Wood Plastic Composites

Structural Design and Applications

By Donald A. Bender, P.E., Michael P. Wolcott, J. Daniel Dolan, P.E.

Most structural applications of wood-plastic composites (WPCs) to date are for residential deck boards and guardrail systems. These manufacturers have typically obtained International Code Council (ICC) Evaluation Service Reports (ESR) that include span ratings. However, some products exist without an ESR. An important point for designers is to be sure to only specify products with ESRs. A listing of products can be found at the following website: **www.wpcinfo.org/consumers/products**.

In addition to these commercial deck products, WPC s are being developed for more demanding structural applications such as residential deck substructures, industrial decking, foundation elements and shoreline structures. A range of product performance is possible by manipulating formulation and section design, fiber reinforcement, and capping. For instance, formulations can be developed to optimize properties such as stiffness, strength and ductility; as well as to resist moisture, decay, and fire. Design methodologies for such engineered WPCs are evolving, but have not yet been codified. This article describes a process from which design values may be derived for WPCs and illustrates some recent demonstration projects.

Design Value Determination

The ASTM D07 Committee on Wood is actively addressing the issue of WPC design value derivation. A ballot is currently being considered with the working title WK8568 *New Standard Specification for Establishing Design Values for Wood- and Natural Fiber-Polymer Composite Products*.

The starting point for deriving working stress design values is to determine characteristic values derived from test data. Characteristic values have a statistical basis to account for variability in the material property, which are then adjusted with a safety factor. One approach for developing the characteristic values is to use the same 5% tolerance limit method used in engineered wood products and then apply a safety factor of 1.3. Using this lower tail of the probability distributions is appealing when there is no consistent variation across products. However, WPCs typically have relatively low coefficients of variation (COV) in mechanical properties. As such, a simpler approach is to assign the sample mean as the characteristic value, and then apply a larger safety factor such as 2.5. ASTM WK8568 includes a commentary that justifies this approach for WPC products with COVs up to 15%.

Once the characteristic value has been determined and adjusted by an appropriate safety factor, additional adjustment factors are needed to account for in-service conditions such as load duration, temperature, moisture and ultraviolet (UV) light exposure. The ASTM draft standards provide guidance on how to develop these adjustment factors. These factors depend on WPC formulation as well as processing conditions and methods. Some construction materials (e.g. plastics, lumber and steel) have standard formulations, grading methods and engineering design values; however, this is not the case for the WPCs. WPC manufacturers have proprietary formulations and hence each manufacturer must develop their own design values and ICC ESRs similar to many engineered wood products (e.g. laminated veneer lumber, I-joists, etc).

Table 1

Load Duration	PVC	HDPE	Timber
10 minute	2.35	3.00	1.6
7 day	1.65	1.95	1.25
2 month	1.40	1.60	1.15
10 year	1.00	1.00	1.00

Load duration factors for wood plastic composite formulations (polymer component used as designator) and timber. Brandt, C.W. and K.J. Fridley. 2003. Load-duration behavior of wood-plastic composites. J. of Materials in Civil Engr. 15(6):524-536.

Thermoplastics typically exhibit strong time and temperature dependent responses. Brandt and Fridley (2003) developed load duration factors for WPCs based on high density polyethylene (HDPE) and polyvinyl chloride (PVC) and compared them with timber load duration factors, as summarized in *Table 1*. The load duration factors can be used to adjust a characteristic value derived from test data, with an approximate 10 minute time to failure, to a "normal duration" of 10 years, as used in timber design.

Table 2 was constructed to allow a general comparison of potential design values for WPCs and solid sawn lumber. The WPC design values for bending, tension, shear, compression parallel, and compression perpendicular (i.e. Fb, Ft, Fv, Fc∥, Fc⊥, respectively) were calculated by dividing the average stress value by a safety factor of 2.5 and the load duration factors of 3.0 for HDPE and polypropylene (PP) and 2.35 for PVC. WPC design values presented here for modulus of elasticity (E) represent average values with no adjustment. Data were accumulated from several studies conducted at Washington State University (WSU) and demonstrate the wide range of properties that can be obtained by manipulating the formulation. As such, designers are warned not to use the values in *Table 2* for designing with commercial WPCs. Instead, design values for commercial WPCs should be provided by the manufacturers.

