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FIRE ISSUES IN ENGINEERED WOOD COMPOSITES FOR NAVAL WATERFRONT FACILITIES[1]

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ABSTRACT

Engineered wood materials, also known as wood-plastic composites (WPCs), are being investigated by the U.S. Navy for waterfront construction applications primarily because of their superior durability characteristics compared to wood. Durability, however, reaches beyond structural integrity and biodeterioration effects. Fire performance requirements are also critical issues in the acceptance of new combustible construction materials. To address fire performance issues in waterfront construction test methods and protocols were investigated. The objectives of this study were to determine Navy requirements for waterfront component fire resistance, to identify or develop test protocol requirements, and to initiate small sample fire testing based on those requirements. Currently the Navy's criteria documents defer to NFPA 307, Construction and Fire Protection of Marine Terminals, Piers and Wharves, where component cross-sectional area is a determining factor. Because WPCs allow for hollow cross sections, these criteria will need to be modified. Standard test methods and modifications thereof were assessed for their relevance and potential application to WPCs. In particular, one test method (ASTM E108) was adapted and evaluated for wood-plastic composites, and found to provide good differentiation between various material types. ASTM D1929 was conducted to address building code acceptance criteria. Finally, it was suggested that a modified version of ASTM E119 could be used for further evaluation.

KEY WORDS: Fire Resistance, Flammability, Composite Materials.

1. INTRODUCTION

Due to the potential impact of fire in Naval waterfront facilities, combustible construction materials require careful scrutiny. Navy fire safety requirements have been based on traditional construction materials. The introduction of wood-plastic composites (WPCs) potentially

changes the criteria for evaluation. Because these new materials are comprised of various ratios of wood and plastic components, the standards used to evaluate either wood or plastic may no longer apply. In an effort to create meaningful measures of fire performance a first step was to identify existing candidate test methods and assess their applicability to WPCs. Two such fire performance tests were evaluated, ASTM E108 [1] and ASTM D1929 [2].

2. FIRE RESISTANCE REQUIREMENTS FOR NAVY WATERFRONT STRUCTURES

The main Navy document pertaining to fire in Navy structures is MIL-HDBK-1008C (6/97), Fire Protection for Facilities Engineering, Design and Construction. For waterfront applications, this handbook further refers to:

- NFPA 307, Construction and Fire Protection of Marine Terminals, Piers and Wharves
- MIL-HDBK-1025/1, Piers and Wharves
- MIL-HDBK-1025/6, General Criteria for Waterfront Construction

All the above references were examined for fire-related structural requirements. Finally all pertinent ASTM standards were also addressed.

2.1 NFPA 307, Construction and Fire Protection of Marine Terminals, Piers and Wharves NFPA defines substructure as "that portion of the construction of a pier or wharf below, and including, the deck". NFPA considers 4 types of substructures:

1. Fire Resistive (4 hr fire rating) (concrete/steel)
2. Non Combustible (4 hr fire rating)
3. Composite
4. Combustible (wood) – this type of substructures applies to the current research. Most requirements are in the form of minimum dimensions needed to delay the loss of load carrying capacity. The required minimum dimensions per component type are as follows:
   Cross braces/bracing piles: component side ≥ 10 cm (4 in), area ≥ 206 cm^2 (32 in^2)
   Pile caps: side ≥ 20 cm (8 in), area ≥ 619 cm^2 (96 in^2)
   Deck stringers: side ≥ 15 cm (6 in), area ≥ 465 cm^2 (72 in^2)
   Deck planks: thickness ≥ 10 cm (4 in) + 5 cm (2 in) of wear surface
   thickness ≥ 7.6 cm (3 in) if no superstructure
   thickness ≥ 5.1 cm (2 in) if a non-decay composite is used

To be allowed to use engineered wood in waterfront applications, these requirements will have to either be met, or modified. A modified ASTM E108 test showed that most engineered wood materials had good fire resistance compared to plain wood. This may suggest that the cross section requirements of NFPA 307 could be revised. In addition, as indicated for the deck planks, if a non-decay composite is used, smaller dimensions are already allowed.

