PERCEPTIONS OF NEW AND ESTABLISHED WATERFRONT MATERIALS: U.S. PORT AUTHORITIES AND ENGINEERING CONSULTING FIRMS

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(Received November 2000)

ABSTRACT

A demand exists for strong, cost-effective, durable, and environmentally benign building materials for weather-exposed infrastructure applications. In particular, port authority officials and engineers are seeking waterfront materials with a combination of "ideal" attributes that may not be currently available in the marketplace. Materials science advancements related to composite technologies are ongoing, and composite product lines for waterfront applications are expanding. This paper examines the perceptions of U.S. port authorities and engineering consulting firms regarding new and established waterfront materials in decking and fendering system applications. The findings from a nationwide survey indicate that the most important decking material attribute for U.S. port authorities and engineering consultants was *reliable strength,* followed by *resistance to impact, resistance to decay,* and *low life cycle cost.* The most important fendering material attribute for these two respondent groups was *resistance to impact* followed by *high energy absorption, reliable strength,* and *structural design flexibility.* The least important attribute for both decking and fendering was *use of recycled materials.* Material performance comparisons generally indicated a strong preference for concrete decking and steel fendering; composites were perceived as intermediate for both applications. In terms of cost, wood was perceived as the best; composites were perceived as the worst. Knowledge ratings of composite products and the receptivity to new technologies indicated that responding engineering consultants perceived themselves to be both more knowledgeable about composite materials and more progressive in the adoption of new technologies as compared to this study's port authority respondents.

Keywords: Decking, fendering, perceptions, product/market development, end-users, specifiers, composites.

INTRODUCTION

Traditionally, the development of new wood products has not been driven primarily by customer needs, but rather by resource availability, resource cost, and proven technology (Rosenberg et al. 1990; Trinka et al. 1992). There has generally been a resistance to customer-orientation as an organizing principle for new product development and marketing in high technology (Cahill 1994; Trinka et al. 1992). However, a new product's success depends on the relevance of the firm's offerings to the consumers' needs (Busch and Houston 1985). Undeveloped preference structures of new products typically require the firm to establish the relationship between the capabilities of the new technology and the existing needs of target consumers (Roberts 2000).

In addition to understanding customer

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Wood and Fiber Science, 34(1), 2002, pp. 28–41

needs, understanding how users, specifiers, and influencers perceive a product on important attributes and relative to competing products is referred to as a product's position (Kotler and Armstrong 1996). Products can be positioned on the needs they fill or the benefits they offer to a certain class of users or directly against or away from a competitor. As shown by Smith et al. (1999, 2000), market research into the perceptions of industrial end-users and specifiers on the relative attribute importance of alternative infrastructure materials can provide valuable information for developing materials and/or product positioning strategies.

Businesses and individuals differ in their openness to new ideas and technologies (Mitropoulos and Tatum 2000). The construction industry is generally perceived as conservative in adopting new technologies (Koebel 1999; Mitropoulos and Tatum 1999). The adoption and innovation of new products, defined as the process by which an innovation "is communicated through certain channels over time among the members of a social system," (Rogers 1995) have been the subject of considerable attention since innovation diffusion theory was introduced into marketing in the 1960s (Arndt 1967; Baptista 1999; Bass 1969; Mahajan et al. 1990; Rogers 1995). Much of the empirical research into the adoption and diffusion of building materials has focused on the home building industry (Fell and Hansen 1999; Koebel 1999; Mitropoulos and Tatum 1999; NAHB 2000) as opposed to industrial applications (Smith et al. 1999, 2000) considered in this study of waterfront applications.

This research examines the perceived importance of waterfront decking[1] and fendering[2] attributes by U.S. port authorities and engineering consultants. In addition, the various materials available for use in these applications are compared among eight select attributes to better understand the relative perceptual position of these materials by end-users and specifiers. This information may guide manufacturers and distributors of new and existing waterfront materials and products in the development of coherent market entry/market expansion strategies targeting these two key user/specifier groups.

Waterfront materials and products

Various combinations of materials are used for waterfront applications to take advantage of the best properties of each material within individual design configurations. Currently steel, reinforced concrete, prestressed concrete, aluminum, plastic, wood, and a variety of composite materials are used. Wood has been the traditional material of choice for many of the individual waterfront components due to its availability, cost, and versatility (Tobiasson and Kollmeyer 1991). However, over 30 U.S. companies now manufacture composite materials for waterfront applications, and the list of product offerings is growing (Anonymous 1999; Anonymous 1996; Craigie 2000; Hudson 1999; Kerber 1999; Knights 1996; Lancaster Composites [brochure not dated]; Lewis 1999; Petru 1999; Pianka 1999; Robinson 1999; Schuyler Rubber Co. [brochure not dated]; Seaward International Inc. [brochure not dated]; Toensmeier 1994; Troutman 1998). U.S. fiber-reinforced composite markets were up 4.9% from 1998 and many wood based composite materials show promise in these waterfront applications (Henriksen 2000).

