LEWIS COUNTY, NEW YORK, BRIDGE USING A LOW PROFILE, 5” DEEP FIBER-REINFORCED POLYMER COMPOSITE DECK

Grant Godwin, Martin Marietta Composites, Inc., Raleigh, NC
Jay Toddie, Creative Pultrusions, Inc., Alum Bank, PA
Philip Steggall, Johnston Industries Composite Reinforcements, Inc., Columbus, GA

Introduction

Infrastructure applications are perfect for fiber-reinforced polymer (FRP) materials due to the high strength to weight ratio and high resistance to corrosion. A major structural component such as a bridge deck is a natural for the materials due to the long durability and reduced superstructure changes as a result of these benefits. As the use of FRP decks increase, other advantages will be recognized, such as quicker construction time and less labor and equipment needed compared to the conventional materials.

After installing a dozen FRP highway decks with its 8-inch profile called DuraSpan™ 766, Martin Marietta Composites, Inc. (MMC) recognized the need for a lower profile to fit specialized market segments. The problem was that truss, lift span, and open steel grate structures were the strongest candidates for the benefits of composites but required a ±4.5” deep deck. It also helped that these decks are more expensive in terms of initial and maintenance costs, thus FRP is more competitive than for conventional concrete decks. MMC, Creative Pultrusions, Inc. (CPI), and Johnston Industries Composite Reinforcements, Inc. (JICR) designed and produced a lower profile deck system. The new system was called DuraSpan 500 (5” deck). The 8” deck is for the superstructure (beams and girders) on bridges being spaced at 7 to 10 feet. The 5” deck is engineered for closer spacing of girders at 5’6” or less and designed to displace 5” steel grating or concrete.

The Lewis County, New York, Bridge structure was the first in the world to use the 5” deck. The beam spacing on this bridge is 5 feet, which is within the design criterion of the 5” deck. This paper is about the fiber, fabric, and design of the 5” deck based on the experience gained from the 8” deck. This paper will show in brief statements the testing, analysis, and actual use of the 5” deck on a highway bridge.

Material Lay-Up Design For 5” Deck

In this case, the load demands in relation to the thin profile of the 5” deck meant that every ounce of fiber had to contribute to the mechanical properties of the deck. We also elected to pultrude a 24” wide profile, versus 12”: we had been doing, in order to reduce assembly costs. The main difference regarding the 5” deep by 24”wide deck product as compared to the 8” deck product was the 33% larger cross-sectional area. Longitudinal stiffness, normally provided by drawing rovings from a creel-fed rack, would be too high in number to be practical, and the demand on torsion and hoop properties would require at minimum a triaxial fabric. Since the 8” deck uses almost 900 ends of unidirectional roving and hence could only be run on one CPI production line due to the creel capacity, this was a definite roadblock. Rough calculations showed that 1,200 ends would not only limit the flexibility to schedule on multiple lines for the 5” deck but would also add to the set up time and difficulty maintaining the line once it was started up, which would add to the cost.

It was soon obvious that a custom-designed, quadraxial reinforcement would be the most cost effective way to meet the strength/stiffness/weight criteria for the thin wall, high-strength deck. Although most quadraxial fabrics are balanced to provide quasi-isotropic strength, this quad would be made asymmetrical to provide the required strength in the short span of the deck.

The project team was looking for a quadraxial fabric (see Figure 1) with a maximum total area weight of 50 to 55 oz/yd² to insure it would wet-out in our process. The design would require the 0° layer to be at least 20 oz/yd² to provide the longitudinal stiffness needed. The remaining off-axis layers should ideally be split 60% off-axis (±45°) and 40% transverse (90°). The material selected was E-QX 5400-10[1]. This fabric weighs 54 oz/yd², with 22 oz/yd² in the 0° direction. The remaining 32 oz/yd² was perfectly divided 60% off-axis (±45°) and 40% transverse fiber (90°). By alternating layers of transverse triaxial fabric, roving, and quadraxial fabric, we could mimic the material lay-up of the already proven and tested 8" deck, thus reducing validity testing and product delivery time.

