Alaska Department of Transportation & Public Facilities
Alaska University Transportation Center

Wearing Surface Testing:
Yukon River Bridge
Final Report (Part 1)

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December 2012

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INE/AUTC 12.24

FHWA-AK-RD-12-21

REPORT DOCUMENTATION PAGE

Form approved OMB No.

1. AGENCY USE ONLY (LEAVE BLANK)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
FHWA-AK-RD-12-21	December 2012	Final Report

4. TITLE AND SUBTITLE

Wearing Surface Testing:
Yukon River Bridge

5. FUNDING NUMBERS

AUTC #410008

DTRT06-G-0011

T2-10-07

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Alaska University Transportation Center
P.O. Box 755900
Fairbanks, AK 99775-5900

8. PERFORMING ORGANIZATION REPORT NUMBER

INE/AUTC 12.24

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

State of Alaska, Alaska Dept. of Transportation and Public Facilities
Research, Development and Technology Transfer
2301 Peger Rd
Fairbanks, AK 99709-5399

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

FHWA-AK-RD-12-21

11. SUPPLENMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The Yukon River Bridge, also known as the E.L. Patton Bridge, carries the twolane Dalton Highway and the trans-Alaska oil pipeline across the Yukon River at a 6% grade. It is 30 feet wide, with 6 spans; it was designed to withstand -60 degrees Fahrenheit temperatures, huge ice loads from the river, truck loads hauling supplies to the oil fields, the oil pipeline, and, in the future, a gas line. Over 30 years, the timber decking has been replaced several times — in 1981, 1992, 1999, and 2007. The trees that produced the original decking were massive old-growth firs, strong and close-grained. Subsequent decking has come from younger trees, which produce softer wood. As timber quality has decreased, time between replacements has also decreased, while material costs increase. Every time the Yukon River Bridge deck is resurfaced, it costs the public millions of dollars. Further, in the past only timber was used, and the quality of this material is decreasing as the cost is increasing. It is imperative that new materials for use as a wearing surface for this bridge be identified. This research seeks to identify a material suitable for bridge decking that will last more than 15 years. A longer-lasting material will mean future savings to the ADOT&PF in the millions of dollars.

14- KEYWORDS : Bridge decks (Pdybbsf), Epoxy coatings (Rbmnfcue)

15. NUMBER OF PAGES
16

16. PRICE CODE
N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	N/A

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	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	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

ACKNOWLEDGMENTS

The authors would like to thank the Alaska Department of Transportation Bridge Section and the Alaska Department of Transportation Northern Region Maintenance and Operations (M&O) and the Alaska Department of Transportation Research section and the Alaska University Transportation Center for providing the funding for this project.

We would like to especially thank George Imbsen and Loren K. Gehring in Bridge Design (AKDOT&PF) who spent countless hours working with us on this project; we also want to thank Frederick Tom Williams from Northern Region Maintenance and Operations for making arrangements for timbers and local aggregates for testing (AKDOT&PF). We want to thank Jim Sweeney and Clint Adler with the Alaska Department of Transportation Research section (AKDOT&PF) for assisting our research staff with administrative matters. The authors are especially appreciative to Billy Connor, Director of the Alaska University Transportation Center and personnel Diane Wallace, Program Assistant for AUTC, and Kathy Peterson, Grant Manager for AUTC. We also want to thank the Institute of Northern Engineering (INE), College of Engineering (CEM) and the Department of Civil and Environmental Engineering at the University of Alaska Fairbanks.

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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 has a 30-foot-wide roadway supported by 6 spans and is over 2,295 feet long. 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 inches thick) was installed as a temporary wearing surface. The bridge carries heavy trucks on their way to the North Slope. During winter, trucks typically require 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 seven years, which is approximately the half-life of most traditional material wearing surfaces. The cost to replace and maintain a timber deck is excessive. With cost increases and deterioration in the quality of timber available for boards, the need to find cost-effective alternatives is paramount.

The Alaska Department of Transportation and Public Facilities (ADOT&PF) and the Alaska University Transportation Center (AUTC) invited companies to submit five 18-inch by 24-inch test panels, 2 inches or less thick. The companies were asked to submit five 3-inch-wide by 18-inch-long samples as well. In spring 2013, the 3-inch-wide samples will undergo a four-point flexural bending test at or near -50°F. Results of the flexural tests will be used to evaluate cold-weather flexural performance.

