INNOVATIVE HYBRID WEARING SURFACES FOR FRP BRIDGE DECKS

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Abstract

Corrosion of steel reinforcing bars in concrete bridge decks is considered the primary limit state in severe environments.

Fiber reinforced polymer (FRP) composite bridge decks are durable alternative to steel reinforced concrete bridge decks. However, conventional wearing surface materials used on concrete bridge decks do not adhere well to GFRP bridge decks. This paper presents the results of an experimental research that focuses on durability of wearing surfaces used on FRP bridge decks. The wearing surfaces investigated under this program were epoxy polymer concrete, polymer modified concrete, polymer modified asphalt, and asphalt. Several thermal compatibility tests were conducted. The results of this research suggest that polymer concrete adheres best to GFRP decks, while polymer modified concrete exhibits the best wear resistance. Three wearing systems were developed and presented.

1 Introduction

Corrosion of steel reinforcing bars causes drastic deterioration of concrete bridge decks, particularly, in severe environments. In addition, some old bridges with concrete bridge deck have limited load carrying capacity to handle new heavy traffic loads. A solution to these bridges is the use of fiber reinforced polymer (FRP) composite bridge decks.

FRP bridge decks offer an excellent alternative to deteriorated concrete decks. They have very high strength to weight ratio, corrosion resistance, and ease of installation. A wearing surface layer is needed on an FRP bridge deck for skid and wearing resistance, and to withstand the daily traffic loads during the service life of the bridge. For FRP decks, a wearing surface also serves as a cover to protect the slick and soft-top surface of the panels. Several conventional wearing surfaces have been used on FRP bridge decks, e.g. polymer modified concrete, polymer concrete, and asphalt.

Most of the wearing surfaces on FRP decks have deteriorated to various degrees. Figure 1 and 2 show some examples of deteriorated wearing surfaces on FRP bridge decks. On some of these FRP decks the wearing surface had to be replaced within just few months after installation [1]. The deterioration of wearing surfaces is attributed to several structural and environmental factors, e.g. poor adhesion, mismatch of coefficient of thermal expansion, and poor wear resistance at elevated temperatures.

Fig. 1. Deteriorated a wearing surface material on FRP bridge deck [1]

Fig. 2. Delamination of a wearing surface material on FRP bridge deck [1]

This paper presents three types of durable wearing surface systems for FRP bridge decks: (1) cast in place hybrid system, (2) Polymer modified concrete system, and (3) Reinforced concrete system.

2 Causes of Deterioration of Wearing Surfaces

GFRP decks have been successfully used to replace deteriorated and heavier concrete decks on existing bridges, however, many have experienced deterioration of the wearing surface material. The cause of deterioration is attributed to several physical and environmental factors. The followings are identified as probable causes for wearing surface delamination from FRP composite bridge decks:

- Material mismatch: modulus of elasticity, and coefficient of thermal expansion. Composite materials commonly used for FRP decks often have moduli of elasticity an order of magnitude higher than those used for wearing surfaces [2], which results in high stresses at the interface leading to delamination.
- Poor construction practice: FRP surface preparation, and casting of wearing surface material. The surface of the FRP deck lacks adequate surface roughness, and temperature of FRP versus the fresh wearing surface material is not maintained within a certain range.
- Cold temperatures: because material properties vary with temperature, and most polymeric materials have a relatively low and narrow ductile to brittle transition temperature [3] their tendency to fracture increases with decreasing temperature. In addition, freeze-thaw cycles in cold region accelerate the deterioration of wearing surface materials.
- Elevated temperatures: while extreme low temperature is detrimental to material strength, extreme high temperature is likely to cause degradation in polymeric materials because of their relatively low glass transition temperature.
- Construction details: on several FRP decks, the deterioration of wearing surfaces initiated at discontinuity in the wearing surface material e.g. location of tie-down anchors, and FRP panel joints.

3 Experimental Program

In order to investigate the roots of the wearing surface problem, a series of tests were conducted. These tests included the followings:

- Tensile and compressive properties of GFRP material under various temperatures,
- Flexural and compressive properties of wearing surface materials under various temperatures,
- Thermal compatibility of wearing surface material and GFRP panels subjected to various environmental conditions,

All the tests were conducted at three different temperatures: -23^{o}C (-10^{o}F), room temperature at about 25 ^{o}C (77^{o}F), and at 60^{o}C (140 ^{o}F).

