Recycled-Plastic Lumber Standards:
From Waste Plastics to Markets for Plastic Lumber Bridges

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ABSTRACT

This paper presents a case study that illustrates the integral link between standards development work and benefits to the environment. Specifically, diversion of large amounts of post-consumer waste plastics from landfills to useful products involves both development of new technologies and standards that enable the adoption of these products by the marketplace. The paper highlights activities that have been undertaken over the past several years to develop industry-consensus, performance-based standards that enable the market acceptance of recycled-plastic lumber (RPL) in structural applications. The results from these activities have three major benefits to the environment: (1) Reduction of municipal solid wastes being landfilled, (2) providing an alternative to pressure-treated lumber that leaches toxic chemicals into waterfront environments, and (3) substitution of wood in certain specific applications with an environmentally friendly alternative such as RPL.

1.0 INTRODUCTION AND BACKGROUND

1.1 Pollution Prevention and Plastics in Waste Streams

Pollution prevention is an integral part of the management of the nation's municipal solid waste (MSW). Integrated management of MSW involves source reduction; recovery and recycling of materials; composting, if possible; and environmentally sound disposal of waste streams through combustion and/or landfills. Of these alternatives, source reduction and materials recycling are the preferred options.

One significant component of the waste stream is discarded plastic products and packaging, which continues to be a growing portion of the MSW. As detailed in a recent EPA report [1], plastics contribute 22.4 million tons (or 10.2 percent) to the total waste stream with only 5 percent of this total currently recovered. More importantly, due to its low density, the volume of plastics in landfills reaches almost 25 percent of the total volume. And the amount of plastics being discarded annually is not expected to decrease anytime in the foreseeable future.

Over the past decade, local, state, and federal agencies have addressed the recycling of plastic discards to reduce MSW. These efforts have focused on making recycling of plastics both technically feasible and economically viable.

1.2 Overview of Recycled-Plastic Products

The adoption of an identification code by manufacturers of plastic products and packaging has greatly enhanced the recovery, characterization, and sorting of the variety of plastics in the waste stream. Six polymer codes identified numerically as: 1-Polyethyleneterephthalate (PET), 2-High-Density Polyethylene (HDPE), 3-Polyvinyl Chloride (PVC), 4-Low-Density Polyethylene (LDPE), 5-Polypropylene (PP), and 6-Polystyrene (PS) constitute the majority of post-consumer plastics. Other types of plastics fall under Type-7.

Figure 1 shows the various steps in the materials flow diagram for plastics recycling. Considerable work has been conducted in characterizing the quantity and types of plastics in different waste streams, and in evaluating and improving collection methods, separation, and sorting, as well as technologies for processing post-consumer mixed plastics [2-6]. There are two broad categories of recycled-plastics products: resin substitution products and material substitution products. The following summarizes the state of the art in these two categories.