Static and dynamic wet and dry traction tests were conducted on the test panels submitted. In addition to traction tests, the researchers conducted tests to assess the damage caused by a truck tire with chains stopping (dragging) and rolling, or the damage caused by chain lashing (a piece of chain that strikes the surface as the tire rolls). The damage caused to the test panels by truck tire chains was evaluated and compared with the damage sustained to wood under the same conditions.

As part of the prequalifying process, companies were invited to submit products for evaluation. The researchers then conducted laboratory traction and chain damage tests on the submitted test panels. If the submitted product failed these aggressive tests, the findings were shared with the company, which was encouraged to revise and resubmit its products for continued testing. This process continued until a test panel passed the tests or the company chose not to resubmit.

This research had two objectives, the first being to prequalify products or materials that are likely to be successful cost-effective alternatives as a wearing surface on the Yukon River Bridge. This objective was met, and the findings are presented in this document. The second objective—the installation and observation of 8-foot by 30-foot field test sections for each prequalified product and an evaluation of their field performance—will be the future purpose of this study.

The work plan for summer 2012 consisted of thoroughly evaluating all wearing surface submissions. The evaluation consisted both of laboratory durability testing and of life cycle cost analyses of all products that passed durability testing.

The proposed work plan for spring to summer 2013 consists of (1) evaluating the wearing-surface durability of products through laboratory cold-weather flexural testing, and (2)

evaluating the field performance of any prequalified products that are installed on the bridge during summer 2013.

The laboratory traction and tire chain damage tests were conducted at room temperature using a custom apparatus designed by Wilhelm Muench, a graduate student at the University of Alaska Fairbanks (UAF). Three kinds of systems were prequalified, and they are recommended for evaluation through field tests on the bridge. The recommended products are listed in Table 1.

Table 1: Recommended products eligible for application on a field test.

Test Panels	Thickness (in.)	Sample Weights (psf)
Polymer Concretes		
Product #1	2	23
Product #2	2	30
Product #7b	2	20
Fiberglass Panels with Traction Surfacing		
Product #10 with Product #8 traction surface	3/4	8
Timber Wearing Surface		
Douglas fir timber with Product #8 traction surface	3 1/8	9

Further laboratory testing on new product submissions received because of ADOT&PF's public notice process may be required during spring 2013. Laboratory testing in 2013 will include cold-weather flexural testing of all previously passed and future products. Field tests and observations will be included in the 2013 research schedule to monitor the performance of field test strips on the Yukon River Bridge.

Test panels provided to the research team that passed durability and traction testing were weighed and sized. The dimensions of the products and their corresponding weights are tabulated in Table 2.

Table 2: Sample weights for the prequalified laboratory test panels.

Product	Weight (lb)	Dimensions (in)	Sample weights (psf)
Polymer concretes			
Product #1	69	2 x 18 x 24	23
Product #2	90.9	2 x 18 x 24	30.3
Product #6a	55.7	2 x 18 x 24	18.6
Product #7a	59.6	2 x 18 x 24	19.9
Product #7b	59.1	2 x 18 x 24	19.7
Fiberglass panel with tractive surface			
Product #8	24.6	0.75 x 18 x 24	8.2
Product #3	10.7	0.4375 x 18 x 24	3.6
Timber wearing surface with tractive surface			
Product #8	9.06	3.125 x 8 x 18	9.06

1. INTRODUCTION

The Yukon River Bridge is a two-lane highway bridge with an orthotropic steel deck structure located about 50 miles north of Fairbanks, Alaska, on the Dalton Highway (see Figure 1). The bridge was designed to carry highway traffic and the Trans-Alaska 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 severe climate changes and intense loading from passing trucks, timber surfaces deteriorate at a rapid rate.

Over a thirty-year period—in 1981, 1992, 1999, and 2007—the upper timber deck boards were replaced. As the quality of wood decreases, the time between replacements is decreasing, and this results in an increase in material costs. The ADOT&PF became interested in finding an alternative wearing surface, one that will provide longer life, be relatively lightweight and flexible, and offer improved traction. The alternative wearing surface needs to be easy to install and maintain, and overall, be a more economical option than timber.