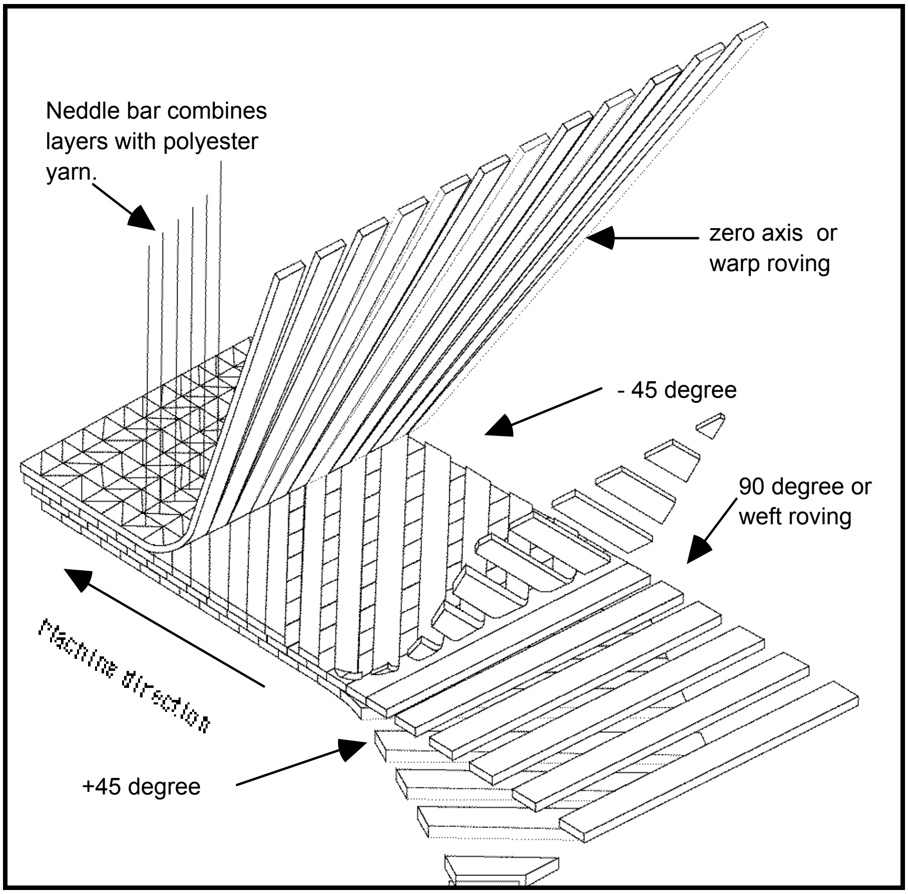

Figure 1. Stitch Bonded Example – Quadraxial[1]. Typical quadraxial ply stack. The 45º and 90º plies are interchangeable with the 0º always on top. Quadraxial fabrics can be made with equal weight in each ply, 0º, - 45º, 90º, + 45º, to produce a laminate of quasi-isotropic strength or unbalanced architecture to provide efficient support for rectangular panels.[2]

1. JICR call out for a quadraxial stitch fabric.
2. Sketch furnished by JICR.

The final top/bottom faceplate construction was designed using the .510” plate thickness recommended from FEA studies. A layer of E-TTX 4008-10 was selected for the top and bottom of each plate because of its ply lay-up of 60% ±45º fibers and 40% 90º fibers, and the binderless chopped mat run against the die cavity. The interior of the plates was comprised of alternating layers of unidirectional roving and E-QX 5400-10. The ply lay-out for the top plate is shown in Figure 2. The number of layers of E-QX 5400 was determined by calculating a desired range of 20-22% by volume with 0° fibers, and by considering the total number of rovings in the entire part. Five layers of E-QX5400 per top/bottom plate would only require 646 ends to give 21.8% volume and 0° fiber. This would minimize set-up time and allow the profile to be pultruded on up to five lines at CPI. If testing showed a lack of stiffness or strength in the longitudinal direction, then one layer of E-QX 5400 could be replaced with a band of roving, increasing the mechanical properties in that direction.