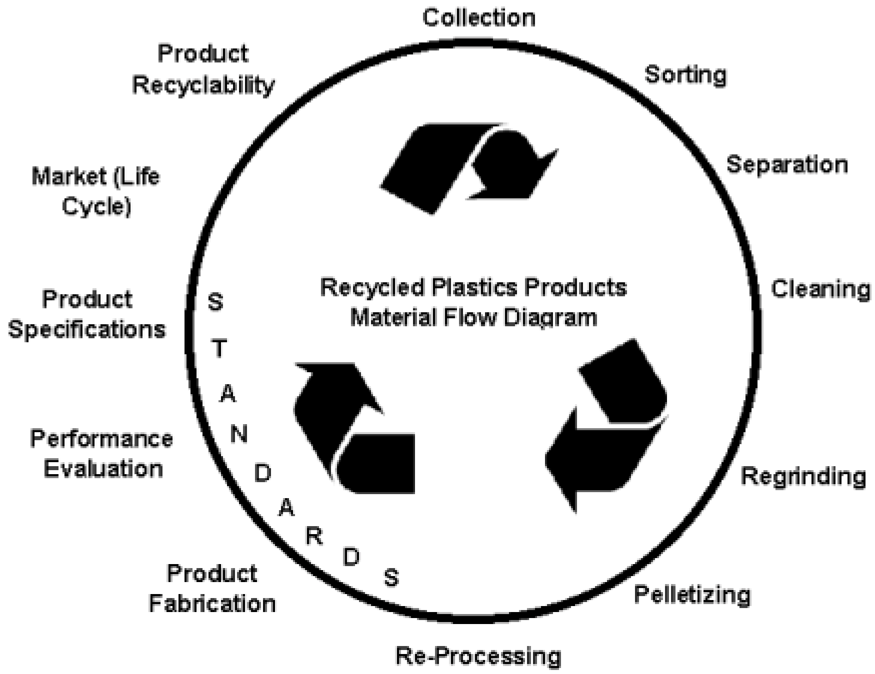

Figure 1 - Material flow diagram for recycling of plastics into products.

Resin substitution products involve applications where the same polymeric product is made by substituting recycled resin for virgin material, either wholly or partly. The technology to ensure product quality and consistency when recycled resin is used is quite advanced, especially in packaging applications. Certain specific additives, ultraviolet-stabilizers, and compatibilizers are added to the feedstock, and some minor modifications in processing parameters are made to ensure both processibility and performance. On a typical material flow diagram (Figure 1), the resin substitution applications have come full circle.

In the second category, post-consumer resins (PCRs) are used as a substitute for the raw materials in products made traditionally from other materials, such as wood, metals, and concrete. One prime example of this application is recycled-plastic lumber (RPL). The manufacture of RPL from post-consumer and post-industrial resins is promising as it *consumes large quantities of waste plastics, that would otherwise be destined to landfills, and converts the waste into useful, durable products*.

Success in the second category of products was limited primarily due to a lack of 'performance-based standards' that would ensure proper and successful use of the material. The lack of standards is a particular barrier for use of RPL by the construction industry, especially for structural applications. This paper highlights some of the major accomplishments in standards and specification developments of RPL over the past few years by the American Society of Testing and Materials (ASTM) under Committee Section D20.20.01 on Plastic Lumber. These standards have contributed significantly to the 40+ percent per year growth rate of the recycled-plastic lumber industry in recent years. As seen in Figure 1, performance based STANDARDS play a critical role after re-processing of the waste plastics.

1.3 State of the Recycled-Plastic Lumber Industry

In the early 1990's, prior to the development of any standards for RPL, a number of small entrepreneurs created the plastic lumber industry in the United States by importing some extrusion technologies from Europe [7-8]. The variation in feedstock materials was significant depending on the source of the PCRs. Therefore, the performance of the RPL varied significantly between lots from the same manufacturer and even more from one manufacturer to another.

The use of PCR in products through material substitution can significantly accelerate the manufacture and use of recycled-plastics products. RPL, if manufactured to a consistent quality with useful properties, can potentially re-use a very high proportion of plastics in the waste stream, thus decreasing the volume of wastes going to landfills.

A few years ago, the total RPL production was approximately 16 million board-feet, which is equivalent to about 40 million pounds of waste plastics. The current annual growth rate for this industry has been around 40 percent. Today it is estimated that the total RPL production is over 300 million pounds or about 120 million board-feet. Assuming a 50 percent recycling rate for all waste plastics, the total production of RPL is estimated to reach 25 billion board feet per year as this industry matures to its full potential [9]. In comparison, the current consumption of softwood lumber is about 34 billion board feet annually. Therefore, the importance of the RPL industry in recycling of plastics cannot be overemphasized.

There are approximately 25 to 30 manufacturers of RPL and related products across North America. Quality control is done primarily by visual checking and sometimes by density measurements. No other properties are measured on the finished product nor are samples from each batch retained for records. Although processing deficiencies, product inconsistency, PCR availability and price volatility, and lack of market penetration have all contributed to RPL's limited use in construction, the most important factor is the absence of standards and specifications. Local, state, and federal agencies that could potentially be large consumers of RPL have been unable to purchase the materials because no established performance-based specifications and procurement guidelines exist.

As a substitute for treated wood, recycled-plastic lumber (RPL) products offer the advantages of being resistant to insects, rot, moisture, and many chemicals. Plus, plastic lumber materials are benign to the environment since they do not need chemical treatments to achieve or maintain their properties.