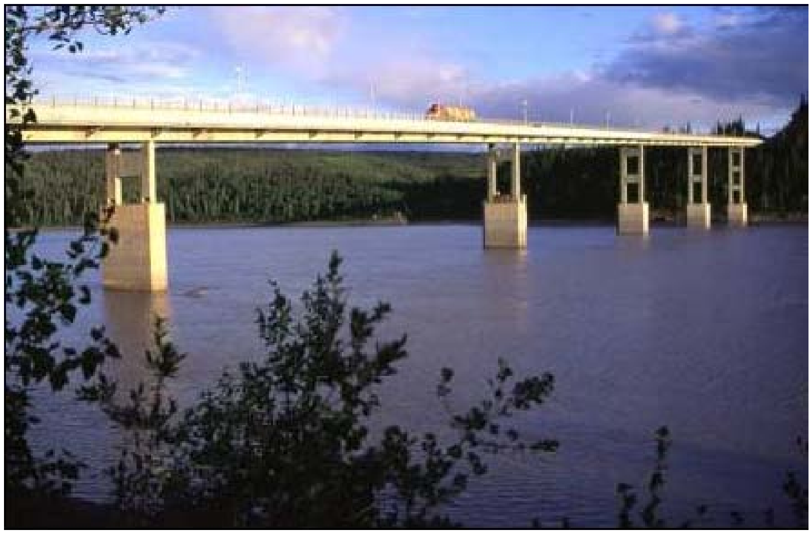

Figure 1: Yukon River Bridge.

1.1 Yukon River Bridge Project 2006

In 1992, ADOT&PF installed panels of alternative wearing surfaces that were produced by participating companies. The panels included Transonite, a fiber-reinforced plastic surface supplied by Martin Marietta Composites; Ultra High Density Polyethylene supplied by Ultra Poly, Inc.; and Super Panel, a fiber-reinforced polymer supplied by Creative Pultrusions, Inc. and Compositech, Inc. ADOT&PF also installed Cobra-X, which was 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 met the weight requirements of the Yukon River Bridge was Cobra-X. However, at the time, Cobra-X was no longer being manufactured, and truckers reported that it provided lower traction than the existing timber deck.

Dr. J. Leroy Hulsey, a professor at 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 to rank the 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 the research funded by ADOT&PF and 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 (Hulsey, Jerla, and Muench 2009; Hulsey and Muench 2007). Jerla 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. Jerla's studies provided a basis for ranking the panels based on structural durability and applicability for the Yukon River Bridge.

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

1.2 Yukon River Bridge 2011 and 2012

Although test procedures were developed to test alternative wearing surfaces, ADOT&PF did not choose to pursue alternative replacements for the timber wearing surface when it came time to replace the timbers in 2007.

Pursuant to finding a feasible wearing surface replacement that would both increase the performance of the bridge and reduce operations and maintenance costs, Dr. Hulsey hired Ty Wardell and Patrick Brandon, UAF undergraduate students, to assist him in continuing the research. The research team used the same test equipment and procedures developed by Muench. Instead of the focus being on developing test procedures, the objective of this study was to find an alternative wearing surface by cooperating with and providing feedback to interested companies.

2. METHODOLOGY

The Yukon River Bridge wearing surface has two layers of 2.5 in. (63 mm) wood planking on top of an orthotropic steel deck. The bottom layer of the planks is bolted to the steel deck, and the top layer is lag bolted to the layer underneath. This wood wearing surface has been used by ADOT&PF since the bridge was constructed in 1976. Depending on the age of the timber, the top layer deteriorates rapidly due to a combination of decay, traffic, and tire chain damage. An alternative wearing surface must provide longer life and accommodate a 6% grade by providing traction in winter conditions or on rainy days for heavy trucks. The alternative wearing surface must also be relatively lightweight, provide flexibility for the bridge, and require a more economical operation.

2.1 Traction and Chain-Wear Test Equipment

Since there was no known laboratory test equipment for determining wear due to tire chains, a testing apparatus was developed by Muench. This testing apparatus consists of a lower and upper steel frame, with a 14-ply 235/85R16 tire attached to the upper frame that spins on an axle. A tray is placed underneath the tire on the lower frame, which is attached to a hydraulic ram that pushes and pulls the tray back and forth over a distance of 7.87 in. (20 cm). The upper steel frame is attached to another hydraulic ram that elevates one end of the upper frame on a pivot, which in turn raises or lowers the tire onto the tray that contains a wearing surface panel to be tested. Electric load cells are attached to each hydraulic ram to measure the vertical and horizontal force on the tire as the tray moves in a direction. These readings are recorded by a data collector and displayed on a nearby laptop. The laptop uses proprietary software designed to work with the data collector to allow for calibration and corrected readings. The apparatus is approximately 23.62 in. (60 cm) wide and 90.55 in. (230 cm) long and weighs around 4,500 lb (20 kN). The tray of the test machine is 18 in. (45 cm) wide by 24 in. (61 cm) long by 5.91 in. (15 cm) thick. Figure 2 is a picture of the traction chain-wear test equipment.

