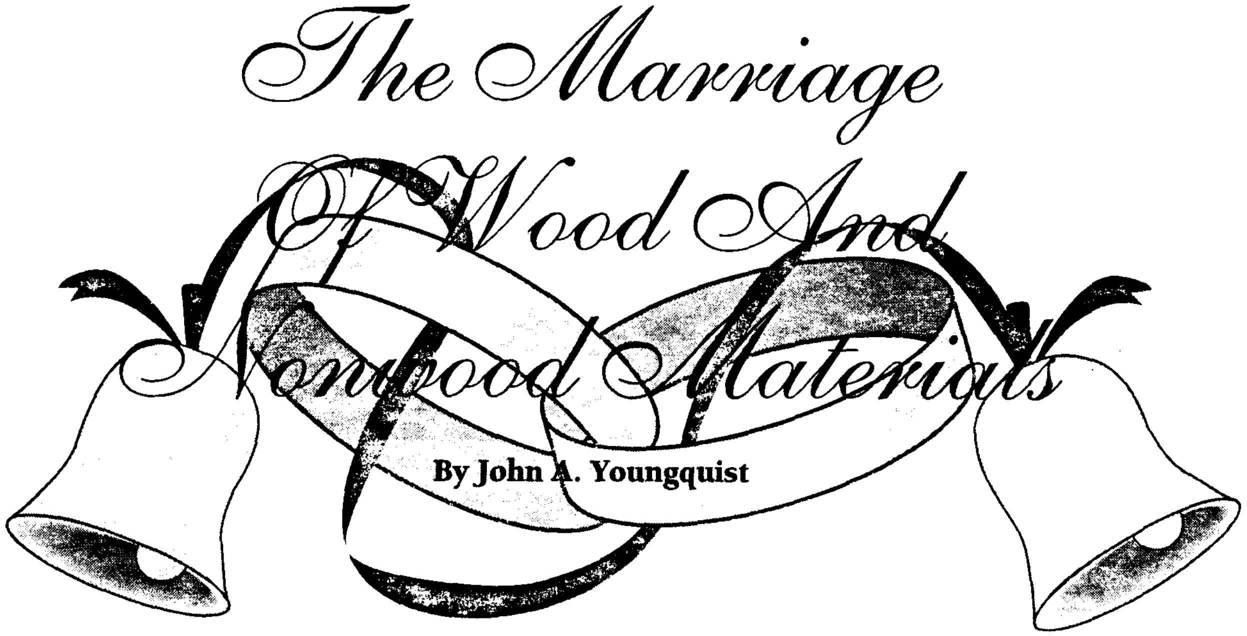
# UNLIKELY PARTNERS?

## The Marriage Of Wood And Nonwood Materials



By John A. Youngquist

COMBINE WOOD WITH PLASTIC? THAT'S IMPOSSIBLE. IT WILL NEVER WORK. OR WILL IT?

The 1990s have witnessed a burgeoning interest in the development of industrial and consumer products that combine wood and other raw materials, such as plastics, gypsum, or concrete, to form composite products with unique properties and cost benefits. The primary impetus for developing these products has come from one or more of the following R&D goals: 1) to reduce material costs by combining a lower cost material (acting as a filler or extender) with a high-cost material; 2) to develop products that can utilize recycled materials and have the products themselves be recyclable; or 3) to produce a composite product that exhibits specific properties that are superior compared to either of the component materials alone (e. g., increased strength-to-weight ratio, improved abrasion resistance, etc.).

Dramatic property modifications can be achieved with wood when it is reduced in size and reassembled to produce many man-made, wood-based composites. Paper, plywood, hardboard, and particleboard are just a few examples of conventional composite products. This feature looks at a number of "non-conventional" composites that combine wood fibers, particles, flakes, or lumber with other materials like plastics, cement, and gypsum. These combinations create enormous opportunities to match product performance to end-use requirements.

*The author is a Project Leader,* USDA *Forest Serv., Forest Products Laboratory, One Gifford Pinchot Dr., Madison, Wis.* 53705-2398.