In a separate phase of the project, Dr. Petru Petrina of Cornell University investigated the wear resistance of the wearing surface materials under axial and lateral wheel loads at various temperatures [1].

3.1 Tensile and compressive properties of GFRP material under various temperatures

The tensile as well as the compressive tests of the FRP were conducted on specimens that were cut out of a new cellular FRP bridge deck. All specimens were subjected to uniaxial loads.

The tensile tests were conducted according to ASTM D3039 *"Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials"* [4]. The purpose of this test is to investigate the sensitivity of tensile properties of GFRP to temperature change. Figure 3 shows an image of the tensile test specimen.

The compression test was conducted according to ASTM D3410 *"Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by shear Loading"*[5]. The purpose of this test was to study the compressive properties of FRP at different temperatures. Twenty FRP strips having dimension of 1"x12"x0.5 in. were tested in compression under uniaxial load at different temperatures. Special bracing setup was used to prevent buckling of the specimen.

These GFRP uniaxial tests showed that the tensile and the compressive strengths and modulus decreases with the increase in temperature.

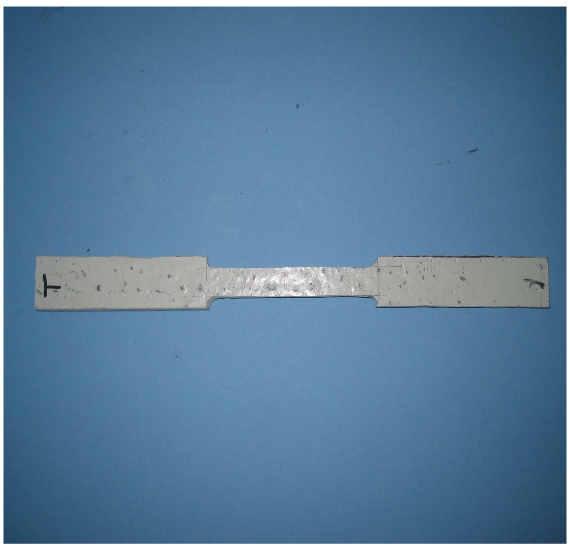

Fig. 3. Image of the tensile test specimen [1]

3.2 Flexural and compressive properties of wearing surface materials under various temperatures

Four primary wearing surface materials were investigated. They included the followings:

- Six types of commercially available polymer concrete (PC),
- Two types of commercially available polymer modified concrete (PMC), and
- Two types of polymer modified asphalt
- Two types of asphalt

Compression test was according to ASTM C579 *"Standard Test Methods for Compressive Strength of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes"* [6]. Flexural test was conducted according to ASTM C580 *"Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacing, and Polymer Concrete"* [7].

These tests showed that the polymer modified concrete is thermally more stable than polymer concrete. While the compressive strength of polymer concrete decreases by about 75% as the temperature increases from 25°C (77°F) to 60°C (140 °F), the compressive strength of polymer modified concrete decreases by just 25% as the temperature increases from 25°C (77°F) to 60°C (140 °F). Figure 4 shows the compressive strength properties of polymer concrete, and polymer modified concrete wearing surface materials.

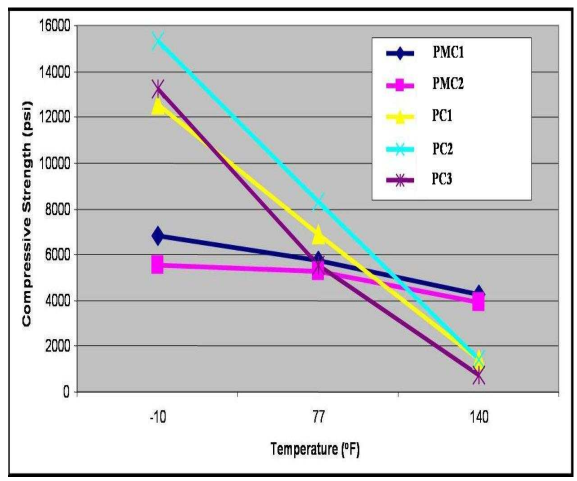

Fig. 4. Compressive properties of polymer concrete and polymer modified concrete [1]

