrip**	Epoxy	$y=308x^{-.1263}$	0.42	10,000,000	100,000,000	Wearing through at 1,300,000
Safelane HDX	Epoxy	$y=1989x^{-.3036}$	0.82	390,000	1,000,000	
Unitex Pro-Poxy Type III DOT	Epoxy	$y=808x^{-.2153}$	0.66	1,200,000	4,400,000	
Safetrack HW	MMA	$y=2955x^{-.3241}$	0.86	580,000	1,400,000	Wearing through at 1,300,000
Kwik Bond PPC MLS	Polyester	$y=651x^{-.1986}$	0.69	1,300,000	5,400,000	

*y is friction number; x is cumulative traffic. **Tyregrip is shown for completeness, but the equation should not be used for prediction due to the low R².

The aggregate properties measured in the laboratory did not provide good predictors of field performance. The most likely aggregate property to correlate with skid resistance, aggregate abrasion resistance measured with Microdeval, had little influence as shown in Figure 4.2. Similarly, system (resin + aggregate) abrasion resistance had little correlation with skid resistance as shown in Figure 4.3. The figures also show that only one overlay system, Tyregrip, had friction numbers greater than that of the concrete on the respective bridges.

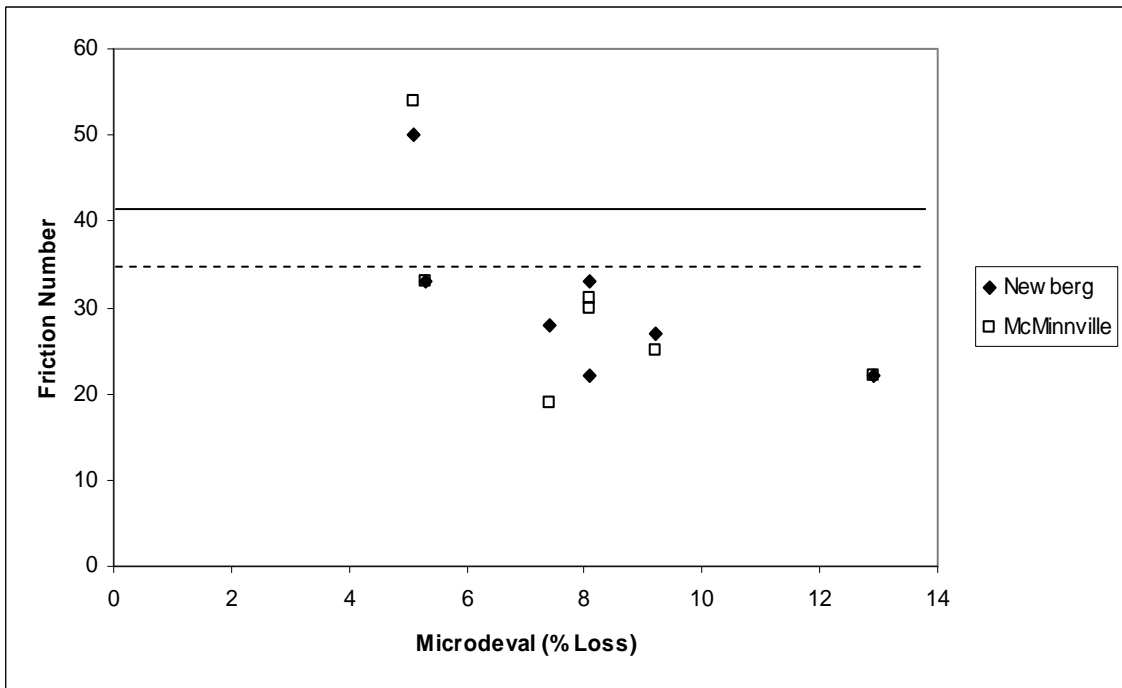


Figure 4.2: Comparison of skid resistance and aggregate abrasion resistance test results. The friction numbers are from the last set of skid tests where Newberg cumulative traffic ranged from 2,131,000 to 2,137,000 and McMinnville cumulative traffic ranged from 8,299,000 to 8,831,000. The solid and dashed horizontal lines show the concrete friction numbers at Newberg and McMinnville, respectively.