### WOODFIBER/PLASTIC COMPOSITES

In 1993, 848 million pounds of reinforced thermoplastics were consumed in the U.S. market. Reinforcing materials are used to increase the stiffness and strength of the thermoplastics. Most reinforced thermoplastic composites use nonrenewable reinforcing fillers such as fiberglass or minerals. In recent years, the USDA Forest Service, Forest Products Laboratory (FPL) has developed a substantial database that indicates that thermoplastic composites made using post-consumer waste paper or waste wood fiber as a reinforcing filler have positive, and very useful, attributes. These materials have the advantage of being renewable, inexpensive, lightweight, and nonabrasive to processing equipment.

It is possible to assemble a wide variety of wood fibers and synthetic plastic fibers into a random web or mat using air-formed web technology. This technology involves mixing, at room temperature, lignocellulosic fibers or fiber bundles with other long fibrous materials. This process can accommodate a wide range of wood-based and synthetic fibers and can be used to produce a variety of products of varying densities,

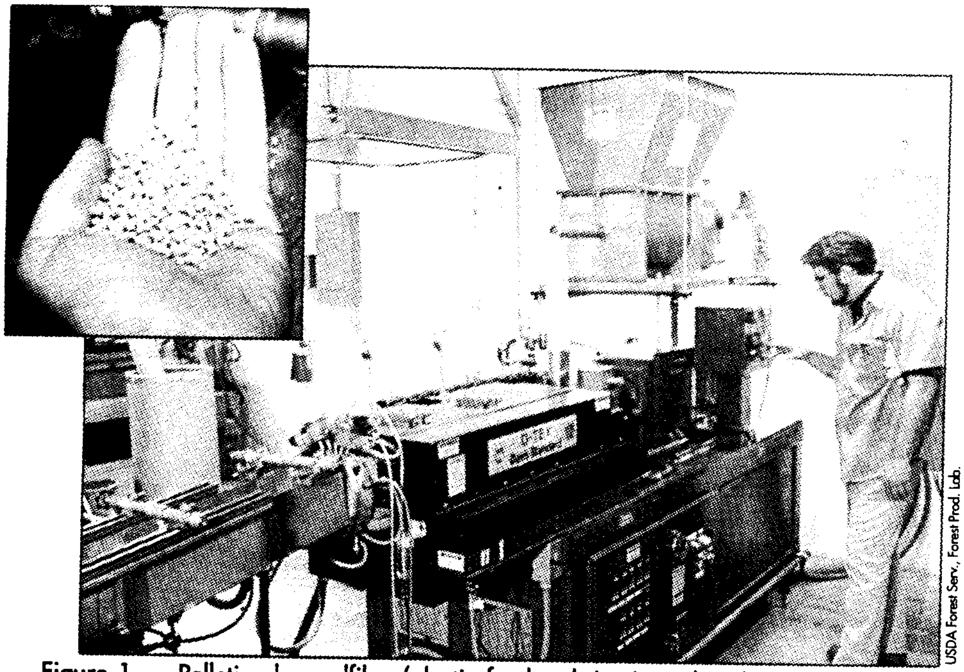


Figure 1. – Pelletized woodfiber/plastic feedstock (top) produced by the twin-screw extruder (bottom) can be used in conventional plastic feeding systems.

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Wood fibers can also be combined with plastics such as polyethylene, polypropylene, and comingled thermoplastics using melt-blending technology, which is an inherently low-cost, high-production rate process in which wood and paper are mixed with molten plastic. These blends can then be formed into products using conventional plastics processing techniques such as extrusion or injection molding. The plastic acts as a means to convey the wood/paper during processing and the wood/paper fiber bears the load in the final composite, offering an effective balance between processability and strength of the end product.

## CURRENT ISSUES

Perhaps the most significant factor currently limiting broader use of woodfiber/plastic composites is one of familiarity. The plastics industry knows little about the wood industry and vice versa. There is almost no overlap in material suppliers, equipment manufacturers, or processing technology. This situation is further exacerbated by the fact that the materials often compete for the same market share. The introduction of slats made from recycled plastic instead of wood on some models of Weber® gas grills is a recent case in point.

