TECHNOLOGY, APPLICABILITY, AND FUTURE OF THERMOPLASTIC TIMBER

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ABSTRACT

This paper describes a new generation of innovative structural products made from 100% recycled consumer and industrial plastics called Thermoplastic timber. Developed by scientists at Rutgers University and tested by the US Army Corps of Engineers, the patented technologies provide products that are extremely strong and durable, flexible in design, and virtually maintenance-free. Successful demonstrations have shown that Thermoplastic timber is a viable alternative to more traditional building materials including wood, steel, and concrete. Initial applications for these materials include bridges, railroad ties, pilings, marinas, boardwalks, and retaining walls. Thermoplastic timbers are an ideal replacement for any application requiring treated lumber.

Keywords: Thermoplastic timber, recycled plastic, corrosion, bridge construction, green technology, innovative solutions, sustainability

INTRODUCTION

Corrosion costs the Department of Defense (DoD) over $22 billion a year. “The insidious and pervasive effects of corrosion have now reached the point where it is a major cost for our economy and quality of life – in fact recent studies estimate the direct cost of corrosion in the United States to be nearly $300 billion dollars per year” (1). When Congress passed section 2228 of Title 10, United States Code it created requirements for all DoD acquisitions as follows:

“(A) To ensure that the use of corrosion prevention technologies and the application of corrosion prevention treatments are fully considered during research and development in the acquisition process; and

(B) To ensure that, to the extent determined appropriate for each acquisition program, such technologies and treatments are incorporated into that program, particularly during the engineering and design phases of the acquisition process (2)"

These requirements ensure that the Program Manager (PM) and the Milestone Decision Authority (MDA) for any acquisition must evaluate the total cost of ownership (TCO) throughout the life of the proposed acquisition. Specific instructions and guidelines for this new law are incorporated into DFARS 207.105, DoD Directive 5000.67, DoD Directive 5000.1 and DoD Directive 5000.2.

Section 2228 of Title 10 provides direction to include the "establishment of a coordinated research and development program for the prevention and mitigation of corrosion for new and existing military equipment and infrastructure that includes a plan to transition new corrosion prevention technologies into operational strategies including through the establishment of memoranda of agreement, joint funding agreements, public-private partnerships, university research and education centers, and other cooperative research agreements (3)."

This paper describes the Technology Innovation Demonstration Project that occurred as a result of this law and funding. It will also show that Thermoplastic timber is the safe choice for compliancy and the optimal choice in the war against corrosion.

BACKGROUND

DoD Goes Green

Federal laws, regulations, and recent DoD Green procurement policies establish acquisition procedures to protect and conserve the environment. The emphasis on environmental conservation was directed by Executive Order 13423 dated January 24, 2007 that requires the use of sustainable environmental practices. The order directs Departments and agencies to increase their use of "green" products. The DoD's Green procurement policy requires that services buy products with favorable energy or environmental attributes consistent with federal mandates. Products should meet provisions of the Environmental Attribute Code (ENAC) by being water efficient, energy efficient, bio-based, or recyclable. They should have a lesser or reduced negative effect on the environment when compared to competing products that would serve the same purpose. Consideration of cost is a factor but to the extent that it affects total life-cycle costs, not just purchase price. The use of Thermoplastic timber addresses both the spirit and letter of the Federal government's laws to go "green."

Practical Application: Technology Innovation Demonstration Project

The Office of Under Secretary of Defense for Acquisition, Technology and Logistics Corrosion Prevention and Control Program funded a Technology Innovation Demonstration Project at Fort Bragg to test the strength and durability of Thermoplastic timber.   The timber was used in the application of a bridge to support 71 ton Abrams tank traffic. The bridge, the first of its kind, was initiated by Richard Lampo of the U.S. Army Construction Engineering Research

Laboratory (USACERL) while ACSIM's ITTP funded and paid for construction and initial load testing. The Army Bridge Inspection Team (ERDC-GSL), with contract support from Bridge Diagnostics, Inc., performed continuous load testing and recorded measurements from strain gauges to measure deflection as well as collected data from video cameras mounted on the bridge to continue remote monitoring. In addition to the Abrams tank traffic, several other types of vehicles crossed the bridge eight times.