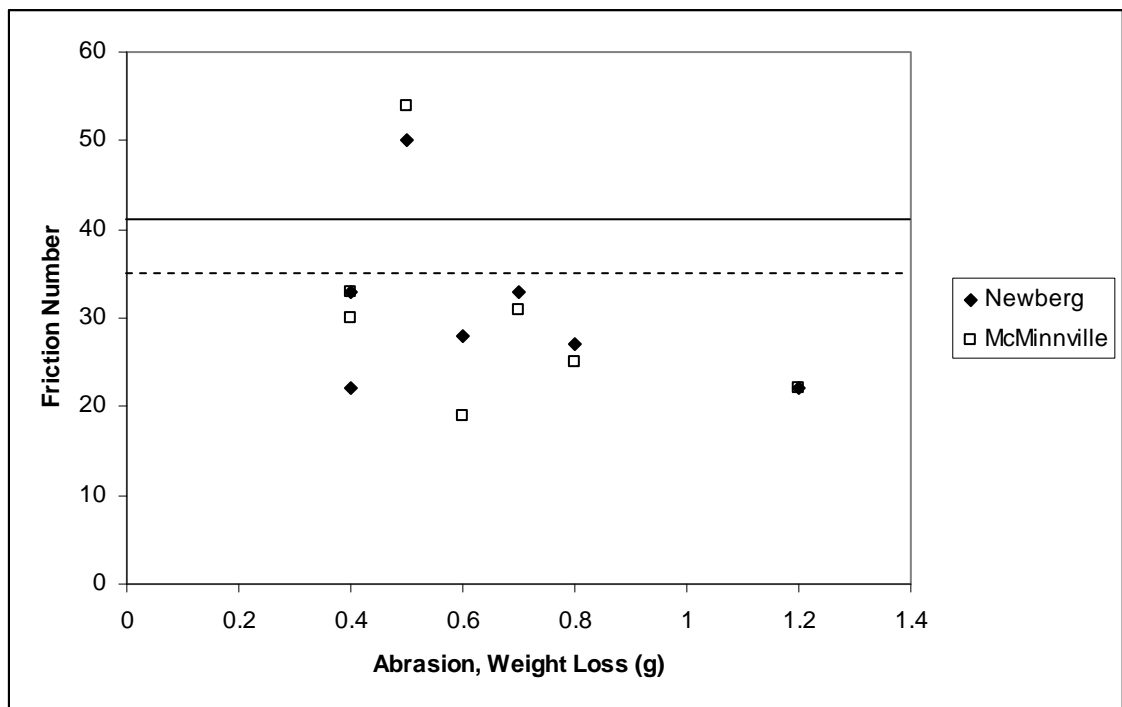


Figure 4.3: Comparison of skid resistance and system abrasion resistance test results. The friction numbers are from the last set of skid tests where Newberg cumulative traffic ranged from 2,131,000 to 2,137,000 and McMinnville cumulative traffic ranged from 8,299,000 to 8,831,000. The solid and dashed horizontal lines show the concrete friction numbers at Newberg and McMinnville, respectively.

4.2 MECHANICAL TESTING

The mechanical testing of the resins and overlay systems did not provide any obvious predictors of in-service performance. Figures 4.4 – 4.9 compare the testing results in conjunction with performance problems of the overlays. General observations are discussed below.

The resin tensile testing was conducted over the temperature range expected on the surface of bridge decks in the winter and summer. All resins showed appreciable reduction in tensile strength at 140°F as shown in Figure 4.4. Based on the comparison of tensile elongations in Figure 4.5, none of the resins showed brittle behavior at 0°F.

Most resins showed some reduction in tensile strength due to simulated sunlight exposure as shown in Figure 4.6. However, only Tyregrip showed continued reduction in tensile strength with increased exposure time. Four of the resins showed relatively large reductions of elongation after exposure, but, with the exception of Tyregrip and Kwik Bond, the elongation did not decrease appreciably with continued exposure (Figure 4.7). The general trend of degradation occurring mostly after initial exposure may be due to the fact that the surface deteriorates but protects the interior of the specimen. In service, however, a deteriorated surface could be worn away exposing a fresh surface for further deterioration. This would occur around an aggregate particle until there was not enough resin to keep the particle in place.