One of the current challenges is to overcome this problem of unfamiliarity. Many plastics manufacturers who have tried using wood fillers have been frustrated, The failure of these manufacturers to process wood-filled materials can almost always be traced to a lack of understanding of wood's hygroscopicity and thermal sensitivity. These manufacturing difficulties have been addressed in a recent project undertaken by the FPL. The project seeks to encourage the use of recycled materials as a reinforcing filler in plastic products by finding ways to overcome the processing problems associated with material feeding and compounding.

To facilitate feeding, plastic product manufacturers typically use a pelletized feedstock. These pellets are about 1/8 to 3/16 inch in diameter with a bulk density of around 30 to 35 pcf. The pellets flow easily by gravity, air-veying, or augers. Feed rates are easy to accurately control and monitor. Feed systems range from simple hoppers for feeding a single material to sophisticated computer-controlled systems for accurately and simultaneously feeding multiple materials.

Wood fibers, particularly paper fibers, do not feed well in these systems. The bulk density of dry paper fiber may be as low as 1 to 2 pcf. Fibers also interlock and entangle, In short, they are unsatisfactory for use in conventional plastic feeding systems. Crammer style feeders can be used, but they are expensive and throughput can be low, Wood flour fares better because of its more granular nature and higher bulk density, and will work in many systems.

Alternative ways to feed the paper have been developed, Densifying fully fiberized paper in a pellet mill results in a feedstock with a bulk density of about 15 pcf. Cutting the paper into small platelets is another strategy and results in a flowable feedstock with a bulk density of around 19 pcf.

The FPL is using these specially prepared paper fibers and/or wood flour to feed a twin-screw extruder to blend, or compound, the wood and plastic, The twin-screw extruder, supplied to the lab under a special arrangement by the Davis Standard Corporation (pawcatuck, Conn.), intimately disperses and distributes the. individual fibers throughout the plastic matrix, The compounded composite mate-

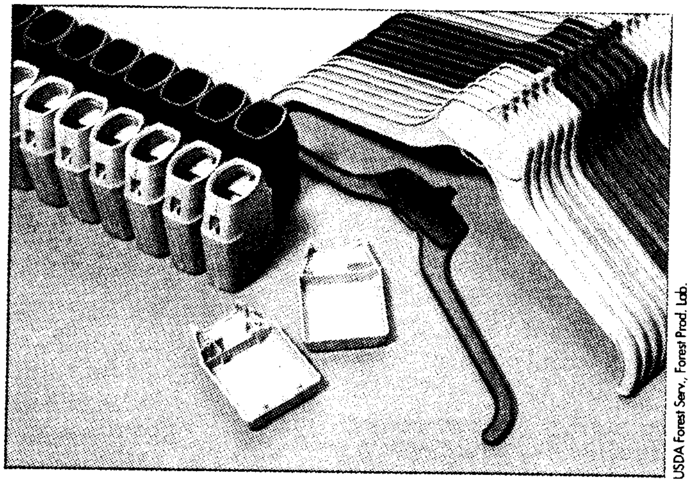

Figure 2.- These flashlight cases and hangers are examples of products made from woodfiber/plastic pelletized feedstock.

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rial is then extruded into strands and cut into pellets in a rotary pelletizer **(Fig. 1).**

The pelletized feedstock can be made into a variety of injection molding and extrusion grades. For this research, the FPL is using polypropylene or polyethylene. Other polymers can be used as well, polystyrene and polyvinyl chloride (PVC) are both viable options. For all practical purposes, the pelletized feedstock produced by the twin-screw extruder is identical in physical configuration to the plastic pellets typically used, and are readily used in any conventional feeding system.