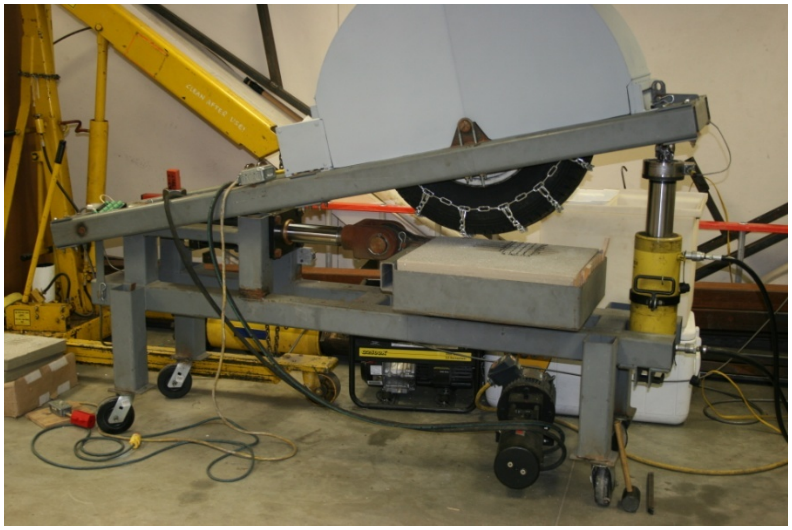

Figure 2: Traction and chain-wear test equipment.

2.2 Test Procedures

This study is based on the hypothesis that wear on the surface of the Yukon River Bridge is caused by three different factors when vehicles using tire chains drive over the bridge:

- When loose chains lash against the surface, the impact causes damage.
- As tires roll over chains, the individual links of the chains apply load to a small surface area.
- When vehicle brakes are applied, the chains drag over the surface, causing wear.

Since it is impossible to conduct a test that covers all of these factors, each factor is tested and analyzed separately. To test for traction, the tire is loaded onto the test panel in the tray with a force of 4,500 lb (20 kN). (This force was determined as an average value for the weight of trucks that pass over the Yukon River Bridge.) Initially, we lock the axle so that the tire does not turn. Then, we engage the hydraulic ram so it moves the tray with the test panel back and forth, resulting in traction between the tire and the test panel. The horizontal forces caused by the traction are measured by the load cell attached to the hydraulic ram. These measurements are then recorded by the data collector and are used to approximate a value for the coefficient of friction for the test panel. This value is taken after the tray has moved back and forth for five to six cycles, which gives a more accurate approximation for what traction the alternative wearing surface has to offer after long-term use.

To test for wear that is caused by dragging chains over the alternative wearing surface, the tire is locked at its axle with the tray moving back and forth. However, tire chains are attached as tightly as possible to the tire. Instead of finding the coefficient of friction, the damage depth to the surface of the test panel caused by the tire chains is measured. This determination is made by using a profiler before conducting the chain-dragging test to measure the relative heights of the surface, and then measuring the displacements in the surface after the test.

Tire chains that roll over a surface can cause punctures in small areas. This damage is simulated by unlocking the tire from its axle and moving the tray back and forth with the test panel. A pre-profile is required before the rolling test is performed.

To account for loose chains that lash against the surface, the apparatus is modified such that an edge of the test panel is exposed to lashing tire chains. With the top steel frame unattached from the hydraulic ram, the top frame is lifted and lowered by an attached lever that is controlled manually by the operator. A motor spins the tire to a speed of 45 miles per hour (determined as an average speed for trucks that pass over the Yukon River Bridge), which causes the loose tire chains to lash against the test panel. This test is done for two seconds, which simulates long-term wear. Once again, to determine the surface profile, a pre-profile is used prior to performing a test. After the test, it is used again to measure the change. The difference in the surface reflects the amount of damage.

3. TEST RESULTS AND DATA

3.1 Test Panels

Test panel products to be tested in the laboratory were required to have the dimensions of 18 inches by 24 inches by 2 inches (note, however, that the thickness of the panel may be adjusted). The tested products were as follows:

- **Product #9**

  The fiberglass panel is about an inch thick with a polymer coating that is typically used on docks to prevent slippage for pedestrians. The test panel was prepared by the company, allowing the coating to cure and bond to the fiberglass for a period.

- **Product #1**

  This product was prepared in the university laboratory with special training provided by the owner of the company. The aggregate mix (which the company makes specific) is a polymer resin that is activated by 30% peroxide. Once activated, the resin hardens within 20 to 30 minutes (during this time, the aggregate and resin are mixed together to produce the final product). The test panel was prepared to be 2 inches thick, and the mix was bonded to a steel plate using a zinc metal solution.