The flexural and compressive strength of the overlay systems in the temperature range of 0°F to 140°F followed the expected trend of decreased strength as the temperature increases (Figures 4.8 and 4.9). Though the strengths are substantially lower at 140°F, none of the systems on the bridges showed evidence of shoving that would indicate hot weather deformation.

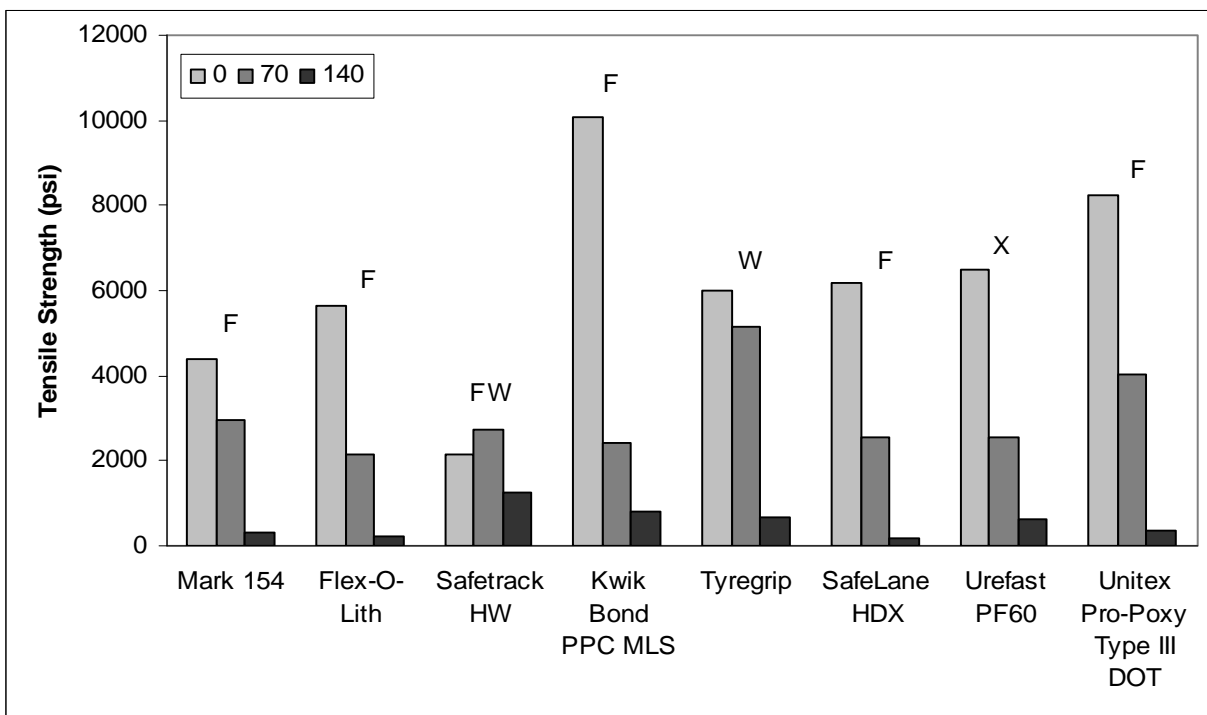


Figure 4.4: Comparison of the tensile strengths of the resins at 0, 70, and 140°F. “F” indicates systems that had friction numbers less than the concrete. “W” indicates systems that have worn through to the concrete. “X” indicates a system that failed early in the evaluation.