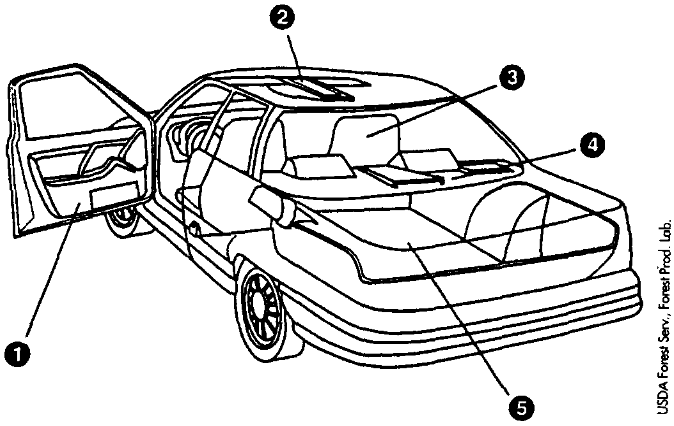

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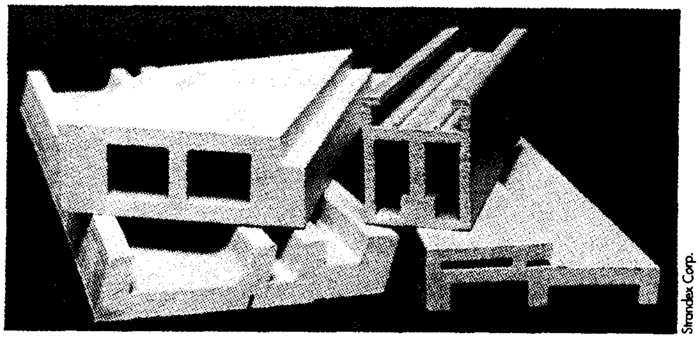
**Figure 3.- Woodfiber/Plastic composites are used extensively in the automobile industry as a substrate far interior door panels (1), roof headliners (2), seat backs (3), rear decks (4), and trunkliners (5). vinyl, carpeting, and other coverings are applied over the substrate.**

After evaluation by a core group of cooperators, these pellets will be made available to plastic product manufacturers to produce a wide variety of products **(Fig. 2).** The ultimate goal of the research is to have compounded woodfiber/plastic composite materials available as a commodity feedstock to the plastics industry. This project involves 15 industrial cooperators and is partially funded by the State of Wisconsin Department of Natural Resources.

## APPLICATIONS

Automotive applications. — Most people don’t know it, but there may be 20 to 30 pounds of wood in their car. It is behind the vinyl and carpeting on the doors, consoles, headliners, trunkliners, and seat backs **(Fig. 3).** The composite is used as a substrate, and vinyl, carpeting, weatherstripping, and other components are added later.

A woodfiber/plastic composite falling into this product category is made by Automotive Industries at their Sheboygan Substrates division (Sheboygan, Wis), This composite material is 50 percent wood flour and 50 percent polypropylene, with some small amounts of other performance-enhancing additives. The wood and plastic are blended together using a compounding twin-screw extruder and extruded into a flat sheet. The flat sheet is then post-formed into the substrate shape. The advantage of this system is that overlays can be applied directly in the forming die. Industry-wide, about 142 million pounds of these materials are made each year.



Strandex Corp.

**Figure 4.- High wood content (typically 70%) woodfiber/plastic products such as these threshold, door rail, and window profiles can be clad with vinyl or used in combination with extruded aluminum profiles**

Exterior construction. — Woodfiber/plastic composites for exterior construction applications are typically made to standard lumber profile cross section dimensions. Two of the products sold in this category, one by Advance Environmental Recycling Technologies (AERT) and the other by Mobil Chemical Company, consist of approximately 50 to 55 percent wood fiber (by weight) and the remainder either high- or low-density polyethylene. Both companies claim their product is practically maintenance free and very durable in exposed environments,

These products are not intended for primary structures. They are used as deck surface boards, landscape timbers (see front cover photo), dock surfaces, picnic tables, industrial flooring, and the like. Because their stiffness is less than that of solid wood, many manufacturers recommend that joist spacing for decks and docks be changed. Typically, the recommended spacing is 12 to 16 inches. Mobil says that 5/4-inch Trex boards are sufficient for residential applications, but nominal 2-inch (1.5 -in.) profiles are recommended for commercial applications. Most manufacturers also recommend that the composite be gapped on both the edges and ends to allow for thermal expansion, unlike solid wood, which is gapped only on the edge to allow for moisture-related expansion.