Increasing marine borer populations, environmental concerns regarding the use and disposal of chemically treated wood in marine environments, and larger service load requirements are factors contributing to an interest in using new engineered materials for waterfront applications. Over the last two decades improved water quality has created flourishing marine borer populations resulting in accelerated decay of many shore facilities (Herszenhorn 1999; Kennedy 1999; March and Jarvis

[1] Components included in decking are the following: decking, bracing, batter piles, bearing piles, pile caps, stringers, string pieces, spacer blocks, step/ladders, hand rails (Malvar 1998).

[2] Components included in fendering are the following: chocks, wales, fenders, camel logs (Malvar 1998).

1997; Rasmussen 1997; Rohde 1998; Tanal and Matlin 1996). Wood pilings are vulnerable to borer attack, resulting in costly solutions such as wrapping the pilings or encasing them in concrete, the latter method costing as much as $200 per linear foot (Krasner 1998). Other alternatives include using preservative-treated wood; however, negative public perceptions regarding possible leaching of toxic chemicals, and increased state and federal regulations mandating against their use have encouraged the use of other materials (Felton and DeGroot 1996; Hansen and Morrell 1997; Crawford et al. 2000; March and Jarvis 1997; U.S. Dept. of Agriculture 1980).

Larger service load requirements, resulting from larger crafts berthing at facilities, favor steel and concrete, which has created more interest in developing increasingly reliable and strong products (Hoffard and Pendleton 1998). In particular, many port authorities have had to accommodate increasingly larger container ships that require higher strength materials for greater impact resistance (Sherman 2000).

U.S. Naval waterfront facilities and component needs

The U.S. Navy is interested in developing alternative materials for use in their shore facilities (See Acknowledgments). Many of the Navy's shore facilities were constructed during or following WWII using preservative-treated wood, but many of these are due for repair and/or replacement (Malvar et al. 1998). Currently the Navy installs $40-50 million in treated wood product replacements annually (Anonymous 2000; Malvar et al. 1998) and disposes of approximately 20,000 tons of treated wood, creating a costly disposal issue (Malvar et al. 1998).

This research study is guided by the U.S. Navy's initial interest in developing new engineered composite materials for "drop-in" applications within existing decking and fendering waterfront systems. Flexible custom design characteristics of composite materials have made them particularly useful in rehabilitation projects (Hastak and Halpin 2000). Additional material and product applications exist for new formulation and design configurations in new waterfront facilities as well (Cofer et al. 1998). Performance attributes such as strength, stiffness, shape, ease of construction, commercial viability, Navy need, and Navy design requirements were considered in the Navy's selection of the two applications of interest: fendering and decking.

Within these two applications, seven specific components were identified as having the greatest potential for material substitution success and were included in our study. The components were grouped into two categories based on their similarity of purpose as follows: 1) decking (decking, bull rails, and spacer blocks); and 2) fendering (chocks, wales, fender piles, and camels) (Hoffard and Pendleton 1998) as shown in Fig. 1.

Additional waterfront material markets

Although much of the interest in engineered composite materials is from the U.S. Navy, other potentially high-volume end-uses exist within civilian construction and infrastructure repair (Ashley 1996; Black 1998; Westrup 1992). In the U.S. alone, there are more than 750,000 public and private piers, wharves, and docks. According to the U.S. Army Corps of Engineers, system deterioration costs total approximately $2 billion annually within marine waterfront communities (March and Colturi 1998). The public port industry is focusing on infrastructure improvements with approximately 20% of total annual expenditures directed towards infrastructure investments (United States Port Development Expenditure Report, October 1998). Additionally, the escalation in boat ownership by larger numbers of Americans has created substantial demand for marina facilities (Tsinker 1995). In 1997, U.S. marina planned capital improvements by type indicated that the largest percentage of expenditures (30%, or approximately $34 million) is directed towards infrastructure (International Marina Institute 1998).