From *Table 2* we observe that WPCs outperform lumber with respect to shear strength, compression strength perpendicular to extrusion (grain), and dowel bearing strength parallel to grain (Fe∥). Bending strength, tensile strength, and compression strength parallel to extrusion are similar between PVC, coupled PP, and lumber. The modulus of elasticity is significantly lower for WPCs compared to lumber. In addition, substantial differences exist among the polymer types used to produce the composite materials. PP and PVC formulations outperform HDPE formulations like those used in many commercial deckboards. PVC exhibits somewhat brittle behavior which can adversely impact workability and energy dissipation. PP is more ductile and easier to work than PVC (unless plasticizers are added which will decrease the mechanical properties). While HDPE has the lowest mechanical properties, it is ductile and the least expensive WPC listed.

Implications of this comparison for structural design are that WPCs appear viable for applications that require durability and high bearing and bending strengths. The high shear and dowel bearing capacities of WPCs are particularly desirable attributes in connection design. However, WPCs are less suited for applications controlled by beam or column stability (buckling), due to relatively low E and tendency to creep. Research is ongoing to address these deficiencies with fiber reinforcement and cross-linked polymer formulations.

Most engineered wood composites (e.g. OSB, glulam, I-joists, SCL) are bonded with thermosetting polymer resins such as resorcinol, phenol-formaldehyde, and/or isocyanates. Once the resins react, they remain thermally stable within the temperature regimes of most structural applications. WPCs differ in that thermoplastic polymer resins soften as temperatures increase. In addition, temperature adjustment factors for wood are only applied for sustained elevated temperatures that cause thermal degradation of the hemicellulose and lignin components. In general, temperature adjustment factors for WPCs result in more severe reductions in properties as compared to solid wood (*see Table 3*).

Table 2

Material	Bending	Tension parallel to grain	Shear parallel to grain	Compression perpendicular to extrusion (grain)	Compression parallel to extrusion (grain)	Modulus of elasticity	Dowel bearing strength
	Fb	Ft	Fv	Fc⊥	Fc∥	E	Fe∥
Wood Plastic Composite (polymer component used as designator)							
HDPE	200 - 490	110 - 290	150	230 - 520	230 - 520	260,000 – 750,000	5,180
PVC	885 – 1,340	620	750	1,420	1,400 – 1,510	700,000 – 1,100,000	10,500 - 18,600
PP	430 – 1,180	390	425	1,070	410 – 1,070	510,000 – 870,000	12,300
Structural Lumber (No.2 visual grade, 2x8 nominal size)							
Douglas Fir-Larch	1,080	690	180	625	1,418	1,600,000	5,600
Hem-Fir	1,020	630	150	405	1,365	1,300,000	4,800
Southern Pine	1,200	650	175	565	1,550	1,600,000	6,150
Spruce-Pine-Fir	1,050	540	135	425	1,208	1,400,000	4,700

Comparison of design values (in psi) for wood plastic composites (WPC) and No.2 lumber. The WPC design values are for comparison only and should not be used to design with commercial WPC products. Designers should consult the WPC manufacturer for design values.

Table 3

Temperature, °F	Ultimate Stress		E	
	Tension	Compression	Tension	Compression
T < 100	0.80	0.80	0.70	0.80
100 < T < 125	0.80	0.70	0.60	0.70
125 < T < 150	0.70	0.60	0.50	0.60
T > 150	0.65	0.50	0.40	0.50

Summary of temperature adjustment factors for ultimate stress and modulus of elasticity (E) for wood plastic composites. Schildmeyer, A.J. 2006. Temperature and time dependent behaviors of a wood-polypropylene composite. M.S. thesis, Dept. of Civil & Environmental Engr., Washington State Univ.