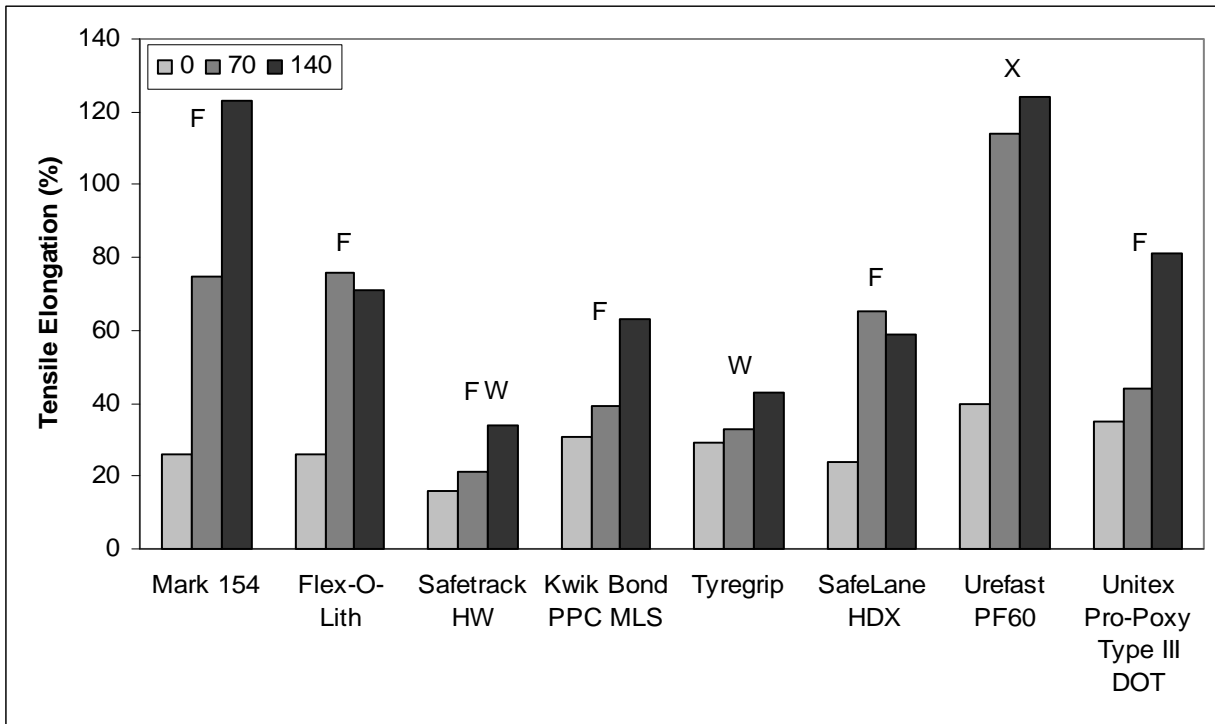


Figure 4.5: Comparison of the tensile elongations of the resins at 0, 70, and 140 °F. “F” indicates systems that had friction numbers less than the concrete. “W” indicates systems that have worn through to the concrete. “X” indicates a system that failed early in the evaluation.