Although fabricated in typical dimensional sizes, one realizes very quickly when handling RPL products that they have some physical and mechanical properties that are much different than their wood counterparts (on a size-by-size comparison). One of the most obvious differences is the much lower stiffness (modulus of elasticity) of RPL materials. Pines and oak typically have moduli of at least 6.9 x 106 kilopascals (1 million pounds per square inch). Unreinforced RPL typically exhibit moduli at least an order of magnitude lower than that.

RPL is also viscoelastic in terms of its mechanical properties. This means that the mechanical properties are time-temperature dependent and subject to permanent deformation (creep) under sustained loads. The rate of creep depends on the magnitude of the stress, the duration of the stress, and the temperature at which the stress is applied. Furthermore, dimensional changes due to temperature are greater in RPL than in wood. (Wood experiences similar dimensional dependence but more as a result from the uptake and release of water.)

Initial applications of RPL were typically for picnic tables, park benches, trash receptacle covers, and other non-critical load bearing outdoor applications. Some of the earliest product designs performed well initially but then 'sagged' due to creep. The use of RPL as a decking over a treated wood substrate also gained popularity. Due to the lesser stiffness of the RPL decking boards and its propensity to creep under its own weight, if the span was too great, joist spacings were decreased and/or thicker deck boards were used (as compared to those used if the decking was made from natural wood). As the plastic lumber industry was struggling to make its way, the use of RPL in outdoor structures such as decks, boardwalks, and docks was seen as a major opportunity. RPL picnic tables and park benches are considered worthwhile, but the demand is just not great enough to divert any significant quantities of waste plastics from landfills.

2.0 RPL STANDARDS DEVELOPMENT

While knowledge of the engineering mechanical properties of RPL materials is important for something as simple as a picnic table, this knowledge is particularly important in order to gain common use of these materials in construction applications. Being able to accurately measure the bending stiffness of the boards, determine creep properties and thermal expansion behavior, and other mechanical properties, are required for the design of effective and efficient structures. Safety and liability are also a part of engineering design. The lack of industry consensus standards and specifications for RPL was viewed as a major barrier to increased use of these materials by the construction industry.

Initially RPL manufacturers specified existing test methods developed for neat plastic resins to measure such properties as compressive strength and modulus and flexural strength and modulus. However, materials researchers quickly realized that there was a shortcoming using these existing test methods for RPL. These methods specify coupon-sized specimens that are either molded or cut from the bulk sample material. This works well for thin-section, homogeneous materials such as plastic sheets or rods. However, RPL materials have thick cross-sections [typically greater than 19 millimeters (3/4 inch)] that are not homogeneous. RPL made from commingled (mixed) plastics may contain material inclusions and impurities. Even if made from 100% virgin polymer, the thermodynamics of processing leads to a non-homogeneous cross-section with a density gradient that is higher at the outer surfaces and lower in the center.

The existing test methods for plastic materials are not applicable to RPL materials with non-homogeneous cross-sections. The results could vary significantly depending on where within the cross-section the specimen coupon is prepared. If taken from the outer surface, the results could be greater than the bulk, and if taken from the center, the results could be significantly less than the bulk product. The solution was to test the material in its original, as manufactured state (at least, relative to the original cross-section).

In July 1993, a new American Society of Testing and Materials (ASTM) Committee Section, D20.20.01, Plastic Lumber, was formed to develop the needed test methods and specifications for plastic lumber materials. The nucleus of this group was comprised of academic and government researchers, private sector engineers, non-profit research organizations, and plastic lumber manufacturing representatives, all who had been working cooperatively to further the commercialization and applications of RPL materials [10-12]. The newly formed Plastic Lumber Trade Association (PLTA) coordinated its meetings with the ASTM D-20 meetings to maximize the interaction of the Association membership with the standards development activities of the ASTM Plastic Lumber committee. This cooperative spirit has led to work with a focus on developing test methods, specifications, and building code acceptance criteria. Each of these is detailed next.