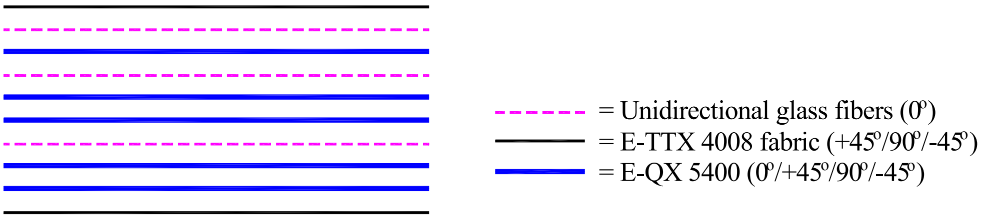

Figure 2. Schematic of Ply Lay-Up for Top Plate of 5” Deck. The bottom layer of E-QX 5400 could be replaced by a band of unidirectional glass if more longitudinal stiffness is required.

The web material lay-up was determined by two factors: a desire for minimum wall thickness from FEA modeling provided by MMC, and how many layers of fabric will fit with a thin band of roving required to “carry” the fabrics through the guiding system and die. Since the stresses on a web region are predominately shear and compressive stresses, we wanted to maximize the volume of E-TTX 4008 (as noted above, containing 60% ±45° fibers and 40% 90° fibers). Unidirectional fibers utilized were only 6.5%, as roving near the neutral axis do little for strength properties. The final design had four layers of E-TTX 4008 with a thin layer of unidirectional fibers. The web wall thickness was increased slightly to 0.262” to accommodate the fabric. Figure 3 shows the ply lay-out in the web sections of the 5” deck.

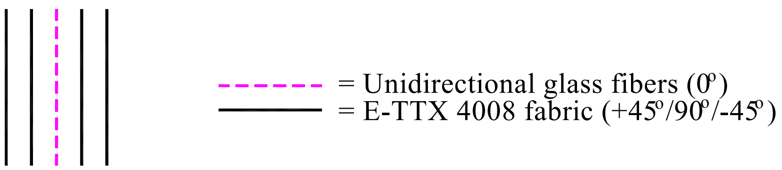

Figure 3. Schematic of Ply Lay-Up in Web Section of DuraSpan 500 Deck.

Pultruding The 5” Deck

It was a challenge pultruding the 5” deck profile 26.5”wide (includes a 2.5” lip for bonding), which weighed approximately 13 pounds per square foot. Fortunately, many of the potential problems were avoided simply from prior experience pultruding the 8” deck and other large components. Fixtures were developed to enable a multitude of fabrics to run from a minimum of floor space. Guides were built to prevent tear-outs and enable operators to replace rolls of fabric more efficiently. Resin delivery systems were already designed that could deliver enough resin to fill the large wet-out boxes. Sewing machines capable of splicing heavy fabrics with no overlap had been used frequently in the pultrusion area since 1997. Handling heavy parts after cutting them on-line was also no problem, with heavy-duty rollers to move and support the part out the door.

With 32 fabrics and mats running constantly, coupled with a relatively high line speed of 6 to 8 inches per minute, splicing efficiently is of premier importance. Maintaining the profile's integrity is also crucial in a bridge application. With approximately 60 yards of material on each roll of E-QX 5400 and E-TTX 4008, the splices can be staggered to leave a minimum of 15 to 20 feet between each 24" horizontal fabric and each vertical (web) fabric. This creates a continuous mode for splicing fabrics, but there is no last minute splicing of several fabrics in a short time frame if a sewing machine should fail, and the structural integrity of the part is intact.

Figure 4. Fabrics and Unidirectional Fibers Being Pulled Into the Mold.

Figure 5. Five-Inch Deck Profile Being Pultruded at Creative Pultrusions, Inc.; May 2001.

Design Criterion For The Pultruded Cross-Section

The American Association of Standards for Highway Transportation Officials (AASHTO) controls the design of bridges, and therefore decks on bridges. The bridge design using reinforced concrete and steel has been established over the past 100 years of experience. But the use of FRP materials for bridge structure does not have such a history. The criterion for designing with FRP materials does not exist specifically, and therefore the bridge community and AASHTO has defaulted to the understandable position of taking a conservative design of the FRP decks. The FRP deck suppliers have been asked to meet a required stiffness for the unsupported distance between beams in the superstructure of the bridge. This number does vary slightly from state to state, but the stiffness requirement usually gives a large factor of safety (FS) in strength. A large FS in strength is the proper way for the composite industry to introduce a new product.