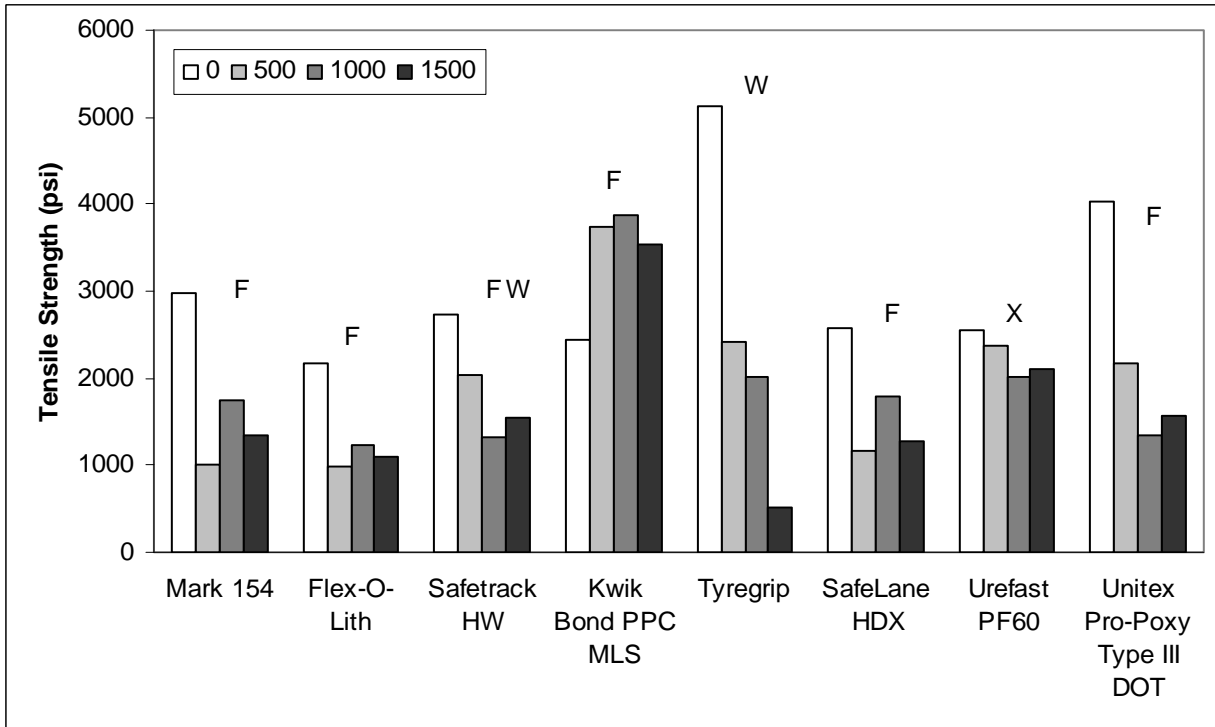


Figure 4.6: Comparison of the tensile strengths of the overlay resins after simulated sunlight exposure of 0, 500, 1000, and 1500 hours. “F” indicates systems that had friction numbers less than the concrete. “W” indicates systems that have worn through to the concrete. “X” indicates a system that failed early in the evaluation.