Weyerhaeuser Company has recently begun distributing the AERT material. It has been used by General Motors as flooring blocks around heavy equipment. These flooring blocks replace creosote-treated oak, and are quite effective in absorbing shock. Other than joist spacing and gapping for expansion, construction practices for this class of materials are much the same as those for solid wood. The composite can be nailed, attached with screws, and sawn with conventional tools. The composites also readily accept paint and stain.

The first generation of these materials did not always fare well in the market. For example, several exterior structures made with early iterations of this class of materials failed. Although the information is mostly anecdotal, it appears that the failures were caused by lack of proper UV stabilization of the plastic component. When the plastic degraded, the unprotected wood became exposed, making it subject to the effects of the environment, In response to these failures, UV stabilization additive technology was improved. Manufacturing practices were also improved, and variation in raw materials, sometimes difficult with recycled materials, was brought under control.

People buy these materials for several reasons. Some are attracted by the claims of low maintenance. others like the recycled content and appreciate that no preservatives are used.

Window and door applications, — Many window and door manufacturers are looking seriously at woodfiber/plastic composites as an alternative to solid wood in clad components. Clear ponderosa pine, a traditional material for these applications, is becoming increasingly scarce and expensive and the pine that is available demands extensive cutting, edge gluing, and finger jointing to get sufficiently clear sections for window and door fabrication. The glued-up material must then be further milled to the correct cross section used in the assembly. This increases costs and the quantity of waste wood generated.

The first composite entries into this application were rectangular lumber-type profiles. To be used as complex profiles for window and door components, the rectangular profile needs to be machined to the correct cross section. This is accomplished using standard millwork operations, just like those used for solid wood. This process is less wasteful than solid wood mill work operations because the shavings can be recycled directly back into product. While still viable, this technology does not exploit the composite's ability to be made to the correct net shape.

*TABLE 1. — Small, clear specimen property comparison.*

| | Specific gravity | Average modulus of rupture | Average modulus of elasticity |
|---|---|---|---|
| | | ------------- (MPa) ------------- | |
| Polyolefins | 0.92 to 0.96 | 8 to 50 | 200 to 2,000 |
| Wood-plastic composite | 0.95 to 1.10 | 30 to 100 | 3,000 to 6,000 |
| Southern pine/Douglas-fir | 0.50 | 85 to 98 | 13,000+ |

(Source: English, B.W. and R.H. Falk. 1995. Factors that affect the application of woodfiber-plastic composites. *In*: Proc. of the 1995 Woodfiber-Plastic Composite Conference. Forest Products Society, Madison, Wis. (in press).

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*TABLE 2. — Large profile property comparison.*

| | Specific gravity | Average modulus of rupture | Average modulus of elasticity |
|---|---|---|---|
| | | ------------- (MPa) ------------- | |
| Plastic lumber profile | 0.70 to 0.95 | --[a] | 300 to 1,400 |
| Wood-plastic lumber profile | 0.95 to 1.10 | 11 to 28 | 1,400 to 4,000 |
| Southern pine/Douglas-fir | 0.50 | 41 | 11,000+ |

[a] Excessive deflections often preclude failure.

(Source: English, B.W. and R.H. Falk. 1995 Factors that affect the application of woodfiber-plastic composites. *In*: Proc. of the 1995 Woodfiber-Plastic Composite Conference. Forest Products Society, Madison, Wis. (in press).

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*TABLE 3. — Effect of selected coupling agents on woodfiber/plastic composites.*

| Percent change in variable | Percent change in flexural properties[a] | | Percent change in Izod impact[a] | |
|---|---|---|---|---|
| | Modulus of rupture | Modulus of elasticity | Notched | Unnotched |
| 0 to 3% E43[b] | +31 | +16 | <10 | +31 |
| 0 to 3 % G3002[b] | +62 | +22 | +21 | +116 |

[a] Percent change based on average values from injection molded specimens.

