OPPORTUNITIES FOR WOOD PLASTIC COMPOSITE PRODUCTS IN THE U.S. HIGHWAY CONSTRUCTION SECTOR

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The aim of this research is to examine the market potential for wood plastic composite (WPC) products in the highway construction sector in place of non-renewable materials (e.g. virgin plastic and steel) and preservative-based products (treated wood). State-level transportation officials indicate that the majority of highway construction purchases are conducted by highway construction contractors. Results from a mail survey of highway contractors in eight western U.S. states indicate that a substantial volume of highway construction material may be suitable for substitution with WPCs. Overall, respondents were not familiar with WPC as a material, but compared it favorably with other materials commonly used in the sector. When making purchase decisions, respondents were most concerned with products meeting regulatory specifications, cost, availability, and trust in quality. Attributes related to sustainability, location of manufacture, and content of recycled material were viewed as less important.

Keywords: Wood plastic composites; Highway construction; Steel; Plastic; Mail survey; Sustainable

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INTRODUCTION

Wood plastic composite (WPC) products have gained significant market share over the past decade, especially in the residential market. The relatively high strength and stiffness-to-density ratio, and relatively low cost make WPCs a multi-purpose material that is extensively used in non-structural applications such as door skins, windows and door frames, interior automobile parts, and furniture, as well as in semi-structures like decking. The production of WPCs emits far less greenhouse gas emissions per unit volume than virgin plastic (Clemons 2002) while, in fact, surpassing virgin plastic in many material characteristics (i.e. Wechslera and Hiziroglub 2007). Given the substantial volume of non-renewable materials (or chemically treated materials) used in highway construction applications, WPCs may provide a more sustainable, bio-based alternative without the need for preservative treatment.

In the highway construction sector, purchasing can be carried out by either the state-level Department of Transportation (DOT) or by highway contractors. According to DOT officials, the majority of highway related purchasing is done by contractors (Dunning 2008). Using a mail questionnaire as the survey instrument, this research targeted highway contractors in eight western states. The objectives of this survey-based research are as follows:

1. Quantify annual procurement of three test products by highway contractors

2. Develop an understanding of the market potential of WPCs in the highway sector
3. Measure highway contractor familiarity with WPC products
4. Examine the effects of product development involvement by contractors on familiarity with new highway-related products
5. Measure highway contractor perceptions of WPCs compared to other materials based on key material properties
6. Determine the importance of various purchasing considerations in the highway sector
7. Evaluate the product attributes used to rate the sustainability of products purchased in the highway construction sector

THEORETICAL BACKGROUND

Wood plastic composites (WPCs) can be defined as hybrid composite materials containing fine wood particles combined with synthetic thermoplastic polymers. Thermoplastics are reusable plastics (can be repeatedly melted) and are commonly used to make products such as milk jugs and plastic bags (Clemons 2002).

Products made from WPCs have experienced tremendous growth in recent years, predominantly in the United States (US). In particular, WPCs have gained a significant share of the residential decking market, a trend due in part to the diminishing popularity and subsequent ban of chromated copper arsenate (CCA) treatments in products such as wood decking (Rowell 2006). Although the CCA ban was used in early marketing efforts for WPC decking, it should be noted that the ban was not the sole driver of increasing market share for WPC decking. Other properties of WPC products such as durability, aesthetics, and cost have also created demand over solid wood products (Ashori 2008). It was suggested that WPCs would command a greater share of the US decking market than softwoods by 2010; however, the emergence of cellular vinyl decking has controlled a significant share of the high-end market, while wood treated with alternative preservatives has reinvigorated the low-end market (Morton 2009). Additional WPC residential products such as siding, fencing, and roofing are also emerging (Principia Partners 2007).

Smith and Wolcott (2006) suggest there are four factors responsible for the recent surge in the WPC residential market: the adverse effect of treating chemicals on the environment, effective marketing, the quality/cost ratio, and, perhaps most importantly, the acceptance of WPCs by builders. Demand for WPCs has also developed in the automotive industry for use in both interior and exterior components. The automotive industry considers WPCs to be a very promising green material that may be able to achieve durability without the use of toxic preservatives (Ashori 2008).

The major advantage of WPCs is that they combine the availability, lightness, machineability, and mechanical properties of wood with durability and environmental resistance of synthetic materials, while allowing great flexibility in engineering their properties for a wide variety of final uses (Wolcott and Muszyński 2008).

