WORLD'S FIRST THERMOPLASTIC BRIDGES

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ABSTRACT

Deterioration of bridges in the United States has been well recognized. According to the FHWA National Bridge Inventory, one third of nearly 600,000 U.S. highway bridges are classified as structurally deficient or functionally obsolete. Since the majority of bridges were built using wood, steel or concrete, the same conventional materials have been used for bridge replacement or rehabilitation, imposing similar patterns for future deterioration. However to address recent emphasis on durability, accelerated construction and sustainability, including "Going Green," new advanced materials are coming on the market.

Developed in conjunction with scientists at Rutgers University, a manufacturing company named Axion International, Inc. was able to produce a thermoplastic composite material made of nearly 100% recycled post consumer and industrial plastics that would otherwise be discarded into landfills. This environmentally friendly thermoplastic was first utilized for railroad crossties and recently extended its application to bridge and structural members.

In early 2009, the first bridges in the world made of recycled plastics capable of carrying a 71-ton tank and HS25 loads were built at Fort Bragg, North Carolina. Virtually all bridge components, including girders, pier caps, decking, railings and pilings, are made from recycled plastics. The bridges were designed for HS25 and the 71-ton M1 Abrams Tank. Impressed by these developments, Fort Eustis in Virginia also decided to utilize the material to replace two aged railroad timber bridges. The world's first railroad bridges made from this innovative and sustainable material with total lengths of 38.5 feet and 84 feet are being designed to carry a Cooper E-60 and a 260 kips alternate load; they are scheduled to open in June 2010. A detailed design process and discussion on this cost-effective and environmentally superior solution will be presented in this paper.

INTRODUCTION

Plastics, plastics, plastics…what would we do without them? We use them all the time without thinking, whether it's for consuming liquids, storing food or throughout our automobiles. We discard them as garbage without thinking of the harm we're doing to the environment. Discarded plastic goes into landfills and stays there for millennia without degrading. Even radioactive materials degrade over time, but not plastic.

The first vehicular bridge composed of an immiscible polymer blend of polystyrene/high density polyethylene-reinforced thermoplastic with rectangular cross section was built at Fort Leonard Wood, Missouri in 1998, with a high initial cost as compared to traditional materials (Figure 1). The bridge used steel girders to support the thermoplastic sections and to this day has not required any maintenance and still looks new. When viewed on a life-cycle cost basis, the bridge paid for its high initial cost in less than eight years.

A second vehicular bridge was constructed as a bowstring truss (arched) in New Baltimore, New York based on concepts published by Nosker and Lampo in 1994 (Innovative Structural Concepts for Plastic Lumber Materials, T. Nosker, R. Lampo, Proceedings, Society of Plastic Engineers 1996 ANTEC Conference, Indianapolis, IN, May 1996).

Next, in 2002, came a vehicular bridge utilizing the same composite used at Fort Leonard Wood, located in Wharton State Forest in New Jersey with a load capacity of 36 tons and an initial cost close to a chemically treated wood bridge (Figure 2). This was the first bridge to take advantage of the fact that I-beams can be molded from the plastics, which is much more efficient in bending than rectangular cross sections. An additional advantage is the possibility of nesting sections to distribute loads and shorten construction time.

Figure 1. Vehicular bridge at Fort Leonard Wood, Missouri built in 1998 with a maximum load capacity of 12.5 tons.

Figure 2. Vehicular bridge in Wharton State Forest, New Jersey built in 2002 with an I-beam substructure and a maximum load capacity of 36 tons.

The latest demonstration of this sort, in early 2009, was a recycled structural plastic composite (RSPC) bridge with both the superstructure and substructure elements made of thermoplastic composites. RSPC is made up of high density polyethylene (HDPE) with polypropylene encapsulated fiber glass fibers. This arrangement was cost competitive with wood to carry the same load. The bridge (Figure 3), located at Fort Bragg, North Carolina was designed to handle 71-ton M-1 Abrams tank loads.