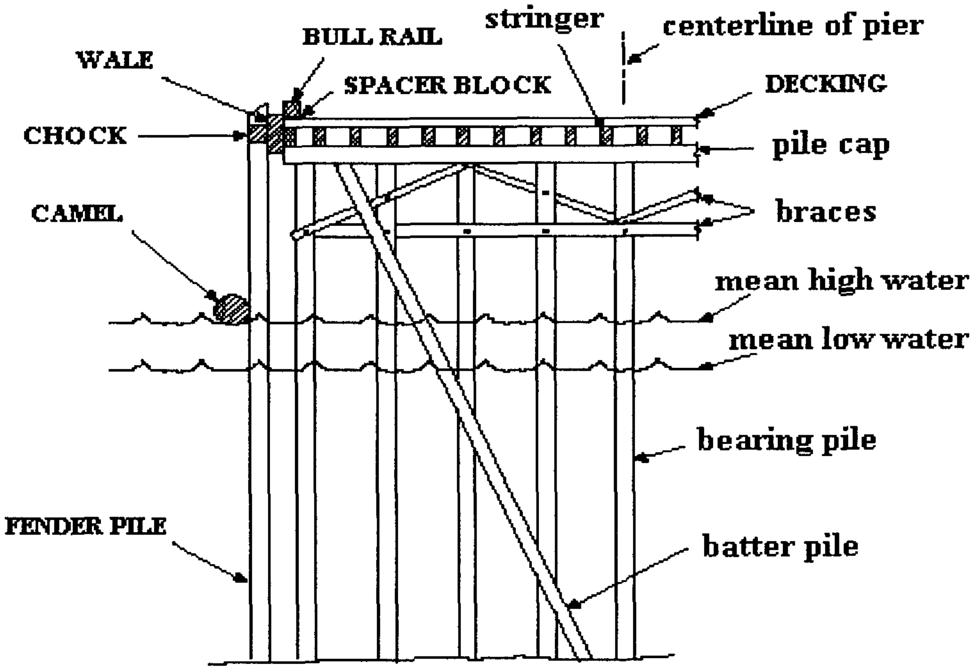

FIG. 1. Typical pier cross section. (Source: Malvar et al. 1998)

Therefore, the primary goals of this research are the following:

1. Examine the perceived attribute importance of new and existing materials available for waterfront decking and fendering for U.S. port authorities and engineering firms by comparing eight select attributes.
2. Rank for importance the relative perceptual position of twenty key decking and piling attributes.
3. Determine respondents' overall knowledge (self-rated) of composite materials and their perception of their port authorities' and engineering consulting firms' receptivity to new technologies.
4. Compare differences for attribute importance and material performance between port authority officials and engineering consultants.

Beyond the Smith et al. (1999, 2000) work, little research on end-users' and specifiers' perceptions of infrastructure materials, and particularly of new products for waterfront applications, is available. The objective of this study is to better understand material perceptions and attribute importance of U.S. port authorities and engineering consultants regarding waterfront infrastructure applications and in particular regarding new composite materials.

METHODS

Sample and sampling procedure

Exploratory interviews of personnel at U.S. port authorities and engineering consulting firms indicated that the American Association of Port Authorities (AAPA) represented the most salient association for development of the target population. The AAPA is the alliance of ports of the Western Hemisphere, and the association promotes the common interests of the port community, and provides leadership on trade, transportation, environmental, and other issues related to port development and operations (Mihaiu 1998). In 1999, 72% of U.S. deep-draft port authorities were AAPA members (Sherman 2000). Not included in

AAPA membership are inland river ports that are not commercially significant (based on revenue and tonnage) and several South American ports with no commercial significance (Mihaiu 2001); these two groups were not included in our sampling unit. Inferences should not be made from this study for these two groups.

All U.S. port authorities (n = 180) and engineering firms (those indicating participation in waterfront construction, n = 99) listed in the 1999 AAPA directory, *Seaports of the Americas,* were included in our sample frame (Mihaiu 1998).

Research instrument

Mail questionnaires were used for primary data collection, as they are the most effective means to collect data from a geographically dispersed population (Blankenship and Breen 1992; Dillman 1978). To reduce the length of the questionnaires, maximize response rates, and obtain complete information, four versions of the mail questionnaire were developed; one for each application (decking and fendering), and one for each user group (port authorities and engineering consultants). Most of the constructs were identical in the four versions of the questionnaire to facilitate comparisons between the two product applications and two user groups. The questionnaire was thoroughly pretested by knowledgeable civil engineers, port authority officials, and university personnel to test for biased, misleading, or confusing questions and instructions. Refinements were made in the set of material attributes, question wording, and questionnaire length.