The project's goal was to provide a low-maintenance, affordable structure using recycled materials. Engineers wanted to avoid the use of any wood components, which require chemical treatments to fight rot and insect attack as well as require costly routine maintenance. DoD is interested in recycled plastic as a possible replacement for wood timbers because deteriorated timber bridges are very costly to repair. More often than not, repairs can exceed the cost of replacement. Moreover, the DoD's maintenance and repair budget is not always adequate to renovate deteriorating bridges. And, if the same materials are used, the degradation cycle associated with wood material begins again. The DoD is interested in recycled plastic as a possible replacement for wood timbers at all of its military installations (4).

Thermoplastic timbers were used for the pilings, girders, substructure, decking, and railings; everything except the steel bolts and sill plates were made from recycled post-consumer and industrial plastic. On June 11, 2009, an M-1 tank safely crossed the newly built bridge, which was built with timbers using some 86,000 pounds of recycled plastic. The tank's successful trips across the bridge marked the completion of load testing and safety validation for the new structure. Innovative plastic I-beam components were used to support the heavy loads and provided a design that compares favorably in cost to a treated-wood bridge designed to carry the same load over the same span. Fort Bragg has built a second thermoplastic composite bridge and has funding approved to construct a third. These structures will be monitored to further validate the technology and provide lessons learned.

The Fort Bragg project received a strong vote of confidence from DoD due to its success. "This thermoplastic bridge, able to withstand heavy loads with little to no maintenance, expected to last at least 50 years, is no longer the bridge of the future – it's the bridge for today," said Daniel J. Dunmire, Director of Corrosion Policy and Oversight. "It also meets national environmental goals of being completely recyclable. This technology is not only good for DoD, it should be immediately transferred to state Departments of Transportation for use wherever possible."

Overview of the Technology: A Brief History

New advances in thermoplastic polymers have given rise to the advanced form of "plastic lumber" known as Thermoplastic timber. While "plastic lumber" has been used mainly for non-structural or low-stress applications such as park benches, picnic tables, and residential decking, Thermoplastic timber is a structural-grade, reinforced plastic lumber that can be used for load-bearing construction.

Because it does not contain any wood material it is inherently resistant to rot and does not require chemical treatment to ward off insects. Thermoplastic timber is made using immiscible polymer blends from 100% recycled, commodity plastics. When blended, the resultant material has excellent structural properties as demonstrated by the test at Fort Bragg.

Recycled Plastics and plastic lumber has evolved over the last two and a half decades. Some recycled plastic lumber (RPL) contains large amounts of fiberglass making it hazardous to work with (it is irritating to skin and membranes) and difficult to dispose of. Others have a plastic compounded with wood filling, which also poses problems; when the plastic coating is penetrated, water is trapped in the wood filling causing rot and degradation (5).

The Thermoplastic timber discussed in this paper was developed after years of research at Rutgers University's Center for Advanced Materials via Immiscible Polymer Processing (AMIPP). The AMIPP Advanced Polymer Center is a group of collaborative researchers and stakeholders dedicated to exploring immiscible polymer blends and the novel structures and materials obtained by processing such blends. Founded as a Research Excellence Center by the State of New Jersey and Rutgers University, the Center depends on an interactive relationship with industry, government, and other universities to generate a steady stream of new technologies, materials, and products in an environment focused on research, development, and commercialization.

The Rutgers experts have developed processing that uses a minimal amount of recycled fiberglass to achieve structural stiffness, strength, and creep resistance. The fiberglass blends thoroughly with the HDPE solution creating a load-bearing product that was demonstrated in the Technology Innovation Demonstration Project discussed earlier in this paper.

Of significant importance is the extrusion process that allows only 11% fiberglass but has the strength of a product with 34% fiberglass. The immiscible polymer blending developed at Rutgers takes HDPE Plastic (#2 and the second most common recycled plastic) and blends it with automotive bumper scrap made from polypropylene and fiberglass in a manner that orient the glass fibers and result in properties that exceed the law of mixtures for the individual materials. This creates a product with the best features of both including the flexibility of HDPE and the stiffness and strength of fiberglass. When blended properly, the resultant material has structural properties with a specific strength higher than steel. The modulus and strength benefits through dual-phase, co-continuous morphology and efficient stress transfer between the stages offering stiffer, tougher products have been well documented in research conducted over the past twenty years(6).