The newest additions are two railroad bridges, one 38.5 feet long (Bridge No. 3) and the other approximately 84 feet long (Bridge No. 7), located at Fort Eustis, Virginia. Bridge No. 3 consists of a four-span continuous unit whereas Bridge No. 7 consists of two three-span continuous units and one two-span continuous unit. The pilings, piers and superstructure are all made of RSPC. Existing abutments made of wood are retained to economize on cost. Construction of these bridges started in January 2010 and they are scheduled to be in service in late June of this year.

Figure 3. A successful crossing of a 30-ton steamroller over Bridge T85-19 at Fort Bragg, North Carolina.

DEVELOPMENT OF TECHNOLOGY

In the early 1990s, HDPE-based recycled plastic lumber (RPL) emerged in the U.S. marketplace as an attractive substitute for natural wood with similar strength values to equivalent-sized wood lumber. However, early RPL products suffered from low elastic modulus as well as significant creep at stresses as low as 80 pounds per square inch (psi), compared to design stresses of 900 psi for many wood species commonly used in construction. Further research led to reinforced thermoplastic composite lumber (RTCL) with higher elastic modulus and creep resistance by incorporating immiscible polymer blends with reinforcing agents within the RPL matrix, such as fibers, or by making immiscible polymer blend composites with one high modulus component. Further research utilizing specialized processing methods resulted in nano-structured morphologies (Figure 4) of the IMPB composites, also called RSPC, with enhanced mechanical properties, including increased toughness without sacrificing modulus or strength. Figure 5 shows the stress-strain curves in tension.

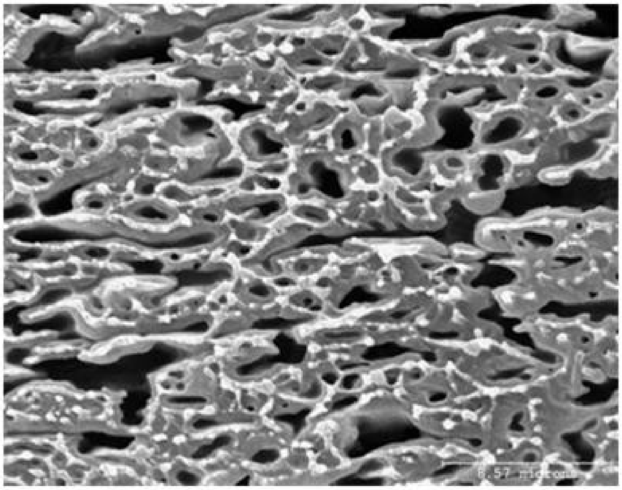

Figure 4. SEM micrographs at 8.57 µm scale of an RSPC material.

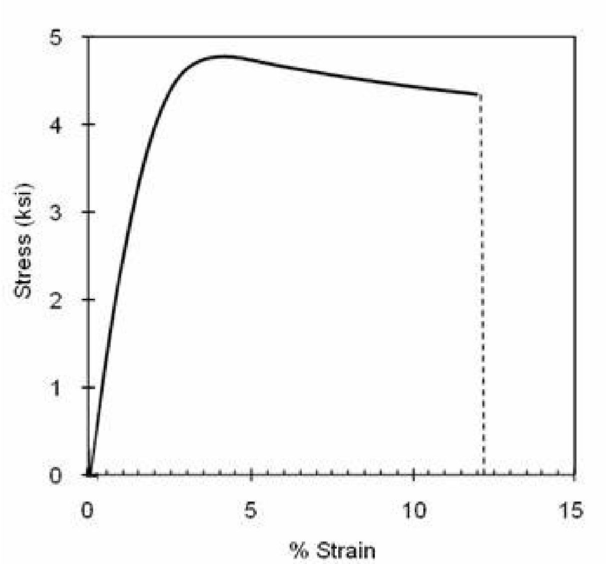

Figure 5. Stress-Strain Curve for Compounding Single Screw.