2.2 MIL-HDBK-1025/1, Piers and Wharves This handbook includes no material or component fire requirements that are applicable.

2.3 MIL-HDBK-1025/6, General Criteria for Waterfront Construction This handbook refers to NFPA 87, Construction and Protection of Piers and Wharves, which is obsolete and was superseded by NFPA 307. It also refers back to MIL-HDBK-1008, which was covered. In

summary, NFPA 307 requirements are the ones that should be addressed and modified for Navy waterfront engineered wood applications.

2.4 ASTM Standards In addition to the Navy requirements, several ASTM standards were reviewed for potential application. These include:

- ASTM D1929, Standard Test Method for Determining Ignition Temperature of Plastics
- ASTM E84, Surface Burning Characteristics of Building Materials
- ASTM E108, Fire Tests of Roof Coverings
- ASTM E119, Fire Tests of Building Construction and Materials
- ASTM E162, Surface Flammability of Materials using a Radiant Heat Energy Source
- ASTM E662, Specific Optical Density of Smoke Generated by Solid Materials
- ASTM E906, Heat and Visible Smoke Release Rates for Materials and Products
- ASTM E1321, Determining Material Ignition and Flame Spread Properties
- ASTM E1354, Heat and Visible Smoke Release Rates for Materials and Products using an Oxygen Consumption Calorimeter
- ASTM E1529, Determining the Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies
- ISO 9705, Full-Scale Room Test for Surface Products
- UL 1709: Large Hydrocarbon Pool Fires On Structural Members And Assemblies.

Among them, ASTM E108 was adopted but modified, ASTM D1929 was adopted, and ASTM E119 was selected for further evaluation.

3. FIRE TESTING

This initial testing included both commercially available deck board products and several Washington State University formulations for deck boards. These tests also included two solid wood products to serve as a baseline for relative performance comparisons. Because of the range in material types tested, the products were evaluated using both wood and plastic test methods. First it was of interest to determine the fire propagation characteristics of deck boards. This test was designed to evaluate a situation where combusting material was deposited on the deck surface and allowed to burn for a prescribed period of time (ASTM E108). The second test evaluated the ignition temperatures of the same decking materials tested in the fire propagation evaluations (ASTM D1929).

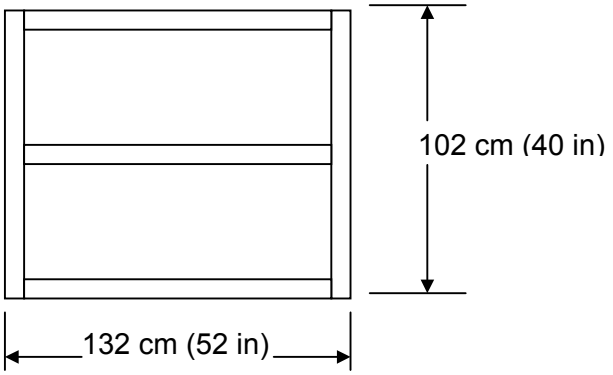
4. FIRE PROPAGATION

4.1 Fire Propagation Test Method The proposed fire test method was intended to be used to determine the acceptability of WPCs for outdoor deck applications where it is permissible (by the U.S. model building codes) to use combustible materials. This test method was based on a modification of the ASTM E108 fire test method for roof coverings. The modifications are explained below. In recent work by ASTM D20.20 (and AAMA) a similar fire propagation test method is being developed. The major difference between the method proposed in this report and the method described by D20.20 is the criteria used to determine pass or fail. The modifications to ASTM E108 included positioning of the deck surface (test specimen) horizontally, limiting the test specimen to 102 x 132 cm (40 x 52 inches) of surface area, adding combustible material below the test specimen, and selecting 60 minutes as a minimum test

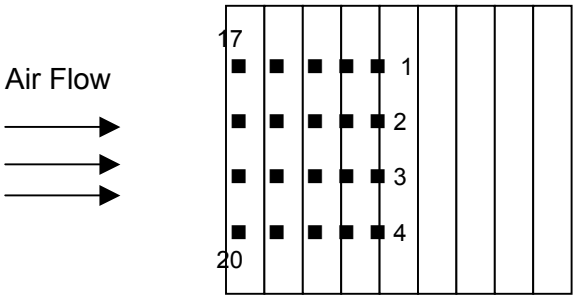
period. All other testing procedures preserve the intent of ASTM E108. The modified test method used is then described as follows.