- **Product #8 applied to Product #10**

  This product was prepared in the university laboratory with a relatively simple procedure. The resin consists of a Part A and a Part B, and once combined, the resin begins to cure within 45 minutes (however, the company recommends a whole day for the resin to fully cure). Two layers of resin and varied types of aggregates were applied to a fiberglass panel (provided by the company). Both the manufacturer-supplied aggregate and ADOT&PF-supplied sieved alluvial aggregate were tested. The final product was around 0.75-inch thick.

- **Product #8 applied to rough-cut Douglas fir timber**

  The epoxy product was prepared in the university laboratory following the manufacturer's recommendations of 1:1 ratio catalyst to resin (part A and B). Two layers of the epoxy product were applied to Douglas fir timbers (matching those currently in use on the bridge). Both the manufacturer-supplied aggregate and ADOT&PF-supplied sieved alluvial aggregate were tested. The overall thickness of the surface coating was 3/8 inch.

- **Product #4**

  This product consists of Douglas fir wood blocks with the grains facing outward to provide better traction. The blocks were glued to a wood panel, resulting in a thickness of 2.5 inches.

- **Product #12**

  This product shares the same qualities as a similar sample tested in 2006/2007; however, a crystalline coating was applied to the surface rather than an aggregate casting. The thickness is around 1.5 inches.

- **Product #2**

  The composition of the product is proprietary and was unknown to the researchers. The test panel was prepared by the company. The roughness of the surface was produced when the product was curing. The company prepared the panel with a thickness of 2 inches.

- **Product #5**

  This product is claimed by the company to perform well in cold climates (the company also claims that the product has already been used in Alaska). The thickness of the product was an inch, and the surface was rough and partially crystalline.

- **Product #6a and Product #7a**

  These products are two revisions of the company's previous submission (Product #5), with the thickness increased to 2 inches and the surface much more crystalline. The difference in composition between Product #6a and Product #7a is unknown.

- **Product #6b and Product #7b**

  These products are revisions to Product #6a and Product #7a, made by the company that supplied them. The only apparent difference between this submission and the previous one was the surface, which was no longer crystalline but instead just rough from curing. The products had the same thickness.

- **Product #3**

  A preliminary sample of this product was provided before actual testing; it consisted of multiple fiberglass layers bonded together with a rough surface produced from curing. The preliminary test panel was 0.5 inch thick; the second test panel was increased to 0.75 inch.

- **Product #13**

  This product consisted of asphalt that was partially bonded and reinforced by an epoxy solution. The test panel was also bonded to a wood panel. The thickness of the asphalt test panel (excluding the wood panel) was an inch.

3.2 Product Results

Table 3 shows the results of the laboratory testing.

Table 3: Results from laboratory traction and tire chain damage assessment testing.

Product	Result
Product #1	Passed
Product #8 coated Product #10	Passed
Product #8 coated Douglas fir timber	Passed
Product #2	Passed
Product #6a	Passed
Product #7a	Passed
Product #7b	Passed
Product #3	Passed
Product #9	Failed
Product #4	Failed
Product #12	Failed
Product #5	Failed
Product #13	Failed
Product #6b	Failed

3.3 Product Pros and Cons

- **Product #9 coating on Product #10**
  - Pros: Fiberglass made the test panel lightweight and flexible.
  - Cons: Anti-slip coating experienced extreme wear during wet traction and chain-dragging tests, exposing a smooth fiberglass panel and reducing traction.
- **Product #1**
  - Pros: Preparation is very simplified, provided good traction in dry and wet conditions, experienced little wear during chain-dragging test, and effectively bonds to steel plating.
  - Cons: Relatively heavy, but the thickness can be adjusted without compromising the performance of the product.
- **Product #8 applied to Product #10**
  - Pros: Very simple two-part solution preparation, epoxy solution effectively bonds to fiberglass. The test panel was lightweight and flexible; provided very good traction with both manufacturer-supplied calcified bauxite aggregate and local sieved aggregate.

- Cons: Epoxy system requires low moisture conditions both in the substrate and in the environment during application.