IMPACT ON ENVIRONMENT, CONSTRUCTION AND COSTS (FIRST CYCLE & LIFE CYCLE)

Environment

RSPC elements lend themselves to recent USDOT guidance in regards to considering innovation, sustainability and being "Green" as important project elements. RSPC components are made from consumer and industrial waste. Though the majority of recyclable plastic today ends up in landfills, using RSPC can make a significant dent in this problem. It also does not put poisons into the soil or water because there are no carcinogens or added chemicals in the product that can leach out over time. Its manufacture also reduces energy usage and related greenhouse gas emissions into the atmosphere.

For example, based on EPA's online resource (Recon) tool, the energy benefit in terms of gallons of gasoline not consumed is 22,296 gallons for one bridge at Fort Bragg (86,000 pounds of recycled plastic was used). This "non-use" of gasoline, in turn, equates to 196 metric tons of carbon dioxide not emitted.

Meanwhile, American railroads replace 20 million railroad ties annually. This translates to enough ties to build 6,670 miles of track, which is equivalent to 5,000,000 trees or 71 square miles of forest—an area larger than Washington, DC, Northern Virginia and part of Maryland.

Structural corrosion costs the Department of Defense over $22 billion per year while the cost to the U.S. taxpayer is closer to $300 billion. This economic drain could be significantly reduced by utilizing RSPC in areas where it is practicable.

Other positive attributes of RSPC include that it's non-porous (doesn't absorb moisture or rot); doesn't conduct electricity; is sustainable and durable; isn't prone to insect infiltration; is sound absorbent; is lighter than concrete or steel and about the same weight as oak wood; and is a good material for use in areas of seismicity due to its low self weight, ability to absorb energy and high strain rate prior to failure. A composite fire retardant can also be applied to the material.

Construction

Low density RSPC lends itself to accelerated construction, the attributes of which are well known to both the design and construction industry, and is also significant due to related cost savings in these challenging economic times. Transporting RSPC products also doesn't require any heavy or special equipment and can be accomplished with standard trucks. This is also true when it comes to construction in the field. Lighter equipment can be used during construction which allows for accelerated schedules and enhanced safety (Figure 6).

Figure 6. I-beam substructure of the Wharton State Forest bridge in New Jersey.

Costs

Table 1 compares the cost of building a 60-foot-long bridge using different types of materials, including maintenance requirements over its life cycle.

Table 1
Cost Comparison of Materials Used to Construct Bridges

Material	Cost	Weight	Expected Life
Wood	$450,000	175,000 lbs	8-12 years + maintenance
Steel/Concrete	$600,000	300,000 lbs	20+ years + maintenance
Virgin Polymers	$1,400,000	195,000 lbs	Untested
Thermoplastic Timber	$300,000	120,000 lbs	50+ years Minimal or no maintenance required on thermoplastic timber

Table 2 shows the cost of railroad ties per mile, with installation, on a per cycle basis.

Table 2
Railroad Ties—Cost Per Mile With Installation, On a Per Cycle Basis
(5-50 years, for wood and concrete, depending on circumstances)

Replacement Cost	Initial Cost	Cycle 2 Cumulative Cost	Cycle 3 Cumulative Cost	Cycle 4 Cumulative Cost	Total Cumulative Cost
Wood	$255,000	$510,000	$765,000	$1,020,000	**$1,275,000**
Concrete	$375,000	$750,000	$1,125,000	$1,500,000	**$1,875,000**
Thermoplastic	$435,000	$435,000	$435,000	$435,000	**$435,000**

MATERIAL PROPERTIES

Weight comparison of RSPC and other commonly used construction materials is shown below:

Wood (Oak)	45 pcf
RSPC	50 pcf
Concrete	150 pcf
Steel	489 pcf

Properties of thermoplastic:

Specific Gravity	0.85-0.90
Elastic Modulus	250,000 psi
Allowable Flexural Stress	600 psi (Ultimate = 3,000 psi)
Allowable Compressive Stress	600 psi (Ultimate = 2,500 to 4,300 psi)
Allowable Shear Stress	350 psi (Ultimate = 1,500 psi)
Coefficient of Thermal Expansion	0.0000282 in/in/deg F
Cyclic Loading Railroad Tie Wear (2 million Cycle Test, 20 kips Vertical Load, 3.75-7.5 kips Lateral Load)	No tie plate cutting damage or cracks