4.1.1 Deck Fire Propagation Test Method (a modification of ASTM E108)

1. Deck Surface – A 2x4 lumber frame is constructed to support the deck boards. The frame shall be 132-cm (52-in) long and 102-cm (40-in) wide with one center support oriented along the 132-cm (52-in) dimension. The deck boards are cut to 102-cm (40-in) lengths and fastened to the lumber frame per the manufacturer's recommendations. See Figure 1 for construction details.
2. Fire Source – Twenty (20) class C brands shall be placed over a 61 x 61 cm (24 x 24 in) square area, centered along the leading 102-cm (40-in) edge of the deck surface per Figure 1. At least one row of 4 brands shall be placed directly across the gap or joint between deck boards. Airflow across the brands shall be maintained per ASTM E108. The first brand shall be placed in position and all subsequent brands placed at approximate one-minute intervals per Figure 1b. Figure 2 shows a class C burning brand.
3. Kraft Paper – A sheet of 8-kg (18-lb) Kraft paper shall be placed not more than 152 cm (60 in) below the surface of the deck. The paper shall be conditioned to EMC at 21°C (70°F) and 50% RH prior to test.
4. Exposure Time – The brands shall be allowed to burn for a minimum of 40 minutes after the last brand has been placed. Brand placement requires approximately 1 minute per brand (e.g., 20 brands take approximately 20 minutes to place). Total test duration shall be no less than 60 minutes.



a) lumber frame



b) deck boards and placement of 20 brands

Figure 1. Test specimen assembly

Figure 2. Class C burning brand

To assess a product's suitability for waterfront application, criteria must be developed to discern the differences between the various product offerings. The following characteristics were judged as effective criteria to stratify the performance of the products tested. It should be noted that a typical E108 test specifies three replicates for each test material. In this experiment only one specimen per treatment was evaluated.

4.1.2 Fire Propagation Acceptance Criteria The tested deck is considered to pass if all the following criteria are met:

1. Flame Spread – Flames shall not spread to any of the deck surface edges.
2. Flaming or Glowing Debris – At no time, throughout the duration of the test, shall combusting material fall below the deck surface in sufficient quantity to ignite and cause to flame a sheet of Kraft paper located 152 cm (60 in) or less below the deck surface.
3. Flame Growth – After the 40-minute exposure period (after the last brand has been place) the flames shall be diminishing. If it is not clear at the end of the test period that the flames are diminishing the test may be extended to verify diminishing flames. Smoldering materials are acceptable provided that combustion has not extended to the edges of the deck.

Criterion 1 addresses the concern of flame rapidly spreading across the surface of the deck and engaging the attached structure in a fire. Criterion 2 was designed to limit the potential spread of the fire to material or other decks below the burning deck surface. Criterion 3 was an attempt to assure the occupants that with a fire of this type the deck material will not continue to provide fuel for the combustion over a reasonable length of time. It is understood that the fire content from 20 Class C burning brands is relatively small compared to either Class A or B brands. This modification is merely an attempt to place practical limits on the use of decking products in building construction where combustible materials are allowed.

4.2 Materials Tested Table 1 describes the test materials included in this investigation. Products ranging from 100 percent plastic to 100 percent wood were tested. Cedar lumber and Chromated Copper Arsenate (CCA) pressure treated 5 x 15 cm (2 x 6 in) lumber were used to establish baseline performance. These lumber products were tested "as delivered". Although there appeared to be no visible difference between product WPC 4 and WPC 3R the same manufacturer claimed the products were of different formulations. The WSU manufactured products WPC 5 and WPC 6 were of different formulations but of the same geometry. WPC 7 was a polyvinyl chloride (PVC) product with a white PVC cap that contained zinc borate (ZB). Finally, PVC 1 was a commercially available plastic decking system.