Wood, as a fibrous material, provides several advantages as a reinforcing additive in plastic composites. WPCs offer a relatively high strength/stiffness to density ratio, often at a reasonably low cost. In terms of sustainability and environmental impact, WPCs can be produced with fewer CO_2 emissions than virgin plastic, the fiber is renewable (Ashori 2008), and WPCs offer a great potential for utilizing woody biomass generated in wild forest fire prevention operations and regular forest thinnings aimed at improving forest health. Mechanical testing has shown that the addition of wood fiber to plastic can improve certain bending characteristics as well as alleviate thickness swelling, a common issue in some virgin plastic products (Wechslera and Hiziroglub 2007). WPCs offer lower life-cycle costs, weather resistance, durability, and a wood-like appearance. The products also cut and nail like wood products and can be colored without ever requiring painting (Principia Partners 2007).

Despite the growing demand for WPCs in the residential, commercial, and automotive sectors, challenges exist in the production of WPCs. The production process involves two contrasting industries, the wood processing industry and the plastics industry. Special care must be taken to minimize damage to the wood additive while optimizing conditions for the extrusion or forming of the plastic. It is also imperative to recognize that wood shrinks and swells due to moisture, while plastic shrinks and swells due to temperature, thus creating issues related to dimensional stability in exposure to elevated temperatures and freeze/thaw dynamics. Other issues include the risk of microorganism attack and ultraviolet degradation, dyeing, color stability, refinishing, and the application of fasteners (Rowell 2007). Some reports, especially in the residential sector, suggest that WPC products have issues with recalls, mildew, and mismanaged color fade (Principia Partners 2007).

Opportunities for Wood Plastic Composites in the Highway Construction Sector

There is a growing interest in 'greening' the US highway and road construction sector, and typically this movement is led at the state level by the DOT. Already prevalent in Europe (Petkovic et al. 2004), government agencies in charge of highway construction in the US are showing interest in using more sustainable products and avoiding potentially harmful preservative-treated products (e.g. treated wood guardrail posts) (Dunning 2008). For example, Washington State DOT has drafted a proposed "Green Roads" system similar to the Leadership in Energy and Environmental Design (LEED) program applied to green building (Muench et al. 2007). The proposed program outlines a sustainability rating system that awards credits for sustainable design, materials, energy, and construction. Credits linked to material usage specifically reference the use of recycled materials, completion of life cycle analyses on materials and products, and the use of local materials to minimize transportation impacts (Muench et al. 2007). WPC products such as decking are often made from varying amounts of recycled plastic as well as recycled, low-grade, local wood waste (e.g. used pallets and mill residue) (Winandy 2004). The WPC industry used approximately 204 million kg of plastic in 2001, of which 95% was recycled (Principia Partners 2007). However, with growth in the WPC decking market, manufacturers have become increasingly dependent on virgin plastic (Klyosov 2007).

WPCs have previously been tested in low-impact, highway applications (e.g. posts and fencing), but they have been scarcely tested as compared to recycled plastic products (i.e. Heidenreich 1997). Recycled plastic products tested poorly due to installation, durability, cost and availability issues. Although WPCs made with virgin plastic have been found to be superior to WPCs made with recycled plastic, based on key material properties (Klyosov 2007), such differences are minimal and may not preclude the expanded use of WPCs in highway applications (Dunning 2008).

According to DOT officials, purchasing in the US highway construction sector can be the responsibility of two entities, the DOT itself, or the highway construction contractors hired by the DOT (Dunning 2008); however it is suggested that the majority of the purchasing for large construction projects is conducted by the contractors.

Regardless of the purchaser, any products used in highway or road applications must be approved and published in a qualified products list (e.g. ODOT 2008). These product lists are updated regularly and indicate that a product has been tested and found to be suitable for use in a specific application. To be included in a qualified products list, a product must undergo a series of tests which, depending on the product, can include the testing of impact effects, mechanical properties, color requirements, and durability (CalTrans 2009).

Familiarity and Perceptions Regarding Wood Plastic Composites

The few articles dedicated to WPC markets in the literature tend to focus on residential markets, mainly decking (e.g. Clemons 2002; Principia Partners 2007). Therefore, the current research is novel in that it attempts to measure familiarity and perceptions regarding WPCs within a specific non-residential market. Although the highway construction sector commonly experiences the entry of new products and materials (Dunning 2008), contractors may be familiar only with products found on the qualified products list (e.g. ODOT 2008). Very few products manufactured from WPC (e.g. guardrail blocks) have been approved and appear on this list and, of the products included, few are commonly used. Therefore, it is logical to hypothesize that highway contractors may have some familiarity with WPCs (perhaps through their own residential experience), but overall, familiarity will be low.