2.1 Test Methods

The ASTM D-20 activities in recycled-plastic lumber and shapes have led to the establishment of seven test methods to date. These include:

- D 6108 Standard Test Method for Compressive Properties of Plastic Lumber and Shapes,
- D 6109 Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastic Lumber,
- D 6111 Standard Test Method for Bulk Density and Specific Gravity of Plastic Lumber and Shapes by Displacement,
- D 6112 Standard Test Method for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes,
- D 6117 Standard Test Methods for Mechanical Fasteners in Plastic Lumber and Shapes,
- D 6341 Standard Test Method for Determination of the Linear Coefficient of Thermal Expansion of Plastic Lumber and Plastic Lumber Shapes Between -30 and 140°F (-34.4 and 60°C), and
- D 6435 Standard Test Method for Shear Properties of Plastic Lumber and Plastic Lumber Shapes.

Given the differences between RPL and wood lumber, and the fact that it is non-uniform in its cross-section, the development of the above test methods was a quintessential first step before developing any specification that may be used for purchasing. These test methods took almost 4 years and were published in 1997.

2.2 RPL Specifications

Simultaneously with the development of test methods, ASTM D-20 also undertook the development of purchasing and distribution specifications for RPL. For each end application of RPL in structures, such as decking board, joists, marine fender piles, pallets, etc. a separate specification needed to be developed per the end-use and performance requirements. Since residential decking boards from RPL promised to be the most significant market, the first of these specifications was targeted toward this market. ASTM D 6662-01 Standard Specification for Polyolefin-Based Plastic Lumber Decking Boards was completed and published in March of 2001. As is done for plastic piping for water, gas, and sewer applications, manufacturers can now use an 'ASTM stamp' on plastic lumber decking boards that meet the specifications.

In the development of D 6662-01 several major issues concerning the use of RPL in decking boards were resolved. These included the following:

Dimensional Tolerances: Acceptable tolerance for dimensional RPL was not available. Tolerance limits that would meet industry requirements and performance consideration were developed.

Creep: The most significant difference between wooden lumber and RPL is sensitivity to elevated temperature. As stated earlier, the viscoelastic nature of RPL makes it susceptible to creep at sustained loads at elevated temperatures. A methodology was developed to use creep data per ASTM D 6112 to define design limits to avoid excessive deflection and creep in the decking boards.

Flammability: The question of plastic lumber's ignitability properties was also addressed. The fire test method described uses a small ignition source, which is appropriate for expected sources on a deck such as hot charcoal briquettes from a tipped over barbecue grill.

Allowable Material Properties for Structural Design: A complete methodology is presented in the standard to determine allowable maximum span lengths for decking boards based on the material properties determined from the test methods listed above. This is analogous to having a design guide or a handbook that is available for other construction materials such as steel, wood, or concrete.

Outdoor Weathering and UV Exposure: Another key factor unique to outdoor applications of plastics is degradation due to exposure to ultraviolet radiation during outdoor weathering. A key finding during the development of this specification was that the mechanical properties did NOT degrade for RPL even though there is surface discoloration of the material. RPL decking boards that were installed in a demonstration project in 1989, and for which original properties were available, were removed from service and tested in 2000 after 11 years. The flexural modulus and strength showed no degradation whatsoever.

Slip Resistance: To date, no in-depth studies have been done to compare the slip resistance or coefficient of friction between wood and plastic lumber. ASTM test methods exist for various materials but the results can vary greatly, depending on factors such as the type of shoe sole material used in the test (e.g., leather vs. rubber) and whether the test sample is wet and/or rough. There are no known instances of personal injury due to excessively slippery plastic lumber surfaces. However, the ASTM Plastic Lumber committee recognizes the concern and is continuing to study the issue.

ASTM D-20 still has on-going activities for developing other standards and specifications for RPL. Nine draft standards that are under development at various stages of balloting within the organization include (by project # and title):

- X-20-28 Guide for Testing of Plastic Lumber,
- X-20-30 Guide for Plastic Decking Construction,
- X-20-31 Specification for Plastic Lumber,
- X-20-41 Flexural Properties of Marine Piles,

- X-20-43 Specification for Plastic Lumber Joists and Beams,
- X-20-44 Engineered PVC Decking Boards,
- X-20-48 Radial Compression of Fender Piles,
- X-20-49 Plastic Lumber for Bulkhead Systems, and
- X-20-51 Plastic Marine Fendering Systems.