Table 1. Products evaluated in the initial fire testing program

TEST	NOMINAL COMPOSITION	GEOMETRY
1	cedar lumber – commercial	Nominal 5x15 cm (2x6 in) solid section
2	100% polyethylene plastic lumber – commercial	Nominal 5x15 cm (2x6 in) solid section
3	WPC 1, 30% polyethylene, 65% wood – commercial	Nominal 5x15 cm (2x6 in) Box section
4	WPC 2, 30% polyethylene, 65% wood – commercial	Three leg "T" section
5	CCA pressure treated Hem-fir – commercial	Nominal 5x15 cm (2x6 in) solid section
6	WPC 4, 50% polyethylene, 50% wood – commercial	Nominal 3.2x 5 cm (5/4x6 in) solid section
7	WPC 3 R, 50% polyethylene, 50% wood – commercial (similar in appearance to WPC 4)	Nominal 3.2x 5 cm (5/4x6 in) solid section
8	WPC 5, 30% polyethylene, 65% wood, 5% ZB – WSU	Nominal 5x15 cm (2x6 in) box section
9	WPC 6, 30% polyvinyl chloride, 65% wood, 5% ZB – WSU	Nominal 5x15 cm (2x6 in) box section
10	WPC 7, 30 % polyvinyl chloride, 65% wood, 5% ZB PVC cap – WSU	Nominal 5x10 cm (2x4 in) two-box section
11	PVC 1, polyvinyl chloride deck board - commercial	Nominal 5x15 cm (2x6 in) net "C" section

4.3 Fire Propagation Test Results and Discussion The initial tests provided the data shown in Table 2. Applying the fire propagation acceptance criteria stated above the data showed that only the solid plastic lumber, WPC 3R, and WPC 5 products failed to pass. In each case the failure resulted from burning brands placed along the joint between deck boards. Figure 3 shows the successful testing of WPC 2. Of particular note were the times to failure. At approximately 29 minutes the plastic lumber product was extinguished because it was growing at a rate where

extinguishing was becoming increasingly difficult (Figure 4). In addition, the flaming material raining down below the deck surface had consumed the paper and was beginning to consume a piece of Oriented-Strand Board (OSB) that was used to replace the paper. WPC 3R took nearly 60 minutes to fail. In this case flaming pieces dropped below the deck surface and began to burn the paper; and the fire on the surface was slowly spreading and growing in intensity. WPC5, on the other hand, failed only because the flame reappeared and was slowly continuing to spread across the deck surface. Figure 5 shows some of the results.

Table 2. Experimental results from the initial fire testing

Test #	Sample	Group	Pass / Fail	Criteria of Failure	Test Length (Minutes)	Comments
1	Cedar Lumber	Wood	Pass		60	Smoldering
2	Plastic Lumber	Plastic	Fail	2 and 3	29	Difficult to extinguish
3	WPC 1	Comp	Pass		30	Self extinguished
4	WPC 2	Comp	Pass		30	Self extinguished
5	CCA Lumber	Wood	Pass		60	Smoldering
6	WPC 4	Comp	Pass		26	Self extinguished
7	WPC 3R	Comp	Fail	2 and 3	60	Steady fire growth
8	WPC 5	Comp	Fail	3	60	Steady fire growth
9	WPC 6	Comp	Pass		24	Self extinguished
10	WPC 7	Comp	Pass		35	Self extinguished
11	PVC 1	Plastic	Pass		29	Self extinguished

5. FIRE IGNITION

5.1 Flame Ignition Test Methods In order to receive building code approval all plastic building construction materials are required to pass a flash ignition temperature (FIT) and spontaneous ignition temperature (SIT) evaluation. Although there currently is no building code requirement for wood plastic composites to conduct this test, some code officials are becoming increasingly concerned with the fire performance of WPCs. The test that is typically conducted is ASTM D1929. The FIT is the minimum temperature at which, under specified conditions, sufficient flammable gases are emitted to ignite upon application of a small external pilot flame. The SIT is the minimum temperature at which the self-heating properties of the specimen leads to ignition or ignition occurs by itself, under specified conditions, in the absence of any additional flaming source. The 1997 Uniform Building Code (UBC) Section 2602.6 requires a SIT of 343°C (650°F).