[b] E43 and G3002 are MAPP products of the Eastman Chemical Co.

(Source: G.E. Myers and C.M. Clemons. 1993. Wastepaper fiber in plastic composites made by melt blending: demonstration of commerical feasibility. )

An example of true net shape forming was developed by Strandex Corporation **(Fig. 4).** This proprietary system uses modified plastics technology to make a high wood content composite (typically 70%) to tolerances of + or – .001 inch. Profiles made to this tolerance can go directly to vinyl cladding operations, and can be used with other precision components, such as extruded aluminum profiles. The Strandex product can also be stained or painted,

The Andersen Corporation integrates woodfiber/plastic composites into their products and manufacturing by utilizing their own in-plant waste. Unlike other manufacturers that use polyethylene, Andersen uses the waste PVC generated in their cladding operations as a polymer base for their composites. Typically formulated from 60 percent PVC and 40 percent wood waste, the profiles are currently being used as sills with aluminum cladding. The composite material's thermal coefficient of expansion is almost the same as that of aluminum,

## FUTURE ISSUES

In order for the market share for these materials to increase, performance will have to improve and better ways to use them will have to be devised. Material science issues such as the inherent incompatibility of wood fiber and thermoplastics will need to be investigated, This incompatibility prevents efficient transfer of stress to the load-bearing fiber and results in composite performance that is much lower than what is potentially achievable.

When comparing the engineering properties of plastics or woodfiber/plastic composites to solid-lumber products, it is important to compare similar-sized specimens. Wood is generally tested as either a small, clear specimen or as full-size lumber. Because small, clear specimens do not contain the defects (e.g., knots, slope of grain) found in full-size lumber, they generally exhibit strength levels greater than full-size lumber. As shown in **Table 1,** small, clear specimens of southern pine or Douglas-fir (common construction species) exhibit both strength and stiffness levels that are considerably greater than that of plastics (polyolefins) or a woodfiber/plastic composite. But if full-size lumber profiles are compared, the differences in these properties are not as great **(Table 2).**

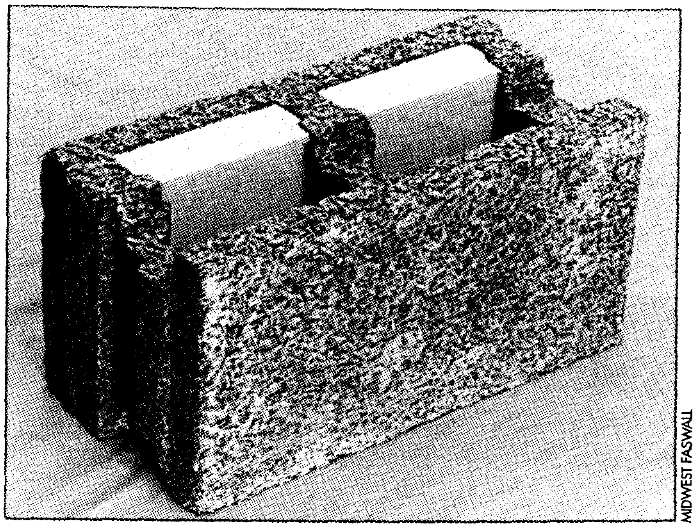

MIDWEST FASWALL

**Figure 5.- FASWALL. forms are filled with reinforced concrete and remain a permanent part of the wall.**

The wood filler increases the stiffness of the plastic but decreases the impact strength of the composite. The addition of coupling agents and compatabilizers helps improve the inherently poor bonding between the hydrophilic wood filler and the hydrophobic polymer matrix and can help recover some of the impact strength. Most of the research in this area has focused on maleated polypropylene (MAPP) and maleated polyethylene. Some results of the addition of two types of MAPP to a wood flour/polypropylene system are shown in **Table 3.**