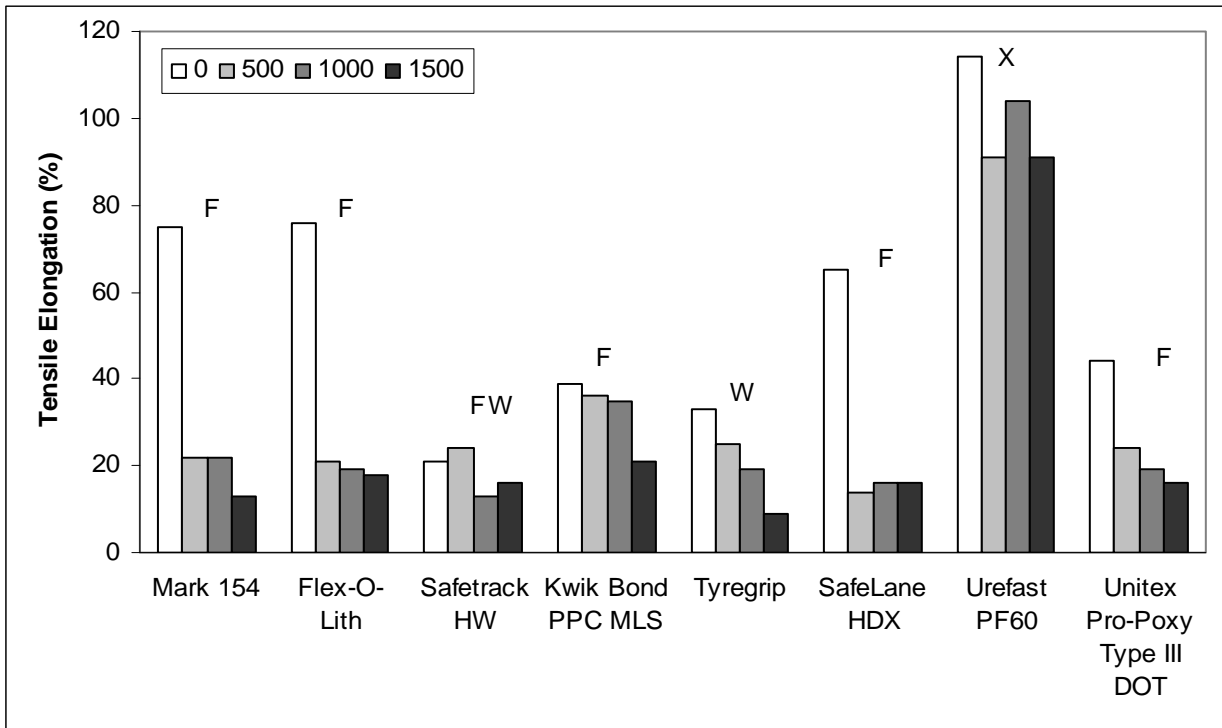


Figure 4.7: Comparison of the tensile elongations of the overlay resins after simulated sunlight exposure of 0, 500, 1000, and 1500 hours. “F” indicates systems that had friction numbers less than the concrete. “W” indicates systems that have worn through to the concrete. “X” indicates a system that failed early in the evaluation.

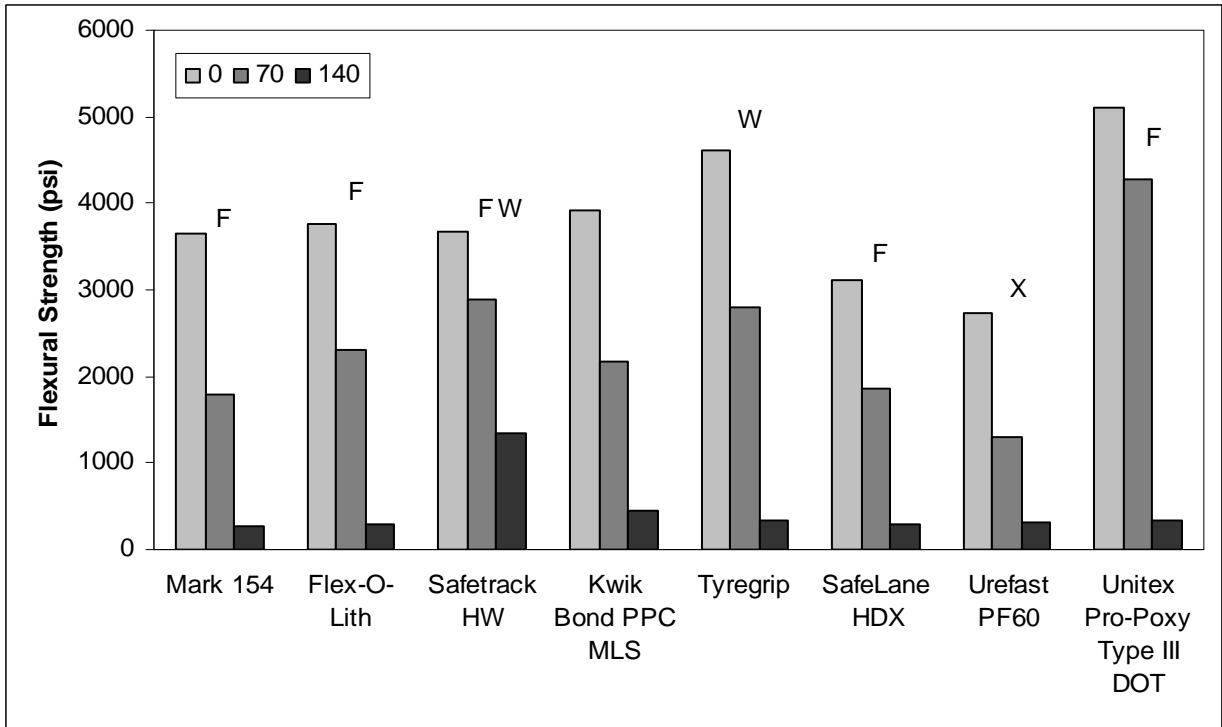


Figure 4.8: Comparison of the flexural strengths of the overlay systems at 0, 70, and 140°F. “F” indicates systems that had friction numbers less than the concrete. “W” indicates systems that have worn through to the concrete. “X” indicates a system that failed early in the evaluation.