Data collection and response rates

To increase response rates, a modified version of Dillman's (1978) Total Design Method was employed as follows: a cover letter explaining the research project team, the cooperators, the purpose of the study, and other instructions was mailed with the questionnaire in the fall of 1999; a reminder postcard was

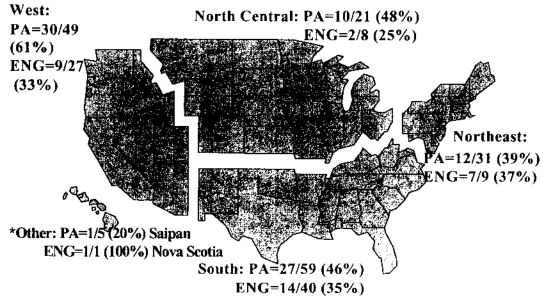

FIG. 2. U.S. Port Authority (PA; n = 80) and engineering firm (ENG; n = 33) response rates by U.S. Bureau of census regions.

sent one week after the initial mailing; three weeks following the initial mailing, a second questionnaire was mailed with a cover letter requesting participation from nonrespondents. In addition, due to our relatively limited population sizes, three weeks following the second mailing, follow-up phone calls to nonrespondents were conducted to further increase response rates.

Adjusted response rates of 48.5% (n = 80) and 34.7% (n = 33) were achieved for port authorities and engineering consulting firms, respectively (Fig. 2).

Study bias

To assess nonresponse bias, those who responded to the initial mailing (early respondents) were compared to those who responded after follow-up steps were taken (late respondents). The later respondents are generally believed to be more like nonrespondents (Pearl and Fairley 1985). Early respondents (48 port authorities and 20 engineering firms) were compared to later respondents (32 port authorities and 13 engineering firms) across a number of survey questions using analysis of variance (ANOVA).[3] No significant differences (at the 0.05 level) were found between the two groups' mean overall perceptions of attribute importance, their perceptions of overall

[3] An ANOVA procedure determines if the mean values of an independent variable are significantly different from each other within each category of an independent variable.

material performance, their knowledge of composites, and their participation in waterfront construction.

Respondent profile

Port Authorities.—Forty-one percent of responding port authority officials were Directors of Engineering at their ports, followed by Executive/Port Directors (30%), Harbor Master/Port Managers (19%), and "other" (10%). The mean years of service at the respondents' current positions was 7.24 years plus an additional 9.12 years of service in their previous positions, totaling an average of 17+ years of work experience. Nearly all (89%) of respondents had participated in waterfront construction projects within the last five years, with the remaining 11% having participated within the last fifteen years.

Based on 1998 statistics for overall annual tonnage (short tons) for U.S. ports, responding port authority officials were employed at somewhat larger port authorities (mean = 12,103,300 short tons; n = 76) compared to the average port authority (mean = 7,302,000 short tons; n = 164) (Sherman 2000).

Engineering consulting firms.—Thirty-three percent of responding engineering consultants were Chief/Senior Engineers, followed by Presidents/VPs of Engineering (30%), Project Managers (24%), and "other" (13%). The mean years of service at the respondents' current positions was 10.29 years plus an additional 10.97 years in their previous positions, totaling an average of 20+ years of work experience. Again, nearly all (97%) had participated in waterfront construction projects within the last five years, with the remaining 3% having participated within the last fifteen years.

Engineering consultants were asked to estimate the number of total employees working at all the firm's locations in 1998. The largest percentage of firms had between 1–100 total employees (56%), followed by those with 101–500 (28%), 501–1000 (6%), and +1001 (10%). Engineering consultants were asked to indicate in what project types their firms participated. This question included fixed-response categories of 12 project types to select, and respondents were asked to check all that applied. The project type that most of the consultants responding participated in was Ports and Harbors (97%) followed by Highways and Bridges (76%).

Construct development

Secondary sources were used to compile an initial list of relevant attributes. Primary sources, including exploratory interviews with vendors of waterfront construction materials, discussions with military/civilian structural and material science engineers from the Navy project team, in addition to on-site interviews of engineers from BERGER/ABAM Inc., (Federal Way, WA), General Construction Company (Seattle, WA), and the Port of Tacoma (Tacoma, WA) were used to refine and finalize a list of 20 attributes for both decking and fendering materials (Tables 1 and 2).

Respondents were also asked to rank wood, concrete, and composite materials for decking, and wood, concrete, composite, and steel materials for fendering on the following eight material attributes: *long life, high strength, low cost, durable, consistent quality of materials delivered to job site, resistant to heat/cold, environmentally safe, and meets environmental regulations.* This attributes list was developed via interviews with waterfront material suppliers and constituted the criteria they emphasized most in their material comparisons.