- **Product #8 applied to rough-cut Douglas fir timber**
  - Pros: Simple two-part epoxy system, effectively bonds to Douglas fir, provides excellent traction; can be adapted for use in conjunction with the current timber wearing surface.
  - Cons: Epoxy system requires low moisture conditions both in the substrate and in the environment during application.
- **Product #4**
  - Pros: Lightweight and provides the same advantages that the current wood decking has to offer.
  - Cons: Suffers intense wear during chain-dragging test; spaces present between wood blocks allow water to seep through, making the panel subject to freezing and thawing; adhesive was not effective in holding blocks to panel underneath.
- **Product #12**
  - Pros: Lightweight and flexible, provides good traction.
  - Cons: Tire chains easily dug through the surface coating, subjecting the product underneath to intense wear, which resulted in extreme changes in coefficient of friction values.
- **Product #2**
  - Pros: Provided good traction in wet and dry conditions, did not experience much wear during chain-dragging test, and provided very consistent coefficient of friction values.
  - Cons: Relatively heavy, but the thickness can be adjusted without compromising the performance of the product.
- **Product #5**
  - Pros: Lightweight, claimed to be resistant to cold temperatures, and provided good traction in dry and wet conditions.
  - Cons: Two panels broke into pieces when 4,500 lb was loaded onto the panels
- **Product #6a**
  - Pros: Provided very good traction in wet and dry conditions; claimed to be resistant to cold temperatures.
  - Cons: Experienced slightly more wear during chain-dragging test compared with other products that passed; surface coating easily brushed off.
- **Product #7a**
  - Pros: Provided very good traction in wet and dry conditions; claimed to be resistant to cold temperatures.
  - Cons: Experienced slightly more wear during chain-dragging test compared with other products that passed; surface coating brushed off easily.

- **Product #6b**
  - Pros: Provided very good traction in wet and dry conditions; claimed to be resistant to cold temperatures.
  - Cons: Experienced severe wear during chain-dragging test.
- **Product #7b**
  - Pros: Provided very good traction in wet and dry conditions, claimed to be resistant to cold temperatures, and experienced very little wear during chain-dragging test.
  - Cons: None.
- **Product #3**
  - Pros: Provided very good traction in wet and dry conditions, very lightweight, very flexible, and experienced very little wear during chain-dragging test.
  - Cons: None.
- **Product #13**
  - Pros: Provided good traction; was relatively lightweight.
  - Cons: Experienced severe wear during chain-dragging test; cracks and voids present which makes product subject to freezing and thawing of seeping water

3.4 Product Results – Traction Data

Test results for the traction tests are provided in Table 4.

Table 4: Dry and wet traction test data.

Product	Static Tests		Dynamic Tests	
	Dry Traction	Wet Traction	Dry Traction	Wet Traction
Product #1	0.67	0.59	0.64	0.58
Product #8 Local alluvial aggregates	0.69	0.67	0.68	0.65
Product #8 Manufacturer-supplied calcified bauxite	0.70	0.64	0.67	0.61
Product #2	0.63	0.64	0.61	0.63
Product #6a	0.66	0.59	0.64	0.57
Product #7a	0.64	0.61	0.62	0.57
Product #7b	0.67	0.63	0.63	0.59
Product #6b	0.55	0.53	0.53	0.52
Product #3	0.64	0.61	0.60	0.58
Product #12	0.58	0.58	0.57	0.60
Product #9	0.66	0.60	0.63	0.61
Product #13	0.66	0.64	0.62	0.58
Product #4	0.55	0.54	0.55	0.48

3.5 Product Results – Chain Drag Ranking

Test results for both chain lashing and chain dragging are shown in the following two tables. Table 5 lists the amount of gouging damage that the test panels showed after being subjected to five cycles of chain dragging. Figure 3 shows how the gouge depth measurements were taken on a given test panel after being subjected to a chain-dragging test.

Table 5: Gouge depths from chain lashing.

Product	Maximum (.001 in.)	Average (.001 in.)
Product #8 Local alluvial aggregate	20	12
Product #3	29	15
Product #1	42	16
Product #2	39	23
Product #7b	64	33
Product #12	56	36
Product #6a	78	42
Product #8 Manufacturer-supplied aggregate	90	43
Product #6b	86	49
Product #9	78	51
Product #7a	109	63
*Product #13	43	29
*Product #4	91	44