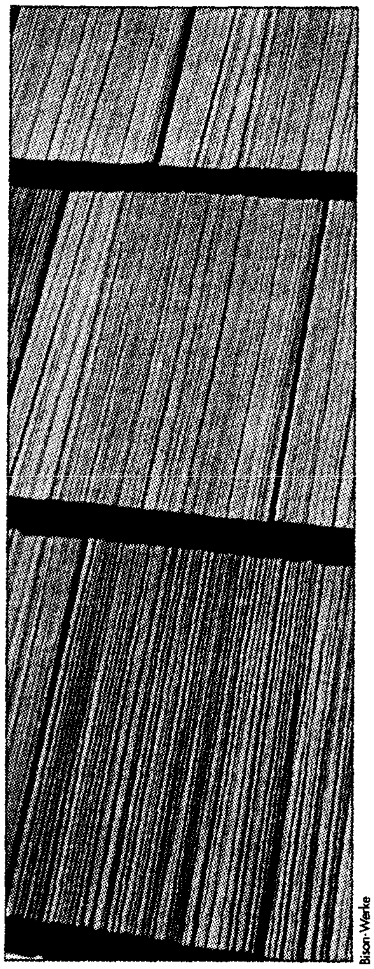

Bison-Werke

**Figure 6.- Demand by regulators and consumers for more durable and fire-resistant roofing materials has led to the development of cement-bonded wood fiber shakes.**

Impact performance is not significant in many applications, however, objects propelled by high winds into a structure could cause serious damage if the woodfiber/plastic composite building element failed. Use in transportation structures may also be limited by low impact values.

Impact resistance, fire performance, and UV degradation are concerns that may limit the use of woodfiber/plastic composites, but additive technology (compatibilizers, fire retardants, impact modifiers, UV stabilizers) may be used to overcome these problems.

The use of woodfiber/plastic composites in building products provides an opportunity to depart from conventional frame and panel building systems. Because thermoplastics are used, a variety of molded products can be developed to provide material efficiency as well as new opportunities in architectural design. As performance is increased, true structural applications may be developed,

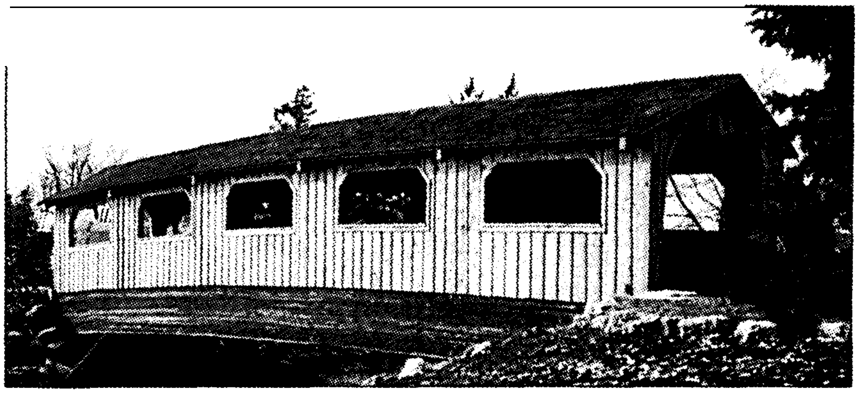
For construction purposes, uniform standards must be adopted to handle the wide compositional ranges possible with woodfiber/plastic composites. Key properties such as creep, fire performance, dimensional stability, and durability need to be fully investigated and compared with construction standards. In response to this need, the American Society for Testing and Materials (ASTM) already has a committee on woodfiber/plastic composite lumber-type profiles, and another committee on plastic lumber profiles.

Woodfiber/plastic composites can be used to fill a performance gap between unfilled thermoplastics and solid wood or other conventional wood composites. These products have several advantages, They can be made to net shape with very little waste, and because of the thermoplastic content, any waste generated is recyclable back into product. The products themselves are also very recyclable. Automotive market share appears relatively stable, but market share in construction will certainly grow, as long as clear solid wood continues to increase in price and scarcity, and preservative treatments continue to be scrutinized. Other markets will certainly follow, including packaging and household goods.