The study was designed around a series of hypotheses, as outlined in the following subsections:

H1: Highway contractors will have a low level of familiarity with WPCs

As it is hypothesized here that familiarity with WPCs amongst highway contractors will be low, perceptions of WPCs in comparison to other materials (e.g. virgin plastic, steel, treated wood) may very well depend on this familiarity. Similarly, contractors claiming to be involved in product development with suppliers may also be more familiar with a broader range of materials and products, such as WPCs.

H1a: Perceptions of WPCs compared to other materials will positively correlate with WPC familiarity

H1b: Respondents who are involved in product development with suppliers will be more familiar with WPC products

There is little extant work available that attempts to measure consumer (industrial or end user) perceptions regarding WPCs. Literature focusing strictly on material properties suggests that while, due to encapsulation of the bio-based material in synthetic polymer matrix, WPCs exhibit higher environmental durability compared to wood, both treated (Balma and Bender 2001) and untreated (Clemons 2002), they remain significantly more vulnerable to biodegradation than virgin plastics. Compared to steel, WPC's are less vulnerable to corrosion resulting from exposure to snow-melting agents (Vitaliano 1992). In addition, highway features made of metals are often subject to theft (Levinson and Gillen 1998). Although these findings in the literature cannot predict perceptions made by highway contractors, they are considered to be rather intuitive and, therefore, sufficient support for the following hypothesis:

H2: Respondents will perceive WPCs to be less durable than virgin plastics and steel, and more durable than treated wood.

The addition of wood fibers to virgin plastic has been shown to drastically improve flexural strength properties (Wechslera and Hiziroglub 2007; Clemons 2002). However, although WPCs can exhibit increased stiffness and resistance to thermal expansion as compared to wood, the strength of WPC products has been found to be lower than solid wood (Clemons 2002). Steel is one of the strongest commonly used materials and is vastly superior to WPC in that respect (Varis 2003).

H3: Respondents will perceive WPCs to be stronger than virgin plastic and less strong than steel and treated wood.

Based on aesthetics, WPCs may compare favorably with other materials due to the familiarity of respondents with WPCs in residential applications. WPCs have experienced significant growth in the residential sector (particularly decking) due, in part, to the diversity of grain patterns and colors available (Principia Partners 2007). Research shows that consumers find WPCs to possess natural wood-like properties and compare favorably with natural wood based on aesthetics; however, natural wood was rated higher in most aesthetic categories (Jonsson et al. 2008).

H4: Respondents will perceive WPCs to be more aesthetically pleasing than virgin plastic and steel, and less aesthetically pleasing than treated wood.

Overall, WPC products (residential products in particular) tend to be slightly more expensive than solid wood products (Clemons 2002; Principia Partners 2007). However, the use of wood fibers in WPCs offsets a substantial volume of plastic used in virgin plastic products, thus comparatively reducing the cost (Clemons 2002). Steel is a relatively expensive product compared to all other materials examined in this study (Lemmon and Chuk 1997).

H5: Respondents will perceive WPCs to be less expensive than virgin plastic and steel, and more expensive than treated wood.

If compared based on environmental friendliness during the production process, the literature suggests that WPCs produce more greenhouse gases than solid wood and less than virgin plastics (Clemons 2002) and WPCs use renewable fibers (Ashori 2008).

Steel requires significantly higher greenhouse gas emissions than most other materials used in structural beams (e.g. Petersen and Solberg 2002). A key driver of WPCs initial success in the residential market is the heightened awareness of the detrimental effects of wood preservatives such as CCA (Principia Partners 2007). Therefore, we hypothesize that these concerns give WPCs a marked advantage over treated wood products with regards to environmental friendliness.

H6: Respondents will perceive WPCs to be more environmentally friendly than virgin plastic, steel, and treated wood.

Purchasing Considerations and Sustainability Ratings

Attribute importance theory, with regards to industrial products (Lehmann and O'Shaughnessy 1974), suggests that availability, price, and trust in quality are among the most important considerations made in industrial purchasing. Attributes with less direct influence over the "bottom line", though present in purchasing decisions, often have less importance (Preuss 2001; Smith and Bright 2002). These attributes might include environmental friendliness, place of origin, and content of recycled material.

H7: Availability, price and trust in quality will be viewed as more important than environmental friendliness, origin and content of recycled material.