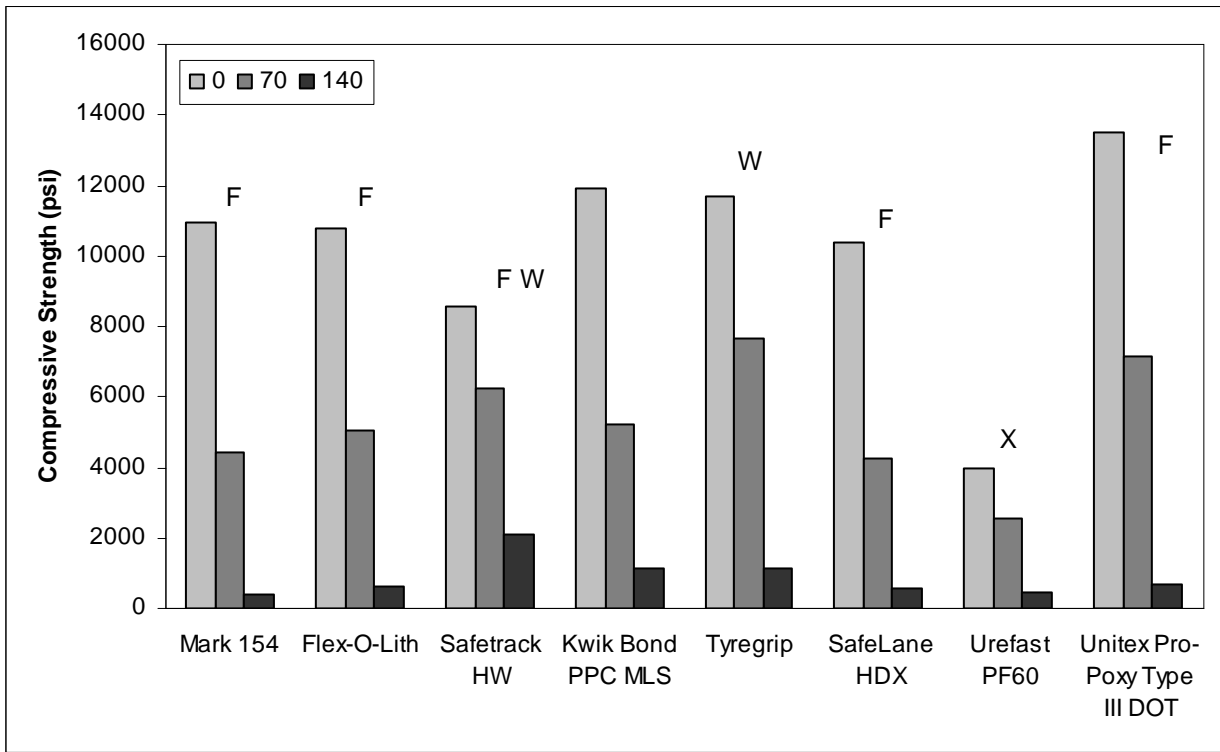


Figure 4.9: Comparison of the compressive strengths of the overlay systems at 0, 70, and 140 °F. “F” indicates systems that had friction numbers less than the concrete. “W” indicates systems that have worn through to the concrete. “X” indicates a system that failed early in the evaluation.

5.0 CONCLUSIONS

Eight thin polymer overlay systems were evaluated in the laboratory and on two bridge decks exposed to a mix of vehicles including those with studded tires. The products were Mark 154, Flex-O-Lith, Safetrack HW, Kwik Bond PPC MLS, Tyregrip, SafeLane HDX, Urefast PF60, and Unitex ProPoxyType III DOT. The results of the investigation supported the following conclusions:

Tyregrip and Safetrack HW started to wear through to the concrete after exposure of approximately 1.3 million vehicles. Urefast PF60 wore through much sooner.

For six of the eight products (Tyregrip and Urefast PF60 excluded), empirical equations were developed that could be used to predict friction number as a function of traffic exposure.

For the five products that did not wear through, none of them performed well under moderate average daily traffic. At a traffic level of 10,000 vehicles per lane per day, the friction number of the best of these five products was predicted to decrease to 40 within five months.

Tyregrip was the only system that maintained friction numbers (50 and 54) greater than that of the concrete at the end of the field evaluation.

Delamination from the concrete was not a major problem with the products.

Laboratory tests were not able to predict performance.

6.0 REFERENCES

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