5.2 Materials Tested The same materials were used again (see Table 1).

5.3 Flame Ignition Test Results and Discussion The results of the tests are shown in Table 3. The higher the FIT or SIT the better the product should perform in a fire (e.g., higher temperatures suggest the possibility of lower flame spread). All products tested seemed to pass

the UBC required SIT of 343°C (650°F). When compared to the results of the Fire Propagation tests, the FIT or SIT neither support or refute the Fire Propagation data, and the differences in ignition temperatures between materials are relatively small, i.e. both tests do not seem to correlate.

Table 3. Flame ignition and spontaneous ignition temperatures

Test #	Sample	Group	FIT °C	SIT °C	Density kg/m^3
1	Cedar Lumber	Wood	276	440	402.5
2	Plastic Lumber	Plastic	425	436	749.5
3	WPC 1	Composite	355	436	1157.9
4	WPC 2	Composite	328	402	961.9
5	CCA Lumber	Wood	277	464	535.6
6	WPC 4	Composite	369	390	691.6
7	WPC 3R	Composite	336	385	909.1
8	WPC 5	Composite	334	391	1247.6
9	WPC 6	Composite	362	405	1387.5
10	WPC 7	Composite	362	365	1265.2
11	PVC 1	Plastic	422	471	1801.2

6. CONCLUSIONS

A modified ASTM E108 test method was used to determine the acceptability of WPCs for outdoor deck applications. The modified ASTM E108 was evaluated for wood-plastic composites, wood, treated wood, and plastic lumber, and found to provide good differentiation between the various material types. In particular it showed the superior performance of engineered wood when compared with wood, and the potential fire propagation problem with plastic lumber. ASTM D1929 proved that all materials were acceptable for building construction, at least according to the UBC.

7. REFERENCES

1. ASTM E108, Standard Test Methods for Fire Tests of Roof Coverings, Annual Book of ASTM Standards, American Society for Testing and Materials.
2. ASTM D1929, Standard Test Method for Determining Ignition Temperature of Plastics, Annual Book of ASTM Standards, American Society for Testing and Materials.