As suggested by industrial purchasing theory, environmental product attributes often pale in importance as compared to price, availability, and trust in quality (Lehmann and O'Shaughnessy 1974; Preuss 2001). A survey of product specifiers for the U.S. Port Authority found sustainability-related attributes of composite products to be lower in importance than any other attribute (Smith and Bright 2002). However, industrial firms (highway contractors in this case) may still evaluate purchases based on the sustainability of the product, and a series of product attributes may be used for such an evaluation. However, since environmental attributes are often less influential in purchase decisions, it is unlikely that any of the sustainability-related attributes are frequently considered.

H8: Sustainability rating attributes are rarely used by respondents to rate the sustainability of their products.

METHODS

Identification of Test Products

Prior to implementing a survey of highway contractors, three test products that can be made from WPC and are suitable for highway applications were selected. These were: 1. Tubular marker, 2. In-road reflector, and 3. Guardrail post. The products were chosen based on discussion with experts in highway product design and testing (Dunning 2008). Products of low, medium, and high technical and safety requirement categories were attained. Additional criteria for selection of specific products included representation of products of various unit volumes, as well as products that are installed as permanent (in-road reflectors and guardrail posts) and temporary (portable tubular markers). These hypothetical products were used to guide the survey of highway construction contractors, as well as define the parameters of an inquiry into material usage by DOTs and Public Works departments in western states.

Sampling

Target population

Highway contractors in eight western US states (Washington, Oregon, California, Idaho, Utah, Nevada, Arizona, and Montana) were targeted for inclusion in the survey phase of the current research. The study was constrained to eight western states due to the research objectives outlined in a federally funded grant. Contractors with greater than ten employees were included in the target population.

Sampling frame

A mailing list, purchased from a mailing list provider (InfoUSA.com), included addresses, phone numbers, and general firm characteristics (e.g. management contact, number of employees, primary business type, etc.) for the target population. InfoUSA.com allows clients to select Standard Industrial Classification (SIC) codes and North American Industry Classification System (NAISC) codes matching the characteristics of the target population. SIC code 1611 (highway/road construction and maintenance) was used in the present research.

Sampling procedure

Within the parameters specified of the target population (e.g. highway contractor, ten or more employees), the mailing list included all known members of the population. Therefore, a simple random sampling procedure was employed, as each sample element had a known and equal chance of being sampled (i.e. each member of the population was also a sampling element in this case). It must be stated, however, that there is no guarantee that the mailing list contained all possible members of the target population.

Data collection

Questionnaires were developed in consultation with industry experts in the field of highway product design, testing, and procurement. The questionnaires were also pretested on five highway contractors outside of the target population. Minor changes were made based on pretest feedback. The questionnaire included items related to firm characteristics, purchasing of "test products", familiarity with WPCs, perceptions about WPCs in relation to other materials, purchasing considerations, and the use of sustainability attributes to rate the sustainability of purchased products. For a complete list of variables/constructs (along with scales), see Table 1.

Respondents were asked to provide estimates of annual procurement of three test products commonly used in the highway construction sector in order to measure the market size for each highway-related product. Respondents were then asked to rate their familiarity with WPCs in general terms along a 7-point scale from 1 (not familiar) to 7 (very familiar). Perceptions of WPCs were measured by asking highway contractors to compare WPCs to three other materials commonly used in the sector: virgin plastic, steel, and treated wood. Comparisons were made based on five material properties:

durability, strength, aesthetics, cost and environmental friendliness. Respondents were asked to evaluate WPCs as compared to each of the three materials based on each of the five material properties. Responses were recorded on a 5-point scale (1= WPC is worse; 5= WPC is better).

Table 1. Construct Descriptions and Sources

Construct	Description (Scale)	Source
WPC Familiarity	Respondents were asked to rate familiarity with WPCs (scale: 1 = not familiar; 7 = very familiar)	Machleit et al. (1993)
Perceptions of WPC Properties	Respondents compared WPCs to three other materials (virgin plastic, steel and treated wood) based on five material properties (durability, strength, aesthetics, cost, and environmental friendliness (scale: 1 = WPC is worse; 3 = neutral; 5 = WPC is better)	Developed for this study
Sustainability Ranking	Respondents were asked to rank six materials (wood, plastic, recycled plastic, steel, recycled steel, and WPC) based on their sustainability (scale: 1 = most sustainable; 6 = least sustainable)	Developed for this study
Purchasing Considerations	Respondents rated the importance of ten purchasing considerations when making decisions about highway-related purchasing (see Table 8 for list of considerations) (scale: 1 = not important; 3 = neutral; 5 = important)	Adapted from Lehmann and O'Shaughnessy (1974)
Determination of Product Sustainability Ratings	Respondents were asked to indicate how frequently their company used ten attributes when determining the sustainability rating of products used by their company (see Table 9 for list of attributes) (scale: 1 = never; 5 = frequently)	Developed for this study