Apart from the above design considerations, additional issues are addressed below:

- Ultraviolet Degradation: less than 0.003 inches/year, much less than wood or rust on steel.
- Fire Resistance: the RSPC ignition point is higher than many wood timber materials especially those with creosote. A composite flame retardant coating is available that prevents ignition completely.
- Moisture Absorption: virtually impervious and retains mechanical properties in humid and wet environments.
- Thermal Resistance: heat deflection temperature is 125 deg C, and material is viable to -125 deg C, well beyond observable Earth temperatures.
- Environmental Resistance: resistant to attack by marine borers, corrosion, insects and rot.
- Abrasion: highly resistant to abrasion that may occur in marine environments due to salt and sand since HDPE is one of the more resistant polymer materials as demonstrated by Taber abrasion tests and chemical resistance tests.
- Creep: thermoplastic products are designed for a 600 psi allowable tensile, compressive and flexural stress, low in the stress-strain curve shown in Figure 5.
- Skid Resistance: the coefficient of friction can be modified through the use of surface texturing during the manufacturing process.
- Acid Resistance: RSPC material is resistant to most acids and salts likely to be encountered in a bridge application.
- Abutment Backfill: needs a lightweight backfill such as expanded polystyrene (or similar).
- Surface Texturing: it's possible to add a surface texturing to deck boards through an embossing process in line. This improves both aesthetics and the coefficient of friction.
- Color: although the basic color of RSPC components is a graphite or black color, it's also possible to produce colors such as gray, beige, etc.

PROJECT APPLICATIONS

Bridges at Fort Bragg

Two bridges, T85-18 and T85-19 using RSPC have been built at Fort Bragg in North Carolina. T85-18 takes Tuckers Road over Big Muddy Creek, while T85-19 takes Gravel Road over Muddy Creek.

T85-18 is a three-span structure of 12-foot spans each for a total length of 38 feet, 4 inches. The width of the bridge is 17 feet, 6 inches out-to-out. The substructure consists of pile bents with 12-inch-diameter RSPC material. The end bents consist of three vertical piles, whereas the interior bents consists of four piles per bent with the two exterior piles battered at 1:6 in the transverse direction. The pile cap (also of RSPC material) consists of an 18-inch deep I-beam and is connected to all the piles through 1-inch drift bolts. The superstructure, which is continuous over the three spans, consists of 11 18-inch-deep I-beams set side by side. The decking consists of 3- by 12-inch RSPC planks connected to the RSPC girders. The girders are connected to the bent cap through bolts. Slotted holes at the ends of the bridges are provided in the girders and steel bearing plates for thermal movement. The side barriers consist of 6- by 6-inch RSPC posts with 2- by 6-inch RSPC railings.

T85-19 is a four-span structure of two 9-foot, 9-inch end spans and 12-foot intermediate spans for a total length of 45 feet, 10 inches. Spans are semi-continuous as they are staggered. The roadway width is the same as T85-18 (17 feet, 6 inches out-to-out). The substructure and superstructure configurations are similar to T85-18.

Figures 7-9 show the construction and operation of one of the bridges (T85-18). Both bridges were designed to handle the 71-ton load of an M-1 Abrams tank in addition to other normal vehicular loadings. For both bridges, piles were driven to a 37.5-ton end bearing using a vibratory hammer and 4,000-pound diesel powered hammer. The piles were about 65 feet long and had a can splice.

Figure 7. Pile caps in place and pinned on three rows of pilings on T85-18.

Figure 8. Girders installed on T85-18 spanning the length of the bridge.

Figure 9. M-1 Abrams tank crossing the RTCL bridge T85-18 at Fort Bragg in September 2009.