Therefore the project team worked to meet the stiffness for the 5” deck design to be a function of the beam spacing in the superstructure like the criterion was for the 8” deck profile. The agreed design stiffness for the 5” deck was L/500. This terminology is the format used to describe the deflection between beams for a deck system on a bridge. The L term is the clear distance between beams supporting the deck structure, and the units are inches. The boundary conditions and type of loading has been a source of disagreement when comparing different FRP deck systems. Some states will accept an L factor as low as 350, but others do not accept less than 800.

MMC has adopted a Deflection Standard Criterion for bridge decks as shown below in Figure 6. The two wheel loads (P) represent the wheels of an AASHTO truck. The P loading is an HS25-rated load with an applied Impact Factor of 1.30.

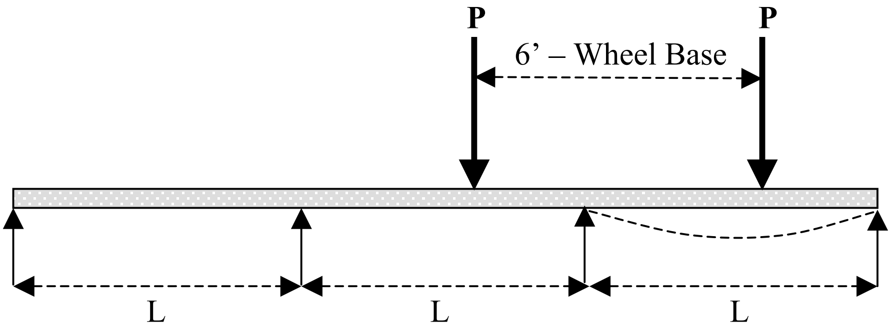

Figure 6. MMC's Definition of Stiffness for Decks on Bridges.

Static Tests Of 5" Deck Specimen

Static 3-point bending tests have been performed at North Carolina State University's Constructed Facilities Laboratory (CFL) under the director, Dr. Sami Rizkalla. The static tests completed for this paper were done on the 5" deck specimen, and the tests were conducted from May 2001 to October 2001. Four static tests were done on different specimens and different combinations of set-ups. Table A shows the different arrangements used to verify the stiffness and strength of the 5" deck system.

Table A. Matrix of the 3-Point Bending Tests Performed on 5" Deck Systems

Specimen Description	Clear Span Distance	Figure of Load vs. Deflection	Failure Load	Type of Failure
Single Tube – Diagonals Up	4' to 4' 4"	Figure 8	75 Kips	Shearing of the Vertical Web
Single Tube – Diagonals Down	4' to 4' 4"	Not Shown	75 Kips	Shearing of the Vertical Web
Two Tubes Bonded	4' to 4' 4"	Figure 9	72 Kips	Shearing of the Vertical Web
Single Tube – Diagonals Up	3' to 3' 4"	Not Shown	71 Kips	Shearing of the Vertical Web