## WOOD/INORGANIC BONDED COMPOSITES

Timber-restricted countries have utilized inorganic local materials in combination with wood for decades, Recently, considerable interest has developed in North America in expanding the technology and applications for composite products that combine wood and inorganic materials.

This technology involves bonding wood particles or fibers with an inorganic matrix, such as Portland cement or gypsum, for example, to form a composite that can be used in a variety of structural and industrial applications. These composites have a unique advantage



Fiber Technologies, Inc.

Figure 7. —The Lakeside Bridge recently constructed in Fond du Lac, Wis., is supported by high strength reinforced glued laminated wood beams.

over some conventional building materials because they combine the characteristics of both the wood fiber and mineral matrix, Some of these composites are water resistant and can withstand the rigors of outdoor applications, and almost all are either fireproof or highly fire-resistant, and are very resistant to attack by decay fungi. These types of composites are made by blending proportionate amounts of wood with inorganic materials. Gypsum-bonded wood-fiber panels are used as replacements for gypsum wallboard and reported to have strong nail- and screw-holding properties; high moisture and fire resistance; and improved impact, mold, and mildew resistance. Other reported advantages include improved anti-sag properties for ceiling boards, better sound insulation, and easy installation because joints do not require taping.

One commercially successful application of woodfiber cement technology is FASWALL permanent insulating wall forms, which are made with the "K-X" process patented by Hans Walter, IHBI (Windsor, S. C.) This process mineralizes wood chips, making them into a free aggregate, which is then bonded with cement and molded into FASWALL forms **(Fig. 5),** Waste wood by-products from the paper and pallet industries are used. When these permanent wall forms are filled with reinforced concrete, a unique post and beam grid is formed.

Cementboard panel products have been used in building construction in Europe for half a century, but have not been able to break into the panel market in the fiber-rich United States. However, over the last decade, the roofing products industry has developed a niche-market for cementboard products. Bison-Werke (Springe, Germany) has been an industry leader for cementboard manufacturing technology. Bison has recently developed process equipment that permits the manufacture of a deeply-textured, wedge-shaped roofing product **(Fig. 6).** This innovative process technology is able to imitate the classic look of wood shakes, thus combining the aesthetic beauty consumers want with the physical performance they demand.

The applications mentioned here represent only a few of the many inorganic-bonded products that are in either development or application stages.

## REINFORCED GLUED LAMINATED TIMBER BEAMS

All the composites we've just discussed blend wood fibers with other materials in a matrix. Another type of composite entering the market is high-strength fiber-reinforced glulam timber beams. In this Technology, high-strength fibers (e.g., carbon, aramid, and fiberglass) are oriented in a thin plastic matrix and then laminated into a glulam timber beam (usually in the tension zone of the beam) using standard gluing procedures. The new product has economic advantages because the reinforcement allows smaller cross sections than conventional glulam timbers, utilization of lower grade lumber, and reduced costs for transportation and chemical treatment.

Since much of the tensile force is carried by the reinforcement, the design capacity of the beam is greatly increased, allowing longer spans and greater loads for a given glulam member. The particular reinforcement material used will depend on the application. For example, aramids work best for tension reinforcement; carbon is best for compression reinforcement.

The technology for high-strength fiber-reinforced glulam timber beams was developed by Dan Tingley, a researcher at Oregon State University, He holds a patent for the concept of reinforcing glulams and has worked with American Laminators, Western Wood Structures, Inc., and Fiber Technologies, Inc., to manufacture and distribute the new product, called FiRP™ Glulams. To date, these beams are being used primarily in the construction of bridges and larger commercial and industrial buildings **(Fig. 7),**

## CONCLUSION

Economics, environmental concerns, and improved properties are the driving forces behind the unprecedented interest in combining wood with other materials, Recent research and development has produced many viable products that are finding commercial acceptance. Several standards writing and building code organizations are currently evaluating these new products and making decisions that will affect the speed of future development and application. These products appear to have a bright future and further research will undoubtedly focus on more marriages between wood and other materials.