Bridges at Fort Eustis

Two bridges, Nos. 3 & 7, have been designed and are under construction for the U.S Army at Fort Eustis, Virginia, to carry a Cooper E-60 and a 260-kip alternate loading with 20% impact. Both bridges are 12 feet out-to-out at the top. Existing timber abutments resisting the backfill loads are being retained to economize on the cost, while the superstructure loads including vertical live load, are being carried through end bents into the ground. Horizontal live load, such as longitudinal force generated due to braking or traction force, is resisted by pier bents and the abutments.

Bridge No. 3 is a four-span continuous 38-foot, 6-inch long structure over a shallow stream. It consists of two end bents and three intermediate bents. The substructure consists of six vertical piles at the end bents and six piles at the intermediate bents. Of the six piles at the intermediate bents, two are battered at 1:6 in the transverse direction, two are battered at 1:6 in the longitudinal direction and the remaining two are vertical. All piles are 12-inch-diameter RSPC piles. The piles are about 45 feet in length and are driven to an end bearing of 17 tons per pile. The pile caps for all bents consist of 18-inch I-beams and are connected to the piles through stainless steel drift bolts.

The superstructure consists of two 18-inch T-beams formed into an I-shape through adhesives and bolting. Each rail is supported on three such beams and the beams are connected together transversely with tie rods (see Figure 10). The superstructure is supported on elastomeric bearings. The girders are prevented from moving transversely by restrainers and longitudinally beyond the thermal limits by restrainers. The girders are stiffened by cover plates at the top which are 3- by 12-inch and 3- by 10-inch RSPC planks glued and screwed to the girders. The RSPC rail ties transfer the load from the rails to the girders and are connected to the girders by J bolts.

Bridge No. 7 is an eight-span 84-foot, 1-inch long structure over a creek. It consists of two end bents and seven intermediate bents. The end bents are supported by four 12-inch-diameter RSPC vertical piles and the intermediate bents are supported by five 12-inch-diameter RSPC vertical and battered piles. The beam consists of two three-span continuous units and one two-span continuous unit. The typical section of Bridge No. 7 is identical to Bridge No. 3, except the pile layout. The piles are expected to be driven to 45 feet in length with a minimum end bearing of 20 tons per pile.

Highway Bridges

The next stage in the development of RSPC products is a standard short span highway bridge designed to Load and Resistance Factor Design (LRFD) specifications. It will be a 30-foot simple span bridge accommodating a two-lane roadway. Subsequently, planning is underway to develop a standard two-span continuous design with spans in the range of 30 feet each.