RESULTS AND DISCUSSION

Analysis of the data began with cross tabulations and range counts to identify coding errors. Analysis of variance (ANOVA) at the alpha levels of 0.05 and 0.10 was used to test for significant differences based on attribute importance and material performance comparisons. For additional confirmation, the Mann-

TABLE 1. *Decking material attributes for Port Authorities (PA) and Engineering Firms (ENG).* "What material attributes do you perceive are the most important for DECKING?"

Decking material attributes[1] (mean ratings)	Total (n = 113)	PA (n = 80)	ENG (n = 33)	Sig.[2]
Reliable strength	**4.51**	**4.59**	**4.37**	**0.041**
Resistance to impact	**4.36**	**4.47**	**4.13**	**0.007**
Resistance to decay	4.34	4.38	4.30	0.445
Low life cycle cost	4.30	4.32	4.30	0.670
Low maintenance cost	4.19	4.26	4.07	0.122
Structural design flexibility	4.18	4.19	4.20	0.878
Resistance to marine borers	4.06	4.03	4.17	0.698
High-energy absorption	**3.98**	**4.18**	**3.53**	**0.001**
Resistance to U.V.	**3.94**	**3.83**	**4.27**	**0.067**
Resistance to fire	3.92	3.92	3.93	0.938
Easy installation	3.88	3.89	3.87	0.740
Low replacement cost	3.57	3.66	3.37	0.140
Low expansion/contraction	**3.55**	**3.67**	**3.27**	0.031
Toxic chemical free	3.54	3.63	3.33	0.226
Non-conductive	3.45	3.47	3.43	0.835
Low initial cost	3.32	3.35	3.27	0.639
Less aquatic biofouling	3.27	3.39	3.00	0.105
Attractive appearance	3.23	3.27	3.13	0.529
Low disposability cost	**3.00**	**3.16**	**2.60**	**0.011**
Use of recycled materials	2.34	2.42	2.13	0.225

[1] Mean rating on a 5-point scale of 1 = no importance to 3 = somewhat important to 5 = critically important.
[2] Bold print indicates statistically significant at the 0.10 level using ANOVA and nonparametric Mann Whitney U Test.

TABLE 2. *Fendering material attributes for Port Authorities (PA) and Engineering Firms (ENG).* "What material attributes do you perceive are the most important for FENDERING?"

Fendering material attributes[1] (mean ratings)	Total (n = 113)	PA (n = 80)	ENG (n = 33)	Sig.[2]
Resistance to impact	4.69	4.69	4.75	0.941
High-energy absorption	4.63	4.60	4.56	0.442
Reliable strength	4.56	4.58	4.56	0.629
Structural design flexibility	4.30	4.27	4.41	0.533
Resistance to decay	4.27	4.26	4.34	0.799
Low life-cycle cost	4.24	4.28	4.19	0.455
Low maintenance cost	**4.19**	**4.29**	**3.97**	**0.021**
Resistance to marine borers	4.00	3.84	4.41	0.029
Easy installation	3.94	3.97	3.88	0.437
Resistance to UV	3.85	3.76	4.09	0.166
Low replacement cost	3.70	3.77	3.57	0.210
Resistance to fire	3.61	3.69	3.44	0.265
Toxic chemical free	3.49	3.59	3.28	0.192
Low initial cost	3.43	3.49	3.28	0.273
Non-conductive	3.33	3.41	3.16	0.261
Less aquatic biofouling	3.32	3.41	3.13	0.220
Low expansion/contraction	**3.21**	**3.36**	**2.84**	**0.027**
Low disposability cost	**3.07**	**3.22**	**2.75**	**0.029**
Attractive appearance	**3.01**	**3.13**	**2.72**	**0.063**
Use of recycled materials	2.46	2.54	2.25	0.224

[1] Mean rating on a 5-point scale of 1 = no importance to 3 = somewhat important to 5 = critically important.
[2] Bold print indicates statistically significant at the 0.10 level using ANOVA and nonparametric Mann Whitney *U*-test.

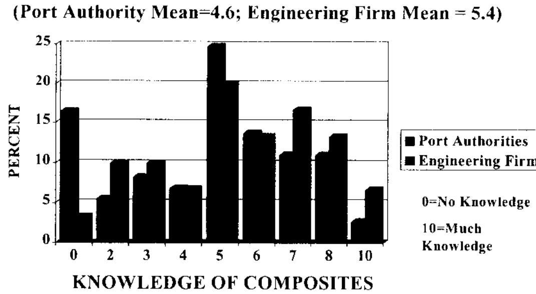

FIG. 3. Self-rated knowledge of composites by U.S. port authorities (n = 72) and engineering firms (n = 29).