Figure 1: Capped PVC wood plastic composite deckboard prototype (4x6-inch).

The thermoplastic matrix in WPCs greatly slows moisture uptake producing obvious benefits in product durability. Additional decay resistance can be achieved by adding low toxicity biocides such as zinc borate. WPC material response to other factors such as UV and fire exposure varies between WPC products and performance levels can be controlled by polymer type, polymer coupling, and chemical additives.

Demonstration Projects

The authors are involved in a number of demonstration projects including Navy pier components, ferry terminal wing walls, building foundation elements, and pedestrian bridges. These projects demonstrate the potential for structural uses of WPC products.

U.S. Navy Shoreline Structures

WPC research for the US Navy has led to technology developments in formulations, fiber reinforcement, foaming methods, and die designs. Applications include deck boards, chocks, whales, and bull rails. *Figure 1* shows a wood-plastic composite prototype that is currently installed at Pier 171 at Naval Station, Newport, Rhode Island. This prototype was engineered to support 600 psf uniform and 18,000 lb point loads.

Figure 2a: Rattlesnake Bridge in Missoula, MT demonstrating WPC decking and small diameter round timbers.

U.S. Forest Service – Rattlesnake Bridge

A new pedestrian bridge has opened near the Rattlesnake National Recreation area in Missoula, Montana. The bridge highlights the use of WPC's for the decking as well as small diameter timber for the lattice truss (*Figure 2a*). The WPC decking is a PVC formulation with nominal 4x12-inch sections as shown in *Figure 2b*. Rubber mats from recycled tires were placed over the decking to protect the surface from horse traffic. The bridge is 8 feet wide and spans 90 feet. Each WPC deck member spans 6 feet between supports. The 4x12 WPCs were load tested in simple bending at a span of 6 feet with an average maximum moment of 160,800 inch-pounds. This product is being commercialized and distributed by McFarland Cascade, in Tacoma, Washington.

WPC Sill Plate for Wood Framed Shear Wall

Initial destructive testing of braced wall panels (i.e., equivalent anchorage to that used in the *International Residential Code*) illustrated the advantage of changing the shape of the sill plate to allow the nail connections between the stud and the shear plate to act in shear. The proof of concept configuration using a PP WPC sill plate (*Figure 3*) resulted in a peak lateral load more than twice that achieved with conventional construction with wood structural panels, and over three times the peak load when subjected to cyclic loading.

Summary and Conclusions

WPC products are emerging for more demanding structural applications, beyond residential deck boards and guardrails. Most WPCs outperform lumber with respect to shear strength, compression strength perpendicular to extrusion (grain), and dowel bearing strength. Bending strength, tensile strength, and compression strength are similar between PVC, coupled PP, and lumber, whereas the modulus of elasticity is significantly lower for WPCs compared to lumber.

Implications for design are that WPCs appear viable for applications that require durability and high bearing and bending strengths. The high shear and dowel bearing capacities of WPCs are advantageous in connection design. Current commercial WPCs are less suited for applications controlled by beam or column stability (buckling), due to their relatively low modulus of elasticity and tendency to creep.▪

Donald A. Bender, P.E. is the Weyerhaeuser Professor of Civil Engineering and Director of the Wood Materials & Engineering Laboratory at Washington State University (WSU) in Pullman, WA.

Michael P. Wolcott is the Louisiana-Pacific Professor of Civil Engineering and Research Director of WMEL at WSU.

J. Daniel Dolan P.E. is a Professor of Civil Engineering and Director of Codes & Standards fot WMEL at WSU.

Reprinted with permission by Wood Design Focus (Vol 16 No. 3) Fall 2006

Figure 2b: Ribbed box sections (4x12-inches.) of PVC composite bridge decking.

Figure 3. Test of braced wall panel using WPC sill plate.