To assess the sustainability of WPCs as perceived by highway contractors, respondents were asked to rank six materials based on sustainability. The six materials included: steel, recycled steel, plastic, wood, WPCs, and recycled plastic. Each ranking was assigned a numeric value (e.g. 1^{st} = 6 points; 6^{th} = 1 point). The highest rank sum total represented the material perceived to be most sustainable.

Respondents also rated the importance of ten purchasing considerations when making decisions about purchasing a highway related product. Consideration items were measured on a 5-point scale (1 = Not important, 5 = Important) (Table 8). Respondents were also asked to report how frequently their company uses ten sustainability attributes when determining the sustainability rating of the products used by their company (5-point scale; 1=Never, 5=frequently) (Table 9).

Questionnaires were delivered via mail and returned in a pre-paid, pre-addressed return envelope. A second copy of the questionnaire was mailed approximately three weeks following the original mailing. Questionnaires were mailed to 1334 potential respondents. A cover letter, accompanying both questionnaires, outlined the purpose of the study and requested that a purchasing manager or someone with knowledge of purchasing respond to the questionnaire. Of these potential respondents, 153 were not in the target population and 92 were bad addresses, leaving an adjusted sample size of 1089 potential respondents.

Response rate and non-response bias test

After two mailings of the questionnaire, a total of 87 completed, usable questionnaires were received resulting in an adjusted response rate of 8.0 percent. To test for non-response bias, 30 non-respondents were randomly selected and contacted via telephone. They were asked a subset of questionnaire items from the original questionnaire. Answers from the non-respondents were compared to answers from highway contractors that responded to the survey. A t test was conducted to determine whether significant differences existed between the two groups. Respondents and non-respondents were compared based on annual procurement of guardrail posts ($p=.52$), familiarity with WPCs ($p=.92$), in-state employees ($p=.97$), perceived durability of WPCs compared to treated wood ($p=.25$), and perceived strength of WPCs compared to treated wood ($p=.67$). No significant differences were found (i.e. all p values > .05).

Statistical Analyses

All statistical analyses, including descriptive statistics and mean comparisons, were performed using SPSS 16.0 statistical software. Scale-based questionnaire items were treated as continuous variables and reverse coded where negative statements were used. Perception questionnaire items were compared to the neutral measure of each scale (3 = no difference) using a t test to determine whether WPCs were perceived to be better (>3) or worse (<3) than other materials.

RESULTS

Respondent Profile

Respondent firms were highly variable when compared based on number of employees and years of operation. Respondent firms employed between 10 and 15,000 employees, with a mean of 651 (SD = 2314.3). Firms had been in operation between 2 and 122 years, with a mean of 37.1 years (SD = 27.1). Most firms were privately held, approximately 89 percent, with the remainder being publicly traded. California represented the most respondent firms (n=30) while Nevada represented the least (n=1). For breakdown of respondents by state, see Table 2.

Estimate of Annual Procurement

Respondents purchased a total of 68,195 tubular markers, 185,086 in-road reflectors, and 8,313 guardrail posts in the previous year (Table 3). Based on the volume of material required for each product (tubular marker = 1,640 cm^3; in-road reflector = 98 cm^3; guardrail posts = 56,634 cm^3), these purchases represent a total of approximately 600 m^3 of material suitable for replacement by WPC material. An estimate was developed for all eight western states by comparing the number of employees represented by the survey and the number of employees in the sector (Punches et al. 1995). This estimate suggests that, based on purchases of three test products, over 4,000m^3 of material may be suitable for substitution with WPC products.