3.3 Thermal compatibility of wearing surface material and GFRP panels subjected to various environmental conditions

The thermal compatibility test specimen consisted of 300 mm x 300 mm (12" x 12") GFRP panel with a wearing surface material bonded to the top surface. Figure 5 shows the forms and GFRP panels for various tests, including the thermal compatibility test specimens. The GFRP panel was 12.5 mm (0.5"), and the wearing surface materials consisted of the followings:

- Six types of 10 mm (3/8") thick polymer concrete,

- Two types of 38 mm (1.5”) thick polymer modified concrete,
- Two types of 50 mm (2”) thick asphalt, and
- PC-PMC Hybrid wearing surface system (10 mm PC, and 40 mm PMC)

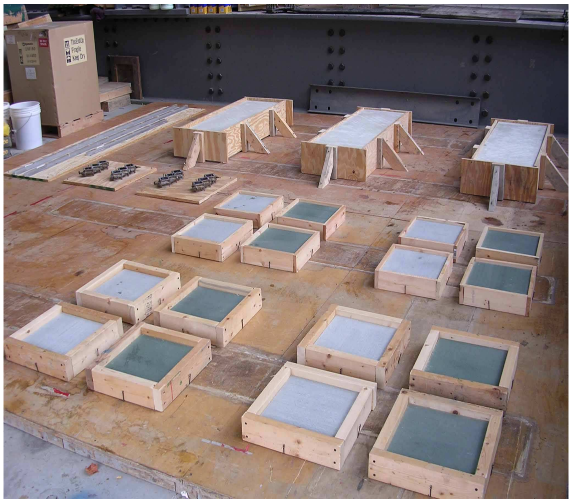

Fig. 5. Forms and GFRP panels for various tests [1]

Figure 6 shows the details of the hybrid wearing system, which consisted of 10 mm thick polymer concrete layer bonded to the GFRP panel followed by a 40 mm thick polymer modified concrete layer bonded to the top surface of the polymer concrete layer.

Fig. 6. Details of the hybrid wearing surface system [1]

The thermal compatibility tests were conducted on three separate phases, as follows:

3.3.1 ASTM C884 Standard Test [8]

The test consisted of five complete cycles of freezing and thawing. Every cycle consisted of placing the specimens in the freezer at temperature of –23 °C (–10 °F) for 24 hours, and then followed by storing the specimens for 24 hours at room temperature of about 25°C (77°F).

3.3.2 Freeze-Thaw-Heat Non-standard Test

After passing the ASTM Standard Test, a non-standard test was conducted. This test consisted of five complete cycles of freezing, thawing, and heating. Every cycle consisted of placing the specimens in the freezer at a temperature of –23 °C (–10 °F) for 24 hours, followed by storing the specimens for 24 hours at room temperature of about 77°F, and then placing the specimens in an oven at temperature of 60°C (140°F) for 24 hours.

3.3.3 Submerge – Freeze Non-standard Test

Specimens that passed both the ASTM C884 Standard Test, and the Freeze-thaw-heat non-standard test were subjected to a submerge-freeze non-standard test. This test consisted of five complete cycles of submerge and freezing. Every cycle consisted of placing the specimens in a water tank at room temperature for 24 hours, and then followed by storing the specimens in the freezer for 24 hours at a temperature of –23 °C (–10 °F).

The results of the thermal compatibility tests suggest that polymer concrete has excellent adhesion bond to GFRP panel surface, regardless of surface preparation (with or without sandblasting), while polymer modified concrete has very poor adhesion bond properties to GFRP surfaces. Asphalt concrete has good bond to GFRP surfaces, however, the bond degrades very rapidly at elevated temperatures.

As the polymer modified concrete has much higher wear resistance than polymer concrete, particularly, at elevated temperatures, a hybrid wearing surface system was developed. This new system makes use of the high PC bond properties, and high PMC wear resistance properties. The hybrid system performed well under all thermal compatibility tests.

4 Discussion of Test Results

The tests conducted under this project demonstrated that the GFRP materials are more sensitive than the wearing surface materials to change in temperatures. While polymer concrete exhibits very good bond strength to GFRP surfaces, it is relatively stiff at low temperatures and creeps under wheel braking loads at elevated temperatures. The fact that polymer concrete is stiff at low temperatures makes it susceptible to cracking over deck joints, particularly, under traffic loads.