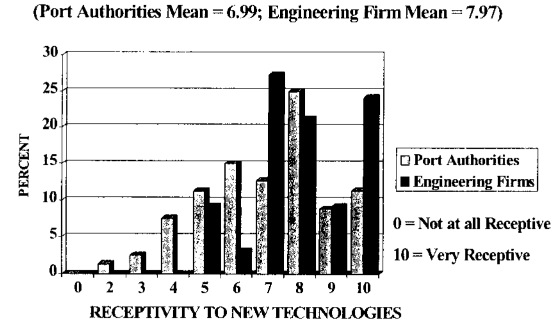

FIG. 4. Receptivity to new technologies by port authorities (n = 76) and engineering firms (n = 31).

Whitney U (nonparametric) statistical test[4] was used due to the relatively small sample sizes.

Composite knowledge and receptivity to new technologies

Respondents were asked to rate their knowledge of composites used for waterfront applications on a ten-point Likert scale from 0 = no knowledge to 10 = much knowledge. Engineering consultants rated themselves higher in composite knowledge (mean = 5.40, n = 29) than port authority officials (mean = 4.67, n = 72) (Fig. 3).

Additionally, port authority officials and engineering consultants were asked to rate their perception of how receptive their port authorities and engineering firms were regarding the implementation of new technologies on a 10-point Likert scale from 1 = not at all receptive to 10 = very receptive (Fig. 4). No engineering respondents rated their firms with a rating of 4 or less and only three respondents rated their firms with a 5. The mean for engineering respondents was 7.97 (n = 31). The minimum rating by port authority officials was 2 (n = 1) with a slightly lower mean of 6.99 (n = 76).

Attribute importance

To determine the relative importance of 20 attributes among our two responding groups, a 5-point Likert scale from 1 = no importance, to 3 = somewhat important, to 5 = critically important was used (Tables 1 and 2).

Decking.—Table 1 shows that *reliable strength* was rated as the most important decking material attribute for port authorities (mean = 4.59), and engineering firms (mean = 4.37). The two least important decking material attributes for both groups were also the same: *low disposability cost* (port authority mean = 3.16; engineering firm mean = 2.60) and *use of recycled materials* (port authority mean = 2.42; engineering firm mean = 2.13). Moreover, environmental attributes for decking, which included *toxic chemical free, less aquatic biofouling, low disposability cost, and use of recycled materials,* were uniformly rated very low (bottom 7 or 8) on attribute importance.

Fendering.—As shown in Table 2, the three most important fendering material attributes for both port authorities and engineering firms were the same: *resistance to impact* (port authority mean = 4.69; engineering firm mean = 4.75), *high energy absorption* (port authority mean = 4.60; engineering firm mean = 4.56) and *reliable strength* (port authority mean = 4.58; engineering firm mean = 4.56). The least important fendering material attribute for both groups was *use of recycled materials* (port authority mean = 2.54; engineering firm mean = 2.25). Furthermore, *non-conductive, less aquatic biofouling, low expansion/contraction, low disposability costs, and*

[4] The Mann Whitney U test evaluates whether the medians on a test variable differ significantly between two groups (Green et al. 2000).

attractive appearance were all rated least important (bottom 6) by both groups. Also the 4 environmental attributes were once again uniformly rated near the bottom in terms of their relative importance in fendering applications.

Analysis of variance was used to determine if significant differences existed between responding port authorities and engineering consultants with respect to attribute importance, and the Mann-Whitney *U*-test (nonparametric) was used to corroborate the results. As shown in Table 1, mean responses from the two groups differed from each other (at the $P = 0.10$ level) on the following decking attributes: *resistance to impact, high-energy absorption, resistance to U.V, low expansion/contraction,* and *low disposability cost.* Table 2 indicates that port authority respondents differed from engineering consultants (at the $P = 0.10$ level) in their mean rating of the following fendering attributes: *low maintenance cost, low expansion/contraction, low disposability cost* and *attractive appearance.*

Material performance

Decking.—Respondents were asked to rank *three* alternative decking materials (wood, concrete, and composites) on a 3-point scale from 1 = worst performance, to 2 = average performance, to 3 = best performance for eight decking material attributes (Table 3). Overall, concrete was ranked the highest (highest means for seven of the eight attributes), composites were ranked intermediate (second highest means for seven of the eight attributes), and wood was ranked the lowest (highest mean for *low cost,* second highest mean for *resistant to heat/cold,* lowest means for six of the eight attributes).

Analysis of variance (ANOVA) was used to determine if significant differences existed between responding port authorities and engineering consultants with respect to material perceptions, and the Mann-Whitney *U*-test was used to corroborate the results from the ANOVA. For decking, the mean rankings between our two groups were statistically different from each other (at the $P = 0.10$) on the following decking attributes: *environmentally safe* (concrete) and *meets environmental regulations* (concrete). In both cases port authority officials rated concrete higher than engineering consultants for these environmental attributes.