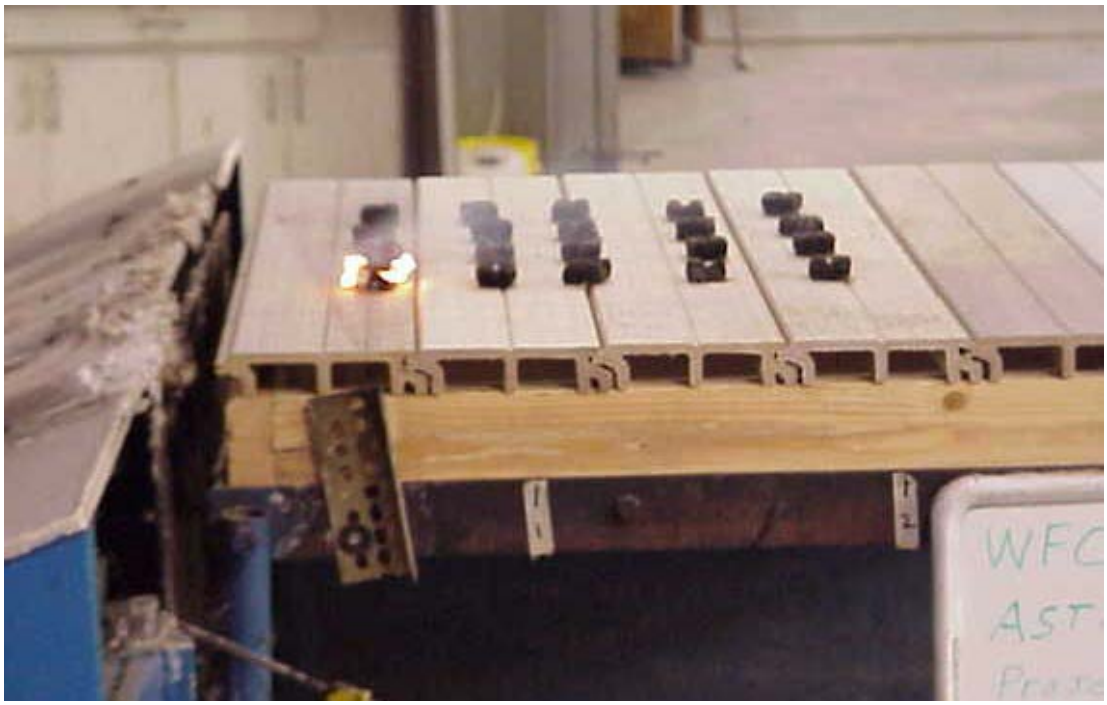


Figure 3. WPC 2 fire propagation test after 20 minutes.

Figure 4. Plastic lumber fire propagation test after 29 minutes.

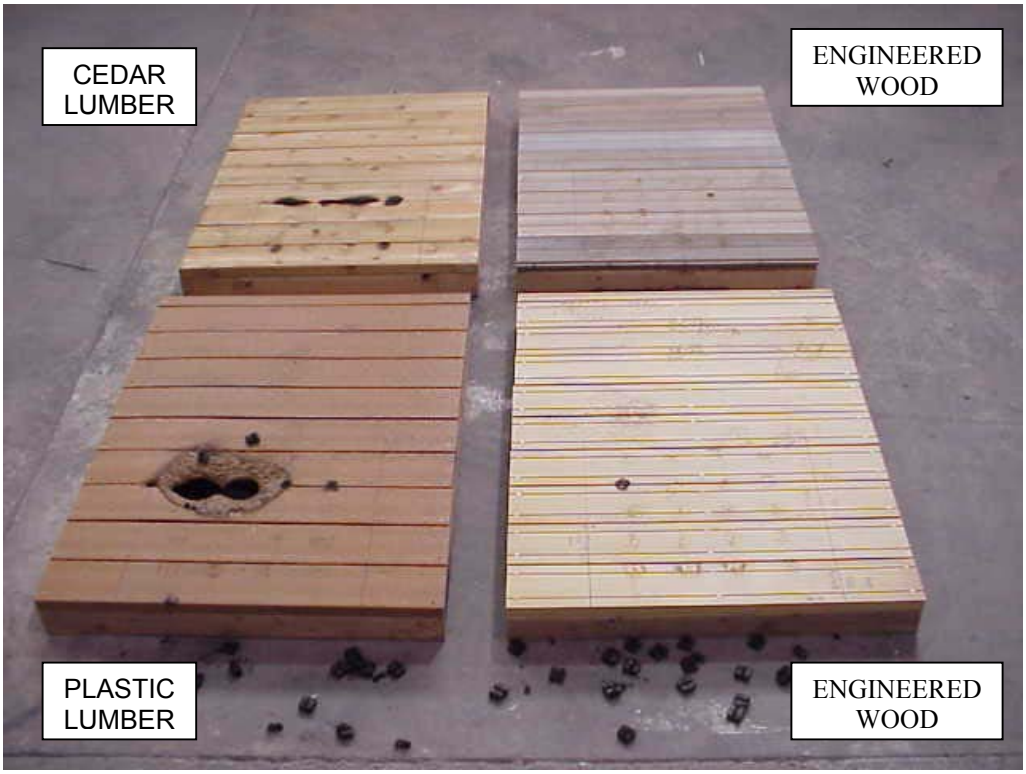


Figure 5. Fire propagation test results.