***Experienced major chain rolling damage at center of test panel

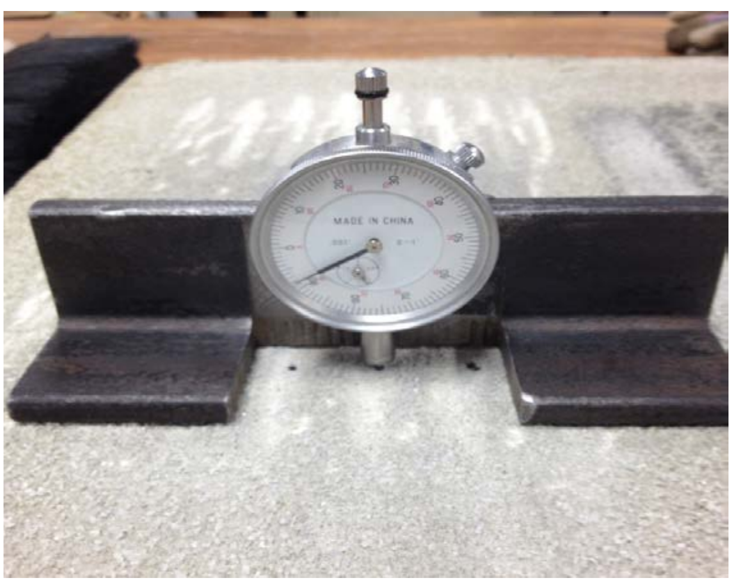

Figure 3: Gouge depth measurements.

Table 6 lists the amount of surface abrasion that test panels experienced after five chain-dragging cycles. The surface abrasion values show how much surface aggregate was removed from the test panel. The average damage value shown in Table 6 is the reduction in the total thickness of the test panel, reported in thousandths of an inch.

Table 6: Chain-dragging surface abrasion results.

Product	Damage (.001 in)			
	Pass 1	Pass 2	Pass 3	Average
*Product #1	1	-1	-1	1
Product #2	3	4	4	4
Product #3	6	4	12	8
Product #7b	8	13	12	11
Product #4	16	15	12	14
Product #6b	16	14	15	15
Product #6a	13	29	24	22
Product #8 Local alluvial aggregate	19	20	27	22
Product #8 Manufacturer-supplied aggregate	35	15	18	22
Product #7a	11	32	37	27
Product #12	31	38	24	31
*Product #9	-15	39	-3	39
*Product #13	-55	-56	-14	-

*Negative damage values were neglected in average damage calculations

The products that passed both forms of chain-damage testing are included below. The products are not listed in any specific order.

1. **Product #3**
2. **Product #8 coated Product #10**
3. **Product #8 coated Douglas fir timber**
4. **Product #1**
5. **Product #2**
6. **Product #7b**
7. **Product #7a**
8. **Product #6a**

Note that the difference in wear between the five top-ranked products is very small, whereas the two lowest-ranked products received slightly more wear than the top five.

3.6 Densities for Products that Met the Test Criteria

- Product #2 – 181.8 lb/ft^3
- Product #1 – 137.9 lb/ft^3
- Product #6a – 111.4 lb/ft^3
- Product #7a – 119.2 lb/ft^3
- Product #7b – 118.2 lb/ft^3
- Product #3 – 85.6 lb/ft^3
- Product #10 coated with Product #8 – 131.2 lb/ft^3
- Douglas fir timber coated with Product #8 – 34.8 lb/ft^3

3.7 Laboratory-Tested Top Products

The list of the eight passed wearing surface systems was reduced to a list of six by selecting only one of the three product submissions by one company. The highest-performing product from this company was Product #7b. The company's other two passed submissions—Product #6a and Product #7a—were rejected. The following list is the six passed products that were selected for product cost analysis.

1. Product #2 – 181.8 lb/ft^3
2. Product #1 – 137.9 lb/ft^3
3. Product #7b – 118.2 lb/ft^3
4. Product #3 – 85.6 lb/ft^3
5. Product #10 coated with Product #8 – 131.2 lb/ft^3
6. Douglas fir timber coated with Product #8 – 34.8 lb/ft^3

4. PRODUCT COST ANALYSIS

After testing was completed, five products that were submitted for evaluation and the Douglas Fir Timber coated with Product #8 (total of six products) were evaluated to determine their cost feasibility. Two aspects of product cost were considered: initial capital investment and life cycle costs. All costs were calculated using a constant purchasing power for year 2014, the expected date of the next timber wearing surface replacement.

4.1 Initial Capital Investment

The initial capital investment of each product is shown in Table 7. This cost includes material purchase, freight, and labor. No cost considerations were given to lodging, project management, or the removal of the current timber wearing surface. Furthermore, no cost considerations were given to the sub-base material of the 3/4-inch panelized systems. Panelized systems of thicknesses less than 5 inches will require a furring system to raise the panels to the required road deck elevation. This furring cost has not been included in Table 7.

Table 7: Initial capital costs.