2.3 Building Code Activities

Once test methods and specifications for RPL were developed, the final step in the standards development process was to incorporate them into acceptance criteria for new materials in the three major building codes in the United States. The PLTA and individual RPL manufacturers have approached the Building Official Code Administrators (BOCA); the International Conference of Building Officials (ICBO); and the Southern Building Code Congress International (SBCCI). To date, the standards activities within ASTM have led to the acceptance of several RPL products for decking board applications by ICBO and BOCA.

3.0 DEMONSTRATION PROJECTS

Another key aspect of developing standards to promote the use of RPL in structures consisted of conducting several demonstration projects with increasing degrees of complexity and sophistication. The two main objectives of these projects were to demonstrate successful use of RPL and to derive information and data that enhances the standards activities.

To this end, five projects have been undertaken:

- Decking boards in a boardwalk at Kelleys Island on Lake Erie, Ohio,
- Bridge at Fort Leonard Wood, Missouri,
- Floating docks for the Op Sail 2000 event in New York City, New York,
- Elevated platforms at the bob-sled and luge track, Lake Placid, New York, and
- An arched truss bridge near Albany, New York.

Some unique features of each project are highlighted next.

3.1 Boardwalk at Kelleys Island

To educate the public on the uses of recycled materials and at the same time test plastic lumber in an extreme environment, construction of a 600-foot long boardwalk in a wetlands area was selected as a demonstration project. The boardwalk is located at the North Pond area of Kelleys Island in Lake Erie, Ohio. This area is owned by the State of Ohio and provides wonderful habitat for birds and waterfowl among other fauna and flora. It is a major resting area for migratory birds, many of which, otherwise, we would never observe. Before construction of this boardwalk, there was no access into the marshland and to the lakeshore. The boardwalk provides public access to this area and is a perfect application to highlight the durability and rot resistance of the recycled-plastic lumber in a wet environment. This area will experience wet and damp conditions, extreme temperature changes from summertime 90°F plus to winter's subzero, and heavy snowfalls and ice heaves. Figure 2 shows the completed boardwalk. Since this was one of the first demonstration projects, the substructural joist system was made of wood (see Figure 3). Plastic lumber from six different manufacturers was used for the decking boards over this wood frame. The boardwalk was constructed using volunteer labor in coordination with the Ohio Department of Natural Resources staff.

Figure 2 - RPL boardwalk at Kelleys Island, Ohio.

Figure 3 -Wooden substructure for Kelleys Island RPL boardwalk.

3.2 Bridge at Fort Leonard Wood, Missouri

With the help of funding from the USEPA, plans for a plastic lumber bridge were developed to demonstrate the structural capabilities of plastic lumber. An existing wood timber bridge at Fort Leonard Wood, Missouri, was selected to demonstrate the structural applications of plastic lumber. The 25-foot long by 26-1/2 foot-wide plastic lumber bridge sits on 6 steel girders that had supported the original wooden bridge. Although the bridge is now used primarily for pedestrian traffic, the original wood bridge was designed for light vehicular traffic. The replacement plastic lumber bridge was also designed to carry vehicular loads. Figure 4 shows an Army Humvee crossing the plastic lumber bridge.

A typical treated wood bridge structure at Fort Leonard Wood would need to be replaced every 15 years, with biannual inspections and maintenance to replace deteriorated boards and loose fasteners. The plastic lumber bridge is expected to last 50 years with minimal maintenance. While the plastic lumber materials cost more than double what they would for a treated wood bridge, a lifecycle cost analysis showed the plastic lumber bridge would begin to pay for itself in less than 8 years. An added benefit is the fact that the plastic lumber bridge used 13,000 pounds of waste plastics (equivalent to approximately 78,000 1-gallon, high-density polyethylene milk jugs and 335,000 8-oz polystyrene foam coffee cups) that had otherwise been destined for landfilling. The bridge will not require application of protective coatings or preservatives that can emit environmentally damaging volatile organic compounds into the atmosphere.

Figure 4 - RPL pedestrian and vehicular bridge at Fort Leonard Wood, Missouri.

3.3 Floating Docks at Op Sail 2000

One of the principal markets for RPL would be in marine and waterfront applications, where chromium copper arsenate (CCA)-treated lumber poses an environmental hazard. Therefore, a demonstration project was undertaken to show the viability of RPL for floating docks during the Op Sail event with tall ships in New York Harbor in July 2000. Seven docks were built as shown in Figure 5. These docks were successfully deployed and used during the event and then donated to public boat clubs in New York City. The performance of these docks has been monitored and to date they have all been working successfully.