Table 2. Respondent Profile by State

State	Employees (M)	Yrs Operation (M)	Private Firms (%)	Respondents (n=)
California	139	37.5	100.0	30
Oregon	1171	34.8	81.0	21
Washington	1507	35.6	78.9	19
Arizona	121	42.4	85.7	7
Montana	174	44.2	80.0	5
Idaho	32	10.5	100.0	2
Utah	70	40.5	100.0	2
Nevada	150	75.0	100.0	1
Total	651	37.1	88.5	87

Table 3. Annual Procurement of Test Products by Highway Contractors

Product	Respondents	Eight States (estimate)[1]
Quantities (# of units)		
Tubular Markers	68,195	454,633
In-road Reflectors	185,096	1,233,973
Guardrail Posts	8,313	55,420
Total Volume	601 m^3	4,005 m^3

[1]Estimate for eight states calculated based on material/per employee in the sector

Respondents were also asked from what materials their guardrail posts are commonly manufactured. If the firm did not purchase guardrail posts, the question was left unanswered. The majority of guardrail posts purchased by highway contractors were made from treated wood (72.6%) (Table 4). Steel, plastic and aluminum comprised the remainder of the guardrail post market in surveyed states; no other guardrail post materials were reported. According to survey results, less than half of respondents reported purchases of guardrail posts in the previous year, hence, the small n values reported in Table 4.

Table 4. Guardrail Post Material as Reported by Respondents.

Material	M (%)	SD	n
Treated Wood	72.6	33.6	33
Steel	13.9	19.5	33
Plastic	11.0	30.4	32
Aluminum	3.0	10.2	32

Familiarity and Perceptions Related to Wood Plastic Composites

Familiarity with WPCs (on a 7-point scale; 1=not familiar, 7=very familiar) ranged from 1 to 6, and no respondents responded with 7 (very familiar). The average reported familiarity was 2.4 (lower than the midpoint of the scale) (SD=1.4), indicating that the familiarity with WPCs amongst highway contractors is low (which supports hypothesis **H1**).

Correlation analyses showed that only perceptions of WPC aesthetics compared to treated wood significantly correlated with WPC familiarity (Pearson's correlation =

0.317; p=0.012). All other correlations between familiarity and perceptions were insignificant (0.96>p>0.21) (partial support for **H1a**). Although contractors that are involved in product development with their suppliers (n=12) had a higher level of familiarity with WPCs (mean=3.00; SD=1.56) than contractors that are not involved in product development (n=74; mean=2.30; SD=1.43), the difference was not found to be significant (p=0.12) (failing to support **H1b**).

WPCs compared favorably with virgin plastics based on each of the five material properties, with the exception of cost. WPCs were rated most favorably based on environmental friendliness (3.94 on a 5-point scale) and least favorably based on cost (2.81), however perceptions of cost were not found to be statistically different from the mid-point (3.00) (Table 5). WPCs compared less favorably with steel, particularly based on strength (2.19) and durability (2.50). However, WPCs were rated higher than steel based on aesthetics (3.66) and environmental friendliness (3.60). Perceptions of cost were found to be statistically neutral, meaning respondents perceived the cost of WPCs to be comparable with the other materials. Compared to treated wood, WPCs were rated quite favorably based on all material properties. WPCs compared most favorably based on environmental friendliness (3.97). See Table 5 for a summary of these comparisons.

Table 5. Perceptions of WPCs vs. Other Materials

WPC vs.	Property	M	SD	Significance
Virgin Plastic				
	Durability	3.21	0.99	
	Strength	3.39	0.78	***
	Aesthetics	3.47	0.84	***
	Cost	2.81	1.03	
	Environmental Friendliness	3.94	0.83	***
Steel				
	Durability	2.50	1.04	***
	Strength	2.19	1.04	***
	Aesthetics	3.27	0.85	**
	Cost	2.85	0.90	
	Environmental Friendliness	3.60	1.11	***
Treated Wood				
	Durability	3.84	0.88	***
	Strength	3.52	0.91	***
	Aesthetics	3.66*	0.87	***
	Cost	3.02	1.03	
	Environmental Friendliness	3.97*	0.86	***

Measured on 5-point scale (1=worse; 3=neutral; 5=better)
* p<0.05, **p<0.01, ***p<0.001 (denotes statistical different than the mid-point)

Therefore, **Hypothesis 2 is partially supported**, however, respondents perceived WPCs to be more durable than virgin plastic. **Hypothesis 3 is partially supported**, however, respondents perceived WPCs to be stronger than treated wood. **Hypothesis 4 is partially supported**, but rather than perceiving WPCs to be less aesthetically pleasing than treated wood, respondents felt that WPCs are more aesthetically pleasing than the other three materials. We **fail to support Hypothesis 5**, as respondents perceived the cost of WPCs to be a similar to virgin plastic, steel, and treated wood. WPCs compared favorably with all other materials based on environmental friendliness, therefore, **Hypothesis 6 is supported**. A full list of hypotheses and results based on comparisons is found in Table 6.