Fendering.—Respondents also ranked *four* alternative fendering materials (wood, concrete, composites, and steel); a 4-point Likert scale (as opposed to the decking 3-point scale) from 1 = worst performance, to 2 = below average performance, to 3 = above average performance, to 4 = best performance on the same eight fendering attributes was used because of the addition of steel as an alternative material (Table 3). Overall, steel was ranked the highest (highest means for five of the eight attributes), composites were ranked highest on *long life* and durability [*durable*], concrete was generally ranked intermediate, and wood was ranked the lowest for six of the eight attributes.

In fendering applications, the mean rankings by our two groups differed significantly (at the $P = 0.10$) using ANOVA and the Mann-Whitney U statistical tests on the following attributes: *low cost* (concrete), *durable* (composites), *resistant to heat/cold* (composites), *environmentally safe* (wood), and *meets environmental regulations* (wood). Engineering consultants rated concrete higher for *low cost,* and port authority officials rated composites higher for *durable* and *resistant to heat/cold.* Also, port authority officials rated wood higher for the two environmental attributes—*environmentally safe* and *meets environmental regulations* as compared to engineering consultants.

Additional observations on material comparison perceptions include the following:

- Wood is only perceived favorably on *low cost,* and it is perceived less favorably for decking as compared to fendering.
- Composites are perceived to be the highest cost material in both decking and fendering applications.
- Composites, concrete, and steel are per-

TABLE 3. *Decking/fendering material perceptions for Port Authorities (PA) and Engineering Consulting Firms (ENG).*

	DECKING			FENDERING		
	Total[1] n = 113	PA n = 80	ENG n = 33	Total n = 113	PA n = 80	ENG n = 33
Long life						
Wood	1.43	1.47	1.34	1.81	1.88	1.68
Concrete	2.68	2.74	2.55	2.38	2.27	2.57
Composites	2.22	2.16	2.32	3.04	3.02	3.07
Steel				2.61	2.72	2.41
High strength						
Wood	1.43	1.39	1.50	1.61	1.69	1.45
Concrete	2.75	2.81	2.64	2.51	2.54	2.47
Composites	2.01	2.10	1.86	2.41	2.46	2.30
Steel				3.37	3.31	3.48
Low cost						
Wood	2.46	2.49	2.39	3.28	3.29	3.26
Concrete	2.09	2.10	2.07	**2.38	**2.25	**2.62
Composites	1.40	1.36	1.48	1.79	1.91	1.59
Steel				2.24	2.32	2.10
Durable						
Wood	1.44	1.46	1.41	1.80	1.85	1.69
Concrete	2.66	2.69	2.61	2.40	2.30	2.61
Composites	2.15	2.18	2.11	**2.95	**3.11	**2.64
Steel				2.68	2.70	2.65
Consistent quality						
Wood	1.59	1.66	1.47	1.82	1.91	1.64
Concrete	2.52	2.53	2.48	2.42	2.46	2.36
Composites	2.12	2.13	2.12	2.65	2.62	2.72
Steel				3.26	3.26	3.27
Resistant to heat/cold						
Wood	2.09	2.12	2.03	2.53	2.59	2.41
Concrete	2.18	2.23	2.10	2.35	2.26	2.50
Composites	2.01	2.02	2.00	*2.53	*2.69	*2.19
Steel				2.81	2.77	2.87
Environmentally safe						
Wood	1.54	1.62	1.38	*1.64	*1.82	*1.30
Concrete	**2.56	**2.64	**2.40	2.82	2.76	2.93
Composites	2.26	2.21	2.35	2.81	2.90	2.62
Steel				3.05	3.02	3.10
Environmental regulations						
Wood	1.55	1.65	1.38	*1.59	*1.77	*1.24
Concrete	*2.61	*2.71	*2.40	2.82	2.78	2.89
Composites	2.21	2.14	2.35	2.80	2.84	2.73
Steel				3.06	3.07	3.03

[1] Mean based on responses to the following scales (decking-3 material comparison) 1 = worst, 2 = average, 3 = best performance; and (fendering-4 material comparison) 1 = worst, 2 = below average, 3 = above average, and 4 = best performance.
* Statistically significant at the 0.05 level using ANOVA and nonparametric Mann Whitney U Test.
** Statistically significant at the 0.10 level using ANOVA and nonparametric Mann Whitney U Test.

ceived as better on environmental attributes as compared to wood.