Characteristics of Thermoplastic Timber

Perhaps most importantly, Thermoplastic timber does not leach harmful chemicals (7).

It can withstand very hot and very cold temperatures and has no biodegradation or oxidation. Accelerated weather testing was stopped at 50 years, demonstrating that Thermoplastic timbers can last more than 50 years with minimal maintenance (8). Practical experience from landfills has shown that HDPE and fiberglass will take thousands of years to decompose. Comparatively, wood placed outside in the presence of water begins to degrade quickly.

Wood also can have knots, soft spots, and other imperfections not found in thermoplastic timbers.

The effect of ultraviolet (UV) rays on Thermoplastic lumber as demonstrated in a 2001 study shows degradation of .003 inch/year, negligible compared to wood, or the effects of rust on steel. Carbon black pigment which is a natural compound is often added to Thermoplastic timber to reduce the effect of UV rays. Thermoplastic timber has a melting temperature of 125 degrees C and freezes at -125 degrees C; *neither temperature is observable under natural conditions on Earth's surface*. The inherent strength of the material as well as its flexibility greatly reduces any concerns of a catastrophic failure. Scientists at Rutgers have also invented a fire inhibitor that has initial testing of up to 2800 degrees Celsius making the product safe from catastrophic failure due to fire (9).

This material is virtually impervious to moisture absorption and retains key mechanical properties in humid and wet environments. In addition, the material is resistant to attack by insects such as marine borers that have been shown to destroy the integrity of marine wood structures. Thermoplastic timber has a high resistance to the abrasion that may occur in marine environments due to sand and salt content in the water environment. The sand and salt-water resistance is based on the fact that HDPE (the major ingredient) is one of the more resistant polymer materials as demonstrated by Taber abrasion tests as well as chemical resistance tests (10, 11). For these reasons, this material is ideal for the harshest of marine conditions.

The extrusion process developed by Rutgers University creates a product with a "grain like" appearance that is rough to the touch. This characteristic makes the product less susceptible to slipping compared to other composite plastic lumbers with smooth surfaces. Coefficient of friction tests have shown a coefficient above 0.5 with rubber and skin but a lower coefficient of friction with leather (when measured according to ADTM D 1894).

Creep is a property of all common structural material; it is the permanent deformation resulting from prolonged application of stress below the elastic limit. Creep is influenced by the magnitude of the load, the length of time the load is applied, and temperature. Testing consists of applying a load to a test specimen and measuring the strain after a specified time. Tensile creep is the strain produced by a specified tensile load after a specified length of application time. Flexural creep is the outer fiber strain produced by a specified flexural load after a specified length of application time. Thermoplastic timbers are designed for 600-psi allowable tensile, compressive, and flexural stress, well below its tested minimum ultimate strength of 3500psi. Designing with such a low allowable stress minimizes creep. This means that one could park a 71 Ton tank on this bridge for 25 years, and then drive off the bridge and the bridge would essentially regain its original shape with inconsequential residual deformation.

Because thermoplastic materials are fabricated in a molding process, engineers have the ability to optimize the geometry of the cross sections. Deflection of the bridge can be controlled using I beams with large I values, ("I" moment of inertia). Larger spans and/or higher loads can be accommodated using I beams with higher I values in order to stay within AASHTO safety limits.

Thermoplastic timber has a specific gravity of 0.85, which is less than water and somewhat greater than most natural wood. It is easy to work with using standard carbide cutting tools and saws. It is easier to transport and inherently easier and safer to work with than chemically treated wood (12).

The following is an example of a thermoplastic marine piling's durability. When driving a wood timber marine piling, one must account for extra length to cut off the top due to the common effect of mushrooming (spreading of the material at the top) from repeated impact. Because of its energy absorbing capability, Thermoplastic timber has been observed during recent construction to have the capability to handle high impact load with little or no mushrooming. The product can be produced with a blunt or tapered end and can be driven to very high resistance as shown at Fort Bragg, where piles were driven up to 65 ft, to a refusal of 37.5 tons, as shown in the photograph below.