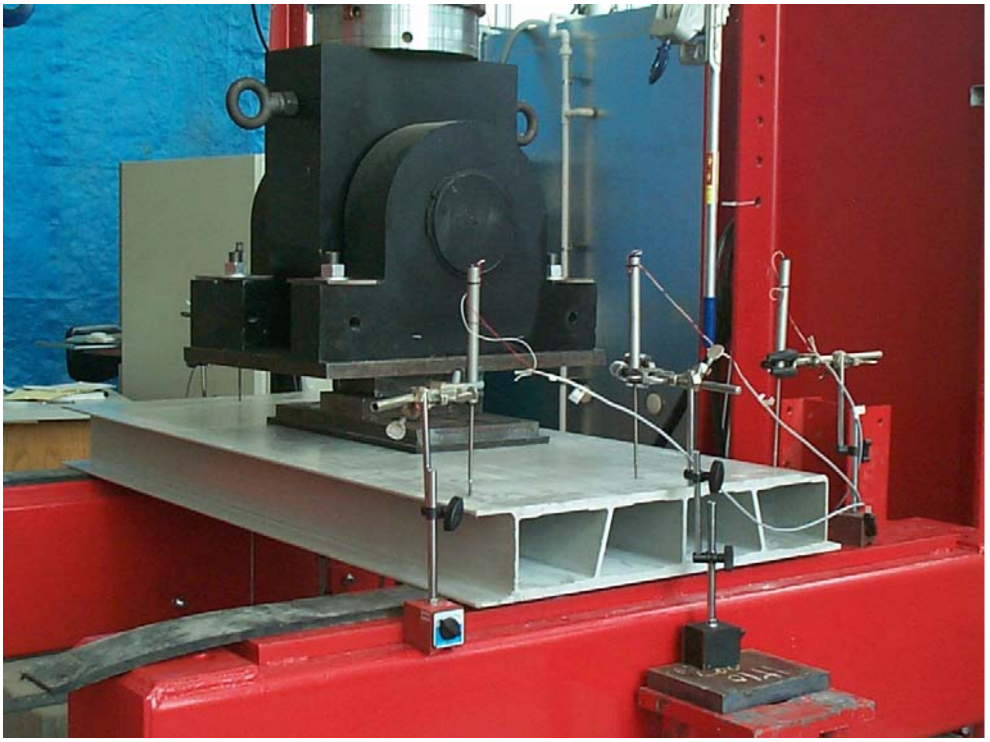

Figure 7. Static 3-Point Bending Test at CFL (NCSU) for the 5” Deck Profile; May 2001.

The 3-point bending test required by the AASHTO code is to have a steel plate that is 10”x20” in size to apply the “tire load” on the deck structure. The steel plate is oriented with the 10” edge being parallel to the traffic direction. This type of loading sometimes creates a local failure of cutting into the FRP deck panel that is a false failure. The initial failure for the 5” deck system has been consistently with the vertical web failing in shear. However, the failure was localized and not catastrophic.