Similar results concerning the perception of wood were found in Smith et al. (2000). Reinforced concrete, prestressed concrete, steel, aluminum, plastic, and wood were rated without regard to specific application on a Likert scale from 1 = below average performance, 4 = average, and 7 = above average performance by marine group decision-makers (n = 100), and wood (mean = 3.84) was perceived only higher than plastic (mean = 3.58).

SUMMARY

In this study, the knowledge ratings of composite products and the receptivity to new technologies indicated that responding engineering consultants perceived themselves to be both more knowledgeable about composite materials and more progressive in the adoption of new technologies as compared to our port authority respondents. Responses to the open-ended comments section indicated a general reluctance on the part of port authorities to specify new materials due to a lack of experience with the materials (25%, n = 12). Engineering consultants indicated a tendency to avoid specifying new materials unless clients, such as port authorities, specifically requested them (33%, n = 9). This "catch-22" may be addressed initially through well-publicized, high-visibility demonstration or showcase projects that help overcome the unfamiliarity these two important user/specifier groups have with new materials and/or products in these waterfront applications.

Similarities between U.S. port authority officials and engineering consultants for attribute importance were found. Both groups rated *reliable strength* (decking) and *resistant to impact* (fendering) as the most important attributes. They also agreed the *use of recycled materials* was the least important attribute for both applications. Uniformly they perceived environmental attributes as less important than the other attributes. This is an interesting finding given the preponderance of sales literature about new materials that emphasizes the "green" image of their products.

Initial cost comparisons are also emphasized in the sales literature of new materials. Attribute comparisons of the five cost variables of this survey (initial, maintenance, replacement, life-cycle, and disposal) indicate more emphasis should be placed on life cycle cost comparisons. Overall port authorities and engineering consultants rated *low life-cycle cost* as the most important (decking mean = 4.30; fendering mean = 4.24) followed by *low maintenance costs* (decking mean = 4.19; fendering mean = 4.19) *low replacement cost* (decking mean = 3.57; fendering mean = 3.70) and *low disposal cost* (decking mean = 3.00; fendering mean = 3.07). However, limited information on life-cycle costs has been identified as one barrier to the acceptance of new materials, and in particular to composites (Eagar 1995; Hastak and Halpin 2000).

A primary interest in low life-cycle cost by respondents of this study is consistent with the relatively high importance of durability issues to the study respondents. For both decking and fendering applications, mean durability scores for *resistance to decay, marine borers, fire and U.V.*) were relatively high. Durability concerns were also mentioned frequently by respondents in their open-ended comments section at the end of the questionnaires (20%, n = 25). Many engineering consultants indicated a willingness to use new materials if convinced of their potential for increased durability, but only if their clients specifically requested them. Port authority respondents indicated a willingness to use new materials if the engineering community provided reliable data on their long-term use. Clearly a need exists for independent, long-term durability test data on new waterfront composite materials. Stake tests and prototype products in demonstration projects may be useful in providing this additional data. Over time new product development must address these important issues with reliable and credible research to allay the concerns of both end-users and specifiers concerning a material's and/or product's use in extreme weather waterfront environments. At the same time, quantification of total costs (life-cycle, maintenance, initial, installation, and replacement costs) would be useful.

Material performance comparisons suggest that concrete decking and steel fendering products were generally perceived to possess the overall strongest performance by respondents. Wood, concrete, and composites were rated for eight decking attributes. For decking, results indicated a strong preference for the performance of concrete, followed by composites, and lastly wood. Wood was perceived as the lowest cost product, followed by concrete and then composites.

In addition to the three materials mentioned above, steel was also rated for eight fendering attributes for material performance. Steel was generally perceived as the best performing material for fendering, followed by composites, concrete, and wood. Composites had a strong intermediate showing for both applications; however, higher perceived costs were again highlighted. Because *low initial cost* was rated as a relatively unimportant material attribute by both port authorities and engineering consultants, effectively communicated differentiation strategies focused on product performance and life-cycle costs are likely to be effective.

This study adds to the literature addressing infrastructure decision-making by addressing product attributes and material comparisons in decking and fendering waterfront applications by U.S. port authorities and engineering consultants. Developments in composite material technology have provided a larger and more complicated array of materials resulting in a more challenging selection process by end-users and/or specifiers. For increased use of new materials for waterfront and other infrastructure applications, marketing communications efforts must effectively address long-term performance and life-cycle cost issues.

ACKNOWLEDGMENTS

The Office of Naval Research, Contract N00014-97-C-0395, sponsored this research under the direction of Mr. James J. Kelly. The authors wish to thank the organizations and individuals that participated in the study for their generous contributions of time and information.

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