Figure 1. Thermoplastic Timber Pilings being driven at Ft. Bragg

Thermoplastic Timber: A Cost Effective Alternative

When designed properly, a bridge constructed of Thermoplastic timber is more efficiently built and certainly cost effective. When the total lifecycle of the bridge is factored in, including maintenance, replacement and disposal costs, the decision to build a thermoplastic bridge is simple. The cost of wood disposal must also be considered in lifecycle costs, based on the use of pressure treatment chemicals. Wood has an observed shorter life span in harsh environments and, as mentioned previously, is susceptible to degradation from insects and moisture. Thermoplastic timber is impervious to both and requires no maintenance. The structures will keep the same appearance without the need for maintenance, as long as allowable stresses have not been exceeded. This can be seen in two bridges, including one that was built in 1998 at Fort Leonard Wood, MO and one built in 2002 at Wharton State Park, NJ. The bridge at Fort Leonard Wood paid for itself in maintenance savings in the first 7 years (13).

Table 1 compares construction costs of building a 60-foot bridge using different types of materials as well as the maintenance requirements over its lifecycle. These estimates are for DOT and DoD 2 lane HS20 bridges. According to subject matter experts, including Joseph York of York Bridge and Malcolm McLaren of McLaren Engineering, the costs depicted represent very conservative estimates.

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

Fort Drum recently awarded a contract to replace a timber bridge (29) to support HS25 rating with a new timber bridge. Based on the dimensions (30 ft long by 23 ft from rail to rail or 690 sq ft. total) the total cost of $841,355 (14) equates to $1219.35 per square foot. By way of comparison, the two Thermoplastic timber bridges at Fort Bragg were contracted for $941,000. At a total of 1395.56 square feet (for both bridges) construction costs equated to $674.28 per square foot, roughly half the cost of the timber bridge at Fort Drum. All bridges required demolition, new pilings, and road work (see Table 2).

Table 2
Cost Comparison Wood vs. Thermoplastic Timber

	Cost	**Dimensions**	**Cost per Sq. Ft.**
One Ft. Drum Bridge Timber replacement with Wood	$841,355	30 ft x 23 Ft = **690 sq ft**	**$1219.35**

Two Ft. Bragg Thermoplastic Bridges	$941,000	16 ft 6in x 38 ft 8 in Plus 16 ft 6 in x 45 ft 10in **1395.56 sq ft**	**$674.28**

Public press releases issued by Fort Bragg and USACE reveal that their thermoplastic bridges were cost competitive on a first-cost basis as well as having an extended life expectancy that is twice as long as a timber bridge. When disposal and environmental costs associated with creosote-coated timber are factored in, the cost savings increase.

A 2001 study completed by Rutgers University, Engineering Mechanics Corporation of Columbus, and Battelle-Columbus entitled, “Weathering Effects on Mechanical Properties of Recycled HDPE Based Plastic Lumber” demonstrated that Thermoplastic materials strengthen with age. The study also included a Life Cycle Cost Analysis (LCCA) advocating the cost benefits of this solution (15). The 11-year study revealed that a small section of a boardwalk showed an increase in modulus, strength, and reduced deflection. In this case, the initial cost of the RPL was double that of wood but given the maintenance requirements of wood and its decreased longevity, the overall cost of using recycled plastic lumber was still significantly less. Even without including environmental benefits, the cost of the HDPE recycled plastic was lower than wood.

Timber bridge and bulkhead designs are constrained by the limitations of wood. Using thermoplastic timber, bridges and bulkheads can be designed to use considerably less product and handle much higher loads. Designing a bridge, bulkhead, or boardwalk with Thermoplastic timber could greatly reduce the overall cost of the project.

The Thermoplastic timber is a molded material and can be produced in almost any cross-sectional geometry required to create an appropriate moment of inertia. The flexural stiffness (modulus X moment of inertia) can therefore be adjusted to optimize the beam to achieve the required strength and performance. In addition, the material can be molded in the length required for a particular application. Examples of this are the 18” I-beams that are 40 ft. in length and weigh 3200 pounds. Acquiring a wood member with similar length and mechanical properties would be virtually impossible. This design flexibility is therefore a key benefit of this material.