Experimental test results indicate that polymer modified concrete has overall more stable mechanical properties than polymer concrete. In addition, wear tests showed that polymer modified concrete has very high wear resistance over wide range of temperatures. However, polymer modified concrete exhibited very poor bond strength to GFRP surfaces. Therefore, it is recommended to use a middle layer to bond the polymer modified concrete to the GFRP panels. Based on the test results, polymer concrete would serve as an excellent middle layer as it bonds well to both the GFRP panels and the polymer modified concrete.

5 Proposed Wearing Surface Systems

Several wearing surface system were experimentally investigated under various environmental conditions, e.g. sub-freezing and elevated temperatures, freezing and thawing cycles. In addition, wear resistance of the selected wearing surface system were investigated under braking and wheel loads. The followings are the three proposed wearing surface systems:

5.1 Cast in Place Hybrid System

The special hybrid plain concrete system consists of two wearing surface materials; polymer concrete under-layer, and polymer modified concrete top-layer. As the polymer concrete has excellent adhesion bond properties with GFRP surfaces, it is used as an under-layer bonded to a sandblasted GFRP surface. Polymer modified concrete, which has excellent wear resistance and thermal stability, is used as a top-layer. The rough surface of the polymer concrete layer offers a good mechanical bond with the polymer modified concrete layer. Figure 6 shows details of the hybrid wearing surface system. The thickness of the PC and PMC layers are 10 mm., and 40 mm, respectively. The performance of this system under fatigue loading is yet to be verified. This system is recommended for heavy traffic use as it offers high wear resistance and adhesion properties.

5.2 PMC Tiled Wearing Surface System

The tiled wearing surface system consists of pre-cast concrete tiles bonded to the GFRP bridge decks using structural polymer concrete. The primary advantage of this system is that it allows for larger flexibility than the hybrid system, which makes it ideal for flexible GFRP bridge decks. The fact that GFRP has relatively low modulus makes this system a good alternative is some specific applications. Figure 7 shows the details of the concrete tiled wearing surface system. This system is recommended for flexible FRP bridge decks, where deformation is the primary limit state.

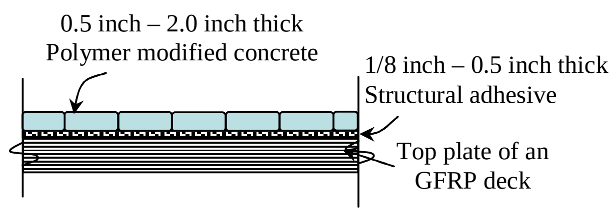

Fig. 7. Details of the concrete tiled wearing surface system

5.3 Reinforced Concrete System

The reinforced concrete wearing surface system consists of FRP reinforced concrete system. The FRP reinforcement is integrally bonded to the GFRP deck and the concrete wearing surface system. Its use is ideal for GFRP bridge decks constructed of pultruded GFRP sections. Figure 8 shows the details of the reinforced concrete wearing surface system. This system is recommended for an FRP bridge deck that is made up of pultruded sub-sections.

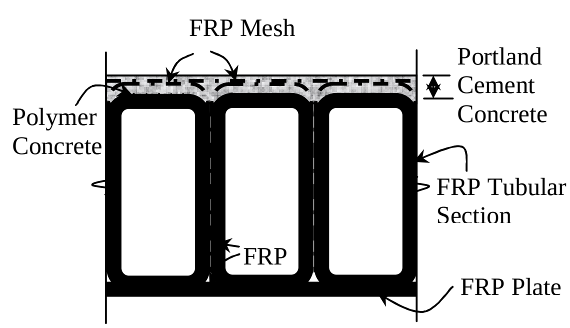

Fig. 8. Details of the reinforced concrete wearing surface system

6 Summary

This paper presents details of an experimental program on durability of wearing surfaces used on GFRP bridge decks. It also presents details of three types of wearing surface systems for GFRP bridge decks. The test results of the experimental program suggest that polymer concrete has excellent adhesion bond to GFRP decks, however, this bond degrades rapidly under wheel loads and elevated temperatures. On the other hand, polymer modified concrete exhibits low bond strength with GFRP decks, however, it has high wear resistance and thermal stability. A PC-PMC hybrid wearing surface system was developed. The hybrid system exhibit high bond strength with GFRP decks, as well as high wear resistance at a wide range of temperatures, including -23 ^{o}C and 60 ^{o}C.

Three types of wearing surface systems for GFRP bridge decks were developed. Each of these systems works best for specific applications, depending on the type of loads, and type and stiffness of the GFRP deck, as presented above.

7 Acknowledgment

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