Table 6. Material Comparisons: Hypotheses and Results

		Virgin Plastic		Steel		Treated Wood	
		Hypothesis	Result	Hypothesis	Result	Hypothesis	Result
H2	Durability	-	=	-	-	+	+
H3	Strength	+	+	-	-	-	+
H4	Aesthetics	+	+	+	+	-	+
H5	Price	-	=	-	=	+	=
H6	Envir. Friendly	+	+	+	+	+	+

WPC is better/more (+), WPC is less/worse (-), WPC is similar (=)

Survey results showed that sustainability rankings of six materials, as judged by respondents, were quite variable. Although wood was ranked as "most sustainable" by the most respondents (n=17), it was also ranked as "least sustainable" by the same number of respondents (Table 7). Interestingly, WPCs were ranked "most sustainable" and "least sustainable" by the fewest respondents (n=3 and n=4, respectively). Using a rank sum procedure that applied points based on sustainability rankings (i.e. most sustainable = 6 points, 2nd most sustainable = 5 points, etc.), it is evident that respondents found recycled steel to be most sustainable. WPCs placed fourth, however, they were comparable with recycled plastic and wood.

Table 7. Sustainability Rankings for Six Highway Construction Materials

Material	Sustainability Ranking 1st	2nd	3rd	4th	5th	6th	Rank Sum*
Recycled Steel	10	18	6	10	13	6	236
Recycled Plastic	12	8	11	12	13	7	225
Wood	17	3	14	10	2	17	224
Wood-Plastic Composites	3	15	16	12	13	4	223
Steel	11	8	9	10	9	16	206
Plastic	5	6	10	14	12	16	182

1st = most sustainable, 6th = least sustainable
*Rank sum applies between 1 and 6 points (1 for least sustainable to 6 for most sustainable)

Purchasing Considerations

While all purchase considerations were found to be at least somewhat important, respondents reported cost (4.60), trust in quality (4.59), and availability (4.59) to be the most important considerations when making purchases (Table 8). The location of manufacture (locally made) (3.69), environmental friendliness (3.37), and content of recycled material (3.12) were found to be least important of all considerations listed. The difference in importance values between the more important and less important purchase considerations were found to be significant ($p<.001$) (supporting **H7**).

Table 8. Importance of Purchase Considerations when Purchasing Highway-related Products

Purchase Consideration	Importance Score (M)	SD
Cost	4.60	0.62
Trust in quality	4.59	0.66
Availability	4.59	0.65
Ease to work with	4.45	0.61
Resistance to damage (decay)	4.24	0.85
Durability	4.24	0.73
Experience with the product	3.93	0.93
Locally made (vs. made elsewhere)	3.69	0.91
Environmental friendliness	3.37	1.06
Content of recycled material	3.12	1.00

Measured on a 5-point scale (1 = not important; 3=neutral; 5 = important)

Determination of Product Sustainability Ratings

None of the sustainability attributes were frequently used by respondents to determine the sustainability rating of purchased products (which supports **H8**) (Table 9). Used most frequently was life cycle analysis (2.90), manufacturing source (2.89), and ability to be recycled (2.83). Least frequently used was content of synthetic materials (2.07) and level of water emissions during the manufacturing process (1.96).

Table 9. Frequency of Attribute Use to Determine Sustainability Rankings of Purchased Products

Product Attribute	Frequency (M)	SD
Life cycle analysis	2.90	1.51
Manufacturing source	2.89	1.07
Ability to be recycled	2.83	1.15
Recycled content	2.59	1.18
Raw material source	2.59	1.18
Content of natural materials	2.32	1.14
Level of air emissions (during manufacturing process)	2.15	1.16
Embodied energy	2.11	1.14
Content of synthetic materials	2.07	1.01
Level of water emissions (during manufacturing process)	1.96	1.02

Measured on 5-point scale (1 = Never, 5 = Frequently)

DISCUSSION

Results from this study reveal key opportunities and challenges that manufacturers of WPC products may encounter as they attempt to enter the highway construction market. Firstly, the reported purchases of three test products by highway contractors suggest that the market for WPC substitutions could be substantial. Annual purchases of tubular markers, in-road reflectors, and guardrail posts are estimated to represent over 4,000m^3 of product within the eight western states included in this survey.

However, a requirement of any product used in highway applications is its inclusion in a qualified products list, typically maintained by the DOT at the state level. The importance of this requirement is highlighted by comments made by respondents in the comments section of the questionnaire.