Not only can Thermoplastic timber bridges be built efficiently, they can be built as fast or faster than bridges using other materials. For example, the bridge at Fort Bragg took six weeks to construct. After the pilings were driven, only two workers were required to complete the project. Experience from this project has resulted in design refinements that will further reduce the construction time for future installations. The material is very adaptable to designs, easy to work with and can be constructed with minimal equipment. Construction permits are easier to obtain. Pressure treated wood contains hazardous materials so it is more difficult to obtain permits for its use, especially over water or in wetlands. Pressure treated wood often requires a Hazmat permit for transport. Alternative construction materials such as concrete can have a longer fabrication time. Concrete typically requires 28 days to cure and if multiple sequential pourings are required this can translate to significant added construction time. In addition, concrete is typically reinforced with rebar, which is prone to corrosion due to water infiltration. This can result in cracking of the concrete.

Thermoplastic timbers for railroad ties are more expensive today than a comparable treated wood timber on a first cost basis. However, in areas of high stress, wood railroad ties need to be replaced every 5 -15 years. The American Association of Railroads (AAR) has been testing thermoplastic railroad ties for the past 12 years. Over 1.5 billion gross tons have run over 100 Rutgers railroad ties at the AAR test track in Pueblo, Colorado and 200,000 Rutgers formulation railroad ties have been in service without incident. Currently there are over 1,250,000 composite plastic lumber ties installed in the U.S.

Table 3 shows the cost benefit per mile taking into consideration disposal costs and installation costs per replacement cycle.

Table 3
Comparison of Railroad Tie Costs

Replacement Cycles	Initial Cost	Cycle 2 Cumulative Cost	Cycle 3 Cumulative Cost	Cycle 4 Cumulative Cost	Cumulative Cost
Thermoplastic Timbers	$465,000	$465,000	$465,000	$465,000	**$465,000**
Wood	$240,000	$480,000	$620,000	$880,000	**$1,120,000**
Concrete	$375,000	$750,000	$1,1250,000	$1,500,000	**$1,875,000**

Costs are based on the cost of new ties, plus cost of installation as follows:

- The cost of plastic, wooden, and concrete ties are $120.00, $45.00, and $75.00 respectively;
- Installation cost of plastic, wooden, and concrete are $35.00, $35.00, and $50.00 respectively;
- 3000 ties per mile are used (disposal costs ignored but plastic assumed to last several cycles of wood or concrete).

Political, Socioeconomic and Environmental Impact

One must also consider the political, socioeconomic, and environmental advantages of Thermoplastic timber. This technology is developed, manufactured and licensed in America.

New Jersey partnered with Rutgers University because the state has 13 times the general population per square mile and produces more waste. "Combining this population density with the highest per capita income in the country, New Jerseyans consume more than their share of materials and produce a huge amount of waste "(16). Thermoplastic timber makes use of consumer and industrial waste. The majority of recyclable plastic still ends up in landfills today; the use of Thermoplastic timber can help to change that statistic.

This technology makes use of waste and excess capacity in existing extrusion factories. Products can be produced at an appropriate extrusion facility near the city of the end user thereby saving transportation costs and creating employment opportunities for the local economy.

American railroads replace 20 million railroad ties a year. This translates to enough ties to build 6,666 miles of track. The railroad industry assumes that it takes 750 old growth hardwood trees to make ties for a mile of track (17). Every year the replacement of railroad ties results in a loss of 5,000,000 trees or 71 square miles of forest. This is a combined area larger than Washington, DC, Northern Virginia, and part of Maryland.