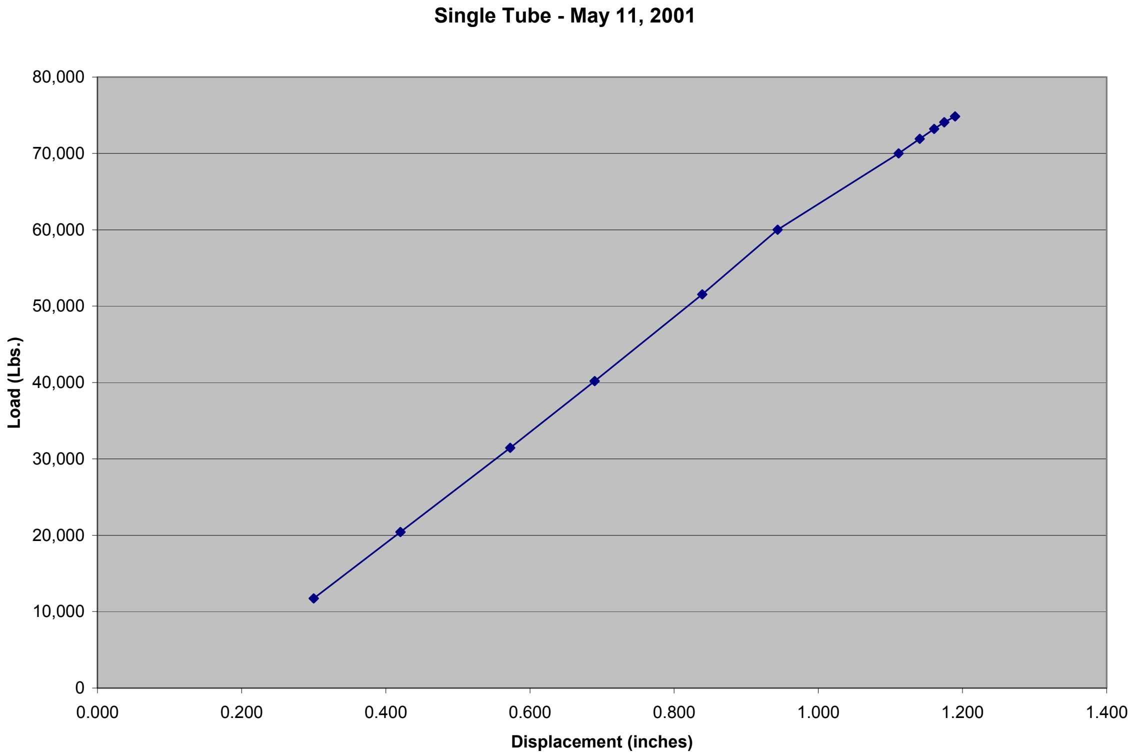

Figure 8. Plot of Load Versus Displacement for the 5" Deck Specimen. Single tube only.

The initial failure in the lab test for the deck was shear in the vertical web. After failing the first specimen (single tube – diagonals up), the failure test specimen was reloaded in the test fixture to a maximum load of 63 Kips before the specimen failed again. Therefore, the HS25 Factor of Safety, 2.88, is not what MMC wanted initially in the design (greater than 3.0), but the type of failure – non-catastrophic – and the residual strength left in the specimen, 63 Kips, allowed MMC to accept a FS of less than 3.0.

Effective bending in the 3-point bending test for the 5" deck specimen is pointed out by bonding two tubes together and duplicating the test from Figure 8 (single tube). In Figure 9, two tubes were bonded together and the results showed that the effective bending cross section is not both bonded tubes in 100% bending. The residual strain damage from the previous loads during both 3-point bending tests is not shown in this paper, but the 5" deck specimen showed a non-linear history for stiffness as the specimens were cycled through the loads.