> "If a product meets state level requirements, cost is then most important. The bottom line is what gets us jobs."
> *– Highway Contractor*

Therefore, a paramount goal of any WPC manufacturer attempting to penetrate the highway construction market will be to subject their products to the testing, required by the DOT, needed to be included in the qualified products list.

Assuming that it is possible for WPC products to satisfy the testing requirement of the DOT and gain inclusion within a qualified products list, this research also aimed to determine highway contractor familiarity and perceptions regarding WPCs. Overall, contractors reported low familiarity with WPCs. Considering that WPC products are rarely used in highway applications and very few are included in a qualified products list, it seems logical that overall familiarity would be low. A lack of familiarity, however, had no significant effect on perceptions of WPCs as compared to other materials. The only exception to this finding was a correlation between familiarity with WPCs and perceptions of WPCs as compared to treated wood based on aesthetics. This finding may relate to the common use of WPCs in residential decking applications. A common advantage of WPC decking over treated wood is the variety of styles and colors available.

When compared to plastic, steel, and treated wood (based on durability, strength, cost, aesthetics, and environmental friendliness) WPCs compared favorably on all tested properties with the exception of cost. As cost has been identified as a priority by highway contractors, manufacturers must ensure that highway products are priced competitively. WPCs compared most favorably based on aesthetics and environmental friendliness. Although aesthetic advantages are less 'valuable' in the highway construction sector, environmental friendliness could become increasingly important as "green roads" systems are developed at the state and federal level. WPCs compared less favorably based on durability and strength, however, provided a product can meet the testing required by the DOT, comparisons with other materials based on these properties become less important. It should be noted, however, that WPCs were perceived to be superior to treated wood based on all tested properties. WPCs compared most favorably to treated wood based on durability and environmental friendliness; two properties that are especially important for products used in guardrail post applications, the majority of which are made of treated wood, according to respondents.

Consistent with attribute importance theory related to industrial purchasing, the cost, availability, and trust in quality were among the most important purchasing considerations. The location of manufacture (local or elsewhere), environmental friendliness, and content of recycled material were found to be least important. Regardless of "green" incentives that may arise over the coming years, cost, availability, and quality should remain a priority of purchasers in the sector. However, as "green road" incentives become available, the latter three considerations may become increasingly important. Currently, respondents indicated that highway contractors rarely use sustainability attributes in order to rate the sustainability of products they purchase. Again, without the presence of incentives to use sustainable materials, it seems likely that contractors will continue to prefer approved products that are competitively priced, readily available, and trusted. The reality of the contract employment realm is that price rules all other considerations. In the highway sector, a successful bid for a construction project is often the lowest bid; therefore, contractors cannot afford to sacrifice cost for product attributes that are not linked to the bottom-line. Without government initiatives which reward sustainable construction practices, the priority of purchase considerations by highway contractors is not likely to change.

CONCLUSIONS

Findings from this research identify key opportunities and challenges that manufacturers of WPC products may face as they attempt to enter the highway construction market.

Opportunities

1. The highway construction sector offers a substantial volume of material (e.g. plastic, treated wood, etc.) that may be suitable for substitution with WPCs.
2. Perceptions of WPCs compare favorably with other materials based on durability, strength, aesthetics, and environmental friendliness.
3. "Green Road" initiatives are being developed which would provide incentives for the use of sustainable materials and locally made products.

Challenges

1. Any product used in the highway construction sector requires extensive testing prior to inclusion in a state-level qualified products list. This can be especially expensive if impact tests are required.
2. Highway contractors tend to have low familiarity with WPC materials.
3. Cost, with the exception of being a qualified product, is perhaps the most important product attribute to highway contractors. WPC manufacturers will need to achieve a competitive price point in order to gain market share.
4. Product availability is key, from the perspective of highway contractors. Manufacturers will need to ensure a constant supply of product in order to maintain customers.
5. Trust in quality has been identified as an important purchasing consideration by highway contractors. Manufacturers will have to work closely with suppliers and retailers to ensure that purchasers are educated about the advantages of WPCs in terms of quality.

LIMITATIONS

Highway construction contractors in eight western states were surveyed for the current study; therefore, results cannot be generalized beyond highway contractors in the eight western states. Unfortunately, the survey response rate was quite low in certain states (e.g. Nevada, Idaho, Utah); therefore, generalizations to the state level should be taken with care. Overall, familiarity with WPCs was quite low and may influence the perception scales presented here. However, statistical analyses did not show significant correlation between familiarity and perceptions of WPCs.

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