Corrosion costs the DoD over 22 billion dollars *per year* while the cost to the U.S. taxpayer is closer to $300 billion. Building with materials that are going to rot and corrode is a classic case of "fighting a losing battle." To keep initial acquisition costs down, outdated procurement regulations still specify creosote-coated and CCA-coated wood to help fight corrosion. There is literature (18,19) describing the consequences of these poisons going into our soil and water supply, including the following article, "**New Jersey Bans Creosote Treated Wood" TRENTON, New Jersey**, July 17, 2007 (ENS), that states, in part, "New Jersey Governor Jon Corzine Friday signed into a law a bill to prohibit the manufacture, sale, use, and burning of creosote and creosote-treated wood products anywhere in the state…Leakage of creosote from industrial and other hazardous waste sites and seepage from creosote-treated wood have led to the contamination of soil and groundwater of New Jersey… Both chromated copper arsenate and pentachlorophenol are used as wood preservatives in utility poles in place of creosote and there are non-wood alternatives including steel and cement poles…"

There is one quote that sums up the danger inherent in creosote-coated and CCA-coated wood products: "In less than 2 weeks, an average 5 year old playing on a CCA-treated play set would exceed the lifetime cancer risk considered acceptable under [US] federal pesticide law"(20).

Thermoplastic timber will not put poison into our soil or water because there are no carcinogens or added chemicals in the product.

What is saved when building infrastructure such as bridges, marinas, and boardwalks using Thermoplastic timber? The bridge at Ft. Bragg used 86,000 pounds of recycled plastic. According to EPA's online resource (Recon) tool, the energy benefit in terms of gallons of gasoline ***not*** consumed is 22,296.99 gallons for just one bridge. The nonuse of gasoline also equates to 196 metric tons of carbon dioxide (greenhouse gas) not being emitted into the air (21).

CONCLUSIONS

Plastic lumber technology has advanced well beyond theory. Its performance has been proven with successful performance of 200,000 railroad crossties in the field, multiple pedestrian bridges, and vehicular bridges with up to AASHTO HS25 ratings to accommodate both passenger and military vehicles. This paper has described specific examples that demonstrate the advantages of using plastic lumber technology as a preferred replacement for DoD's wood timber bridges. Moreover, it is useful for any project where treated lumber is used, particularly where corrosion and environmental conditions are an issue.

While the current focus has been on short span bridges, this technology is scalable to longer total bridge spans. There is virtually no technical limit to the size of beams and other shapes that may be made and molded from these materials. By increasing the size (moment of inertia) of the I-Beams and other appropriate structural engineering, a bridge could be designed to meet almost any specified vehicular load requirements. The majority of plastic waste being generated in the US is being disposed of in landfills. If a market for these materials is encouraged to develop, more landfill materials will be turned into useful products.

This technology has benefits as a building material for marinas, bulkheads, retaining walls, fender pilings, boardwalks, railroad crossties, and more. The material is also not subject to insect infestation from pests such as marine borers that can attack wood materials in coastal environments. This structural material is made from 100% post consumer and industrial waste providing a low cost solution while simultaneously solving a high cost problem.

Thermoplastic timber offers an environmentally compatible, Green solution for today's infrastructure needs. With the specific strength of steel it can handle the weight of military and vehicular bridge traffic. It is cost competitive on an installed cost basis compared to traditional products like wood, concrete, and steel, and because it is maintenance free, it offers distinct advantages over other composites. Thermoplastic bridges can be constructed more quickly than bridges constructed with traditional materials. Its use keeps recycled plastics out of landfills. As a "Made in America" product, it creates much-needed jobs for today's workforce.

FUTURE OF THERMOPLASTIC TIMBER

Current developments include new I-beams, pilings, board cross-sections, and integrated systems of these components that leverage the inherent strengths of the material. This includes marine fender wall systems that must survive in extremely difficult environments. A key property is overall "toughness" and ability to absorb the energy of an impact. This capability will be used to develop fender wall systems for various marine and coastal installations. This same concept will be applied to highway protection systems such as approach and guardrail applications. Other potential applications could include sheet piles, culverts, and water management systems. Thermoplastic forms can even be used for boat hulls and other products that require molded components.

A composite fire retardant material has also been developed and is currently undergoing final testing. This material has been demonstrated to reduce heat transmission through various media as well as provide ignition mitigation on substrates such as standard building materials (22).

Commercialization and scale-up is key to insure that the highest quality materials are delivered on time at the best possible total cost. Having an optimal supply chain model is essential and the ability to make use of excess capacity in existing extrusion facilities is a plus for the client, community, and vendor.

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