Figure 5 - Floating docks at Op Sail 2000 in New York City.

3.4 RPL Platform at Lake Placid, New York

In the winter of 2000, the platforms leading up to the start and the end of the bobsled and luge track at Lake Placid, New York, were being renovated for the Goodwill Games. In a project coordinated with the Environmental Investment Management Group of New York's Department of Economic Development, RPL platforms were designed and installed in weather that reached lows of -40°F in time for the start of the games. This was the first major project in which reinforced structural plastic lumber was used in joists, beams, girders, and decking boards. Figure 6 shows one of these platforms. Since being constructed in February of 2000, the RPL platform has performed very successfully and has not had problems with temperature swings from -40°F to 90°F. The gaps between adjacent decking boards that were left during installation to account for thermal expansion and contraction have not changed at all. No creep or permanent deformation of the material has occurred anywhere in the reinforced RPL structure.

The initial success of RPL at Lake Placid has prompted the department to use the material for all other platforms at the bob-sled and luge track including a 10-ft x 10-ft platform at the end of the run made exclusively from reinforced RPL. This particular platform is being tested for creep under sustained loading. Sandbags that result in a 100 lbs-per-square-foot loading have been placed on this deck for a year; the results will be used to further enhance the standards for structural RPL designs by ASTM.

Figure 6 - RPL platform at the start of the bob-sled and luge track in Lake Placid, New York.

3.5 Arch Truss Bridge in Albany, New York

One way that wooden structures are designed involves 'laminated beams' where smaller dimensional lumber such as 2x6's or 2x8's are used to make 'built-up' beams. This results in a more efficient and cost-effective use of materials. Therefore, a 30-foot span bridge was used as a demonstration project to investigate if structural reinforced RPL may be used to construct laminated beams. Figure 7 shows a picture of the structural RPL beams that consumed approximately 60,000 discarded milk jugs. The arched top chord of the bridge consists of laminated 2x8 curved members while the bottom chord is a standard dimensional 8x8 reinforced RPL. Although the bridge only needed to be designed for H-10 (10 ton) emergency vehicular loading, it was designed and tested for H-15 loading (15 tons or 30,000 lbs). As seen in Figure 7, a fully loaded dump truck weighing almost 32,000 lbs was used for testing the bridge. The maximum deflection was only 1.2 inches, which is more than acceptable for such structures. The data from testing the bridge four times over a 1-year period to investigate the effect of temperature will be used again to develop further standards for structural RPL designs.

Figure 7 - RPL arch truss bridge near Albany, New York.

4.0 CONCLUSIONS

RPL has come a great distance from the novelty material applauded by environmentalists but largely ignored by the construction industry. The new ASTM standards have played a critical role in pushing RPL materials to the marketplace. As the international focus begins to shift more and more toward a sustainable environment, RPL product use is destined for increased growth. With increased understanding of the material's performance through standard test methods and specifications and the construction industry's growing comfort with its use, RPL will one day be an integral part of the built environment.

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Acknowledgements

The authors would like to give special acknowledgement to the following individuals and organizations for their valuable contributions over the years towards this effort: Ms. Kathie Morgan, Staff Manager of D-20 Plastics at ASTM, Mr. Alan Robbins and the manufacturing members of the Plastic Lumber Trade Association (PLTA), Mr. Peter Dinger at the American Plastics Council (APC), Ms. Donna Stusek of the Ohio Department of Natural Resources (ODNR), Mr. Keith Lashway of New York State Department of Economic Department, Ms. Dana Arnold of the US-EPA's Office of Solid Waste, Dr. Jim Kennedy at Battelle-Columbus, Mr. Malcolm McLaren of MG McLaren Engineering, Professor Tom Nosker of Rutgers University, Professor Vijaya Gopu of University of Alabama at Huntsville, and Professor Roger Seals of Louisiana State University. Standards development is a "team" effort and thanks must also be given to the many other ASTM D-20 Committee members, past and present, for their time and effort over the last several years to make these standards for recycled plastic lumber a reality.