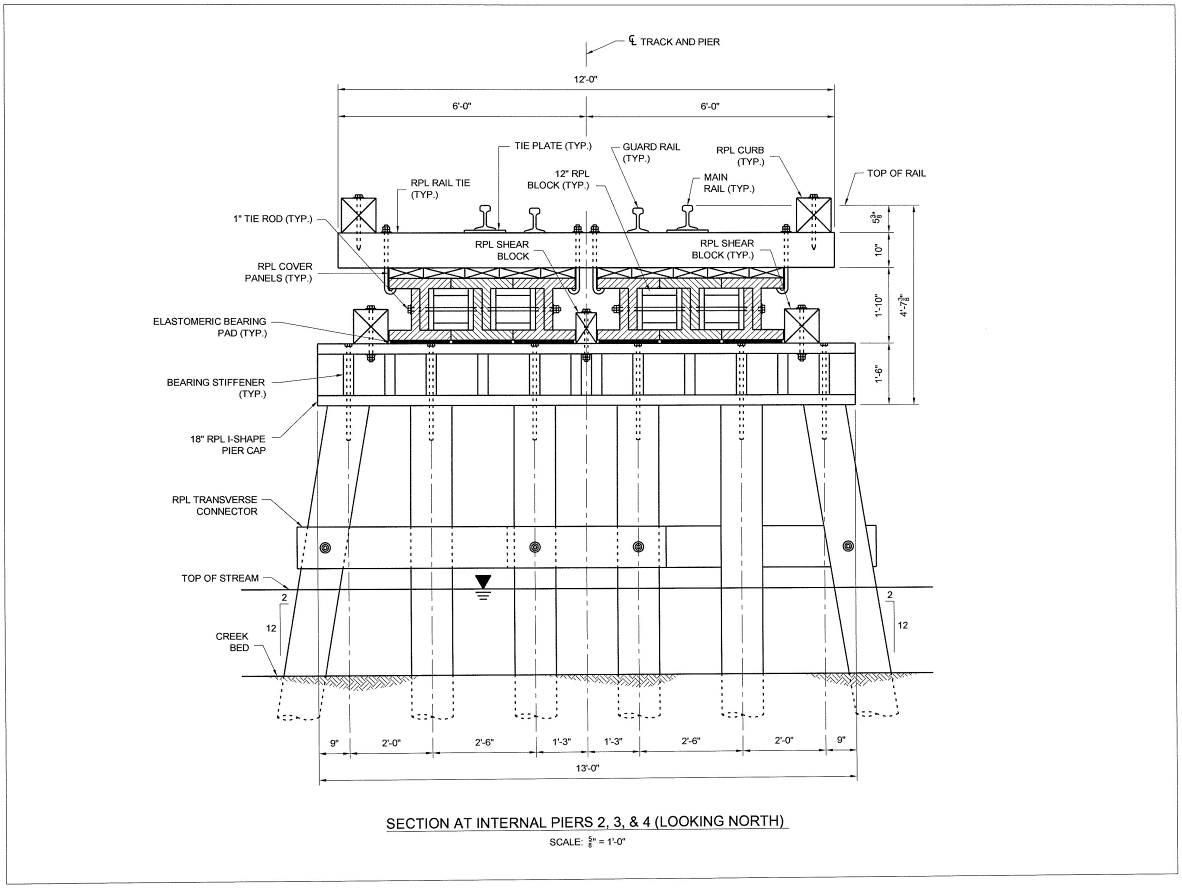

Figure 10. Typical cross section of bridge at Fort Eustis, Virginia

Other Applications

The application of RSPC products can be quite varied and could be used for marinas and waterfront structures such as fenders, pilings, jetties and piers; boardwalks; rapid deployment bridges; temporary reusable bridges and other areas where durability, sustainability and accelerated construction coupled with the benefits of “Green” products is desired.

CONCLUSIONS

RSPC products have come a long way in 20 years with advancements in materials and applications. Already, they have been applied to bridges carrying tanks, railroads and vehicular traffic; used for over 200,000 railroad ties; and for switch sets. And many more areas are being continuously explored. Design assumptions for the bridges at Fort Bragg have subsequently been validated by instrumentation and monitoring.

RSPC products offer many environmental benefits due to the opportunity to reuse what would otherwise be eternal, non-decaying plastics in landfills. They provide energy savings during manufacture, reduce forest degradation while proving a building product that does not corrode or rot, and is not susceptible to attack by insect or marine organisms—all while providing a stable, light platform suitable for accelerated construction with minimal maintenance. Its use will undoubtedly increase as new ideas are explored. The material definitely lends itself to the FHWA’s slogan: “Get In, Get Out and Stay Out”.

CREDITS

The RSPC material was researched at Rutgers University over the last couple of decades and developed to what it is today. They hold the patent rights to the fabrication process. Axion International, Inc. is the licensee of the patents. Innovative Green Solutions (IGS) is the sales and marketing consultant for the product and Parsons Brinckerhoff, Inc. is the designer for Axion.

The material for this paper came from many sources and in particular from two papers. One was written by Dr. Thomas J. Nosker, Dr. Jennifer K. Lynch and Richard G. Lampo, all of Rutgers University. The paper is entitled “The Utilization of Recycled Thermoplastic Composites for Civil and Military Load Bearing Applications.” The other paper was written by Ms. Lisa Miles Jackson, President of Innovative Green Solutions and Dr. Thomas J. Nosker of Rutgers University. The paper is entitled “Technology, Applicability, and Future of Thermoplastic Timbers” and was presented at the Department of Defense Corrosion Conference, Washington, DC on August 10-14, 2009.