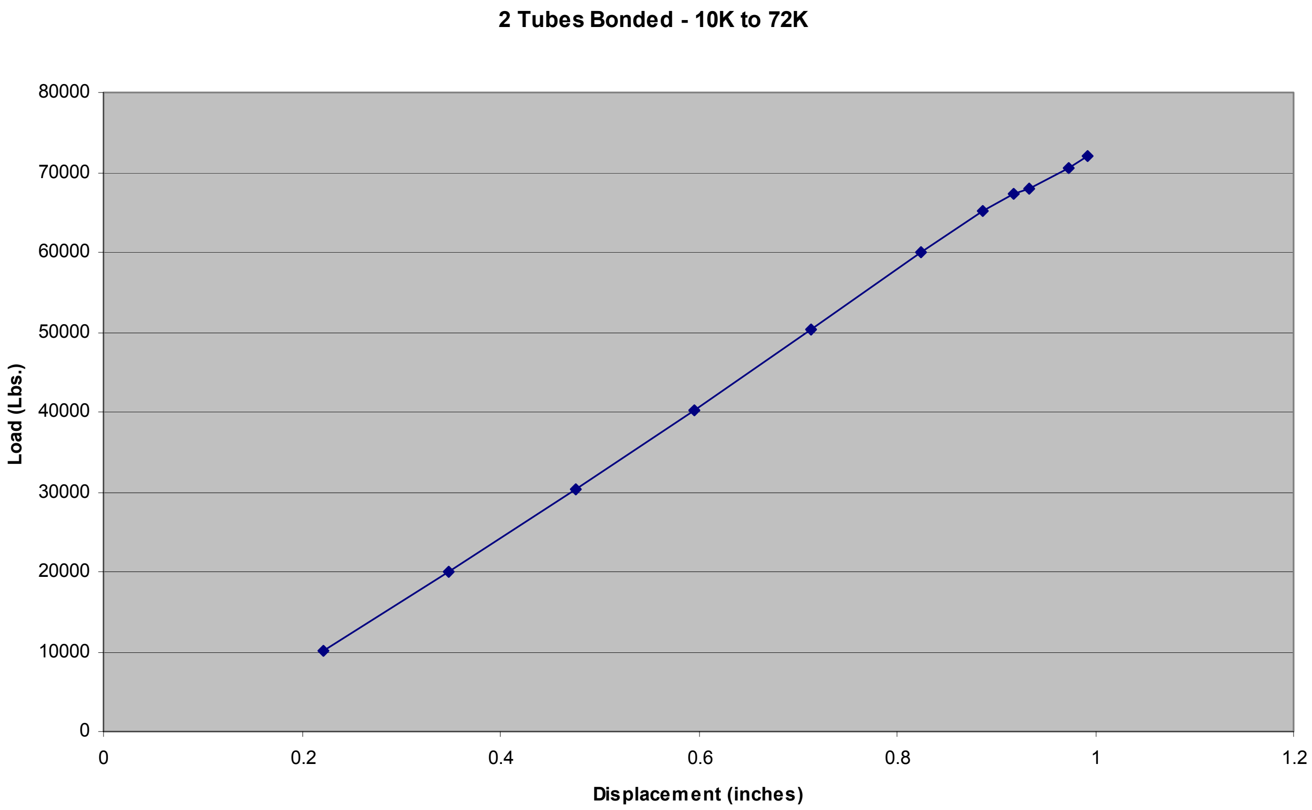

Figure 9. Two 5” Deck Specimens Bonded Together. July 2001 test at CFL (NCSU).

Finite Element Models

North Carolina State University’s Mechanical & Aerospace Engineering Department, under the direction of Dr. Eric Klang (Professor), has been doing Finite Element Analysis (FEA) models for MMC since 1997. The experience gained was used in predicting the stiffness and strength of the low profile deck product. The stiffness predictions have been more accurate than the strength. But the models overall have given indications of where the higher strains do occur in a design. The stiffness has been accurately predicted and verified in the lab tests within approximately 4%. The strain predictions have not been consistent enough yet to use as a prediction in the design of pultruded laminates. This paper will not show the FEA models, but the presentation will discuss more of the FEA models for the 5” deck.

Fabrication of the Deck Panels

Fabrication of the FRP low profile deck system begins with each different tube bonded to another tube to achieve a panel 8’ wide by the width of the bridge for shipping on trucks to the bridge sites. The first step is to apply the adhesive to the female joint (U-shape, facing up); the male joint edge of the tube is then dropped in to form the bond line. See Figure 10 below.

Figure 10. Adhesive Being Applied to the Female Part of the Bond Line Joint in the 5” Deck.

The process is repeated until the desired panel size is achieved. The panels are not limited by weight but by size, due to the restrictions on wide loads by the highway system. See Figure 11 for the making of a panel in a vertical stand.

Prior to shipping, the panels are pre-drilled on 2’ centers for connection studs; ends are closed out with a C-channel; and an epoxy grit surface is applied for better adhesion of final wear surfaces.

Figure 11. Bonding Deck Tubes to Make Panels for the Bridge Installation.

Installation Of The 5” Deck Panels At Lewis County, New York

The installation of the panels for the Lewis County, New York, project took place in October 2001. The installation took place in two days. The first panel was placed, adhesive applied, and subsequent panels placed and jacked into position to form full interlocked joints. Nelson studs were then welded to the steel girders through the pre-drilled holes. Cementitious grout was used to fill the holes. The panels were bonded together on the first day and left overnight for the epoxy adhesive to cure. On the second day, triaxial-stitched, 48 ounce e-glass fabric was laminated with a vinyl ester resin to seal up the field joints and add strength for load transfer. See Figure 12 for the panels being placed on the steel I-beams.

Figure 12. Five-Inch Deck Panels Being Installed on the Lewis County, New York, Bridge; October 2001.

Conclusions

The FRP 5” deck system will be a product that the infrastructure industry can use in the future for beam or girder spacing of 5.5’ or less. It is a strong example of how to adapt a profile to meet different customers’ needs and expand services to the market. MMC is scheduled to install two more 5” deck projects this year – one in Ohio and one in Washington. As the installed data history grows (a load test by Bridge Diagnostics, Inc.[3] for the New York Department of Transportation was done but not available in time for this paper), use of FRP will increase due to its light weight and resistance to corrosion.

3. Bridge Diagnostic, Inc. is located in Boulder, Colorado and has done over ten load tests for MMC on FRP bridge decks since 1997.