Item #	Product	Material & Shipping Cost (Psf)	Labor Cost (Psf)	Initial Capital Cost (Psf)	Initial Capital Cost ($)
1	Product #3	$35.61	$ 3.90	$39.51	$2,720,300.00
2	Product #7b	$26.87	$12.50	$39.37	$2,710,600.00
3	Product #2	$21.80	$15.40	$37.21	$2,561,900.00
4	Product #8 coated Product #10	$28.48	$ 5.03	$33.50	$2,306,500.00
5	Product #1	$13.46	$12.50	$25.96	$1,787,300.00
6	Product #8 coated timbers	$ 8.89	$ 7.85	$16.74	$1,152,300.00
7	Current timber system	$ 6.32	$ 6.98	$13.30	$ 915,400.00

4.2 Life Cycle Costs

Total life cycle costs were evaluated over a 105-year period. This time frame accommodated the varying replacement schedules of the passed wearing surface replacements. Table 8 shows the expected maintenance and replacement schedules of the selected wearing surface replacements. The wearing surface replacements were grouped into three categories: polymer concretes, panelized systems, and coated timber systems.

Table 8: Maintenance activity timing.

Year	Current Timber	Timber with 21-Year Lower Deck Life	Epoxy Based Timber Coatings	Polymer Concretes	Panelized Systems
0	Top Surface	Top Surface	Top Surface	2" Base	Installation
7	Full Replacement	Full Replacement			
14	Top Surface	Top Surface	Full Replacement		Flip
21	Full Replacement	Top Surface			
28	Top Surface	Full Replacement	Top Surface	Overlay	Full Replacement
35	Full Replacement	Top Surface			
42	Top Surface	Top Surface	Full Replacement		Flip
49	Full Replacement	Full Replacement			
56	Top Surface	Top Surface	Top Surface	Overlay	Full Replacement
63	Full Replacement	Top Surface			
70	Top Surface	Full Replacement	Full Replacement		Flip
77	Full Replacement	Top Surface		Overlay	
84	Top Surface	Top Surface	Top Surface		Full Replacement
91	Full Replacement	Full Replacement			
98	Top Surface	Top Surface	Full Replacement		Flip
105	Full Replacement	Full Replacement		Overlay	
# of Activities	**16**	**16**	**8**	**5**	**8**

It has been reported that the lower pressure-treated timbers still had usable life at the end of 14 years of service. The researchers explored the cost-reduction possibilities of extending the in-service use of the lower timbers from 14 years to 21. Subsequently, the expected annualized costs presented in Table 9 accounted for new products and adjustments to the replacement schedule of the lower deck for the current timber system.

The maintenance activities shown in Table 8 indicate that polymer concrete systems will require the least major rehabilitation projects over the life of the bridge. Furthermore, the table shows that the current timber wearing surface requires the most rehabilitation and replacement effort of all the systems evaluated. Panel and epoxy coatings are expected to require half the rehabilitation effort of the current timber system.

Table 9 shows the expected annual cost of the six laboratory passed products and the two timber variations. No future cost discounting was used due to ADOT&PF's funding being allocated annually for maintenance and replacement operations of wearing surfaces. Future cost discounting & Present Value Analysis methods may be used in subsequent reports with an internal rate of return (ROR) dictated by AKDOT&PF.

Table 9 shows that panelized systems are expected to cost more than polymer concretes or timber-based systems over the life of the bridge. The cost analysis shows that all of the panelized systems will cost more than the current timber system.

Table 9: Average annual costs.

Product	Annual Cost
Timber:	
Product #8 coated timber	$ 86,000.00
Timber with 21-year lower deck life	$105,000.00
Current timber system	$124,000.00
Concretes	
Product #1	$ 69,000.00
Product #2	$ 83,000.00
Product #7b	$ 91,000.00
Panels:	
Product #8 coated Product #11 (3/4")	$152,000.00
Product #3	$166,000.00
Product #8 coated Product #11 (1")	$172,000.00

5. FINAL RECOMMENDATION

5.1 Researchers' Recommendations

The following list shows the top five products recommended by the researchers for field testing. The products are listed in order of least expensive to most expensive life cycle costs.

Product #3 was the only product eliminated from the laboratory passed-products list. The differences in the expected life cycle costs of the panelized systems were small and based solely on the purchase price of the paneling.

1. Product #1
2. Product #2
3. Product #8 coated Douglas fir timber
4. Product #7b
5. *Product #8 coated Product #11
   (*The life cycle cost of this product exceeds the costs associated with the current timber wearing surface. This additional cost may be offset by the additional safety associated with the higher coefficient of friction that this product provides.)

REFERENCES

Hulsey, L., Jerla, Z., and Muench, W. (2009). Evaluation of Wearing Surfaces for the Yukon River Bridge. Prepared for the Alaska Department of Transportation and Public Facilities.

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