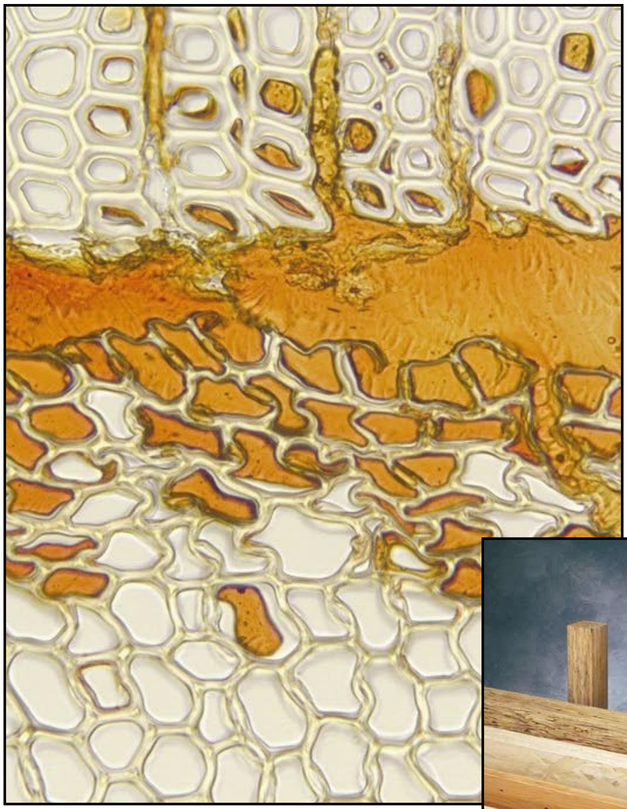
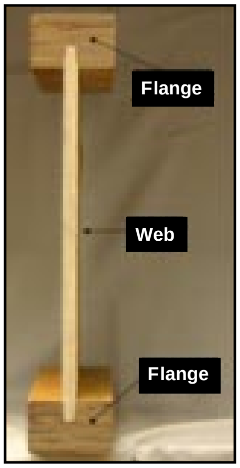
ADHESIVES AWARENESS GUIDE





American Wood Council

American
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ADHESIVES AWARENESS GUIDE

The American Wood Council (AWC) is the voice of North American traditional and engineered wood products, representing over 75% of the industry. From a renewable resource that absorbs and sequesters carbon, the wood products industry makes products that are essential to everyday life and employs over one-third of a million men and women in well-paying jobs. AWC's engineers, technologists, scientists, and building code experts develop state-of-the-art engineering data, technology, and standards on structural wood products for use by design professionals, building officials, and wood products manufacturers to assure the safe and efficient design and use of wood structural components. For more wood awareness information, see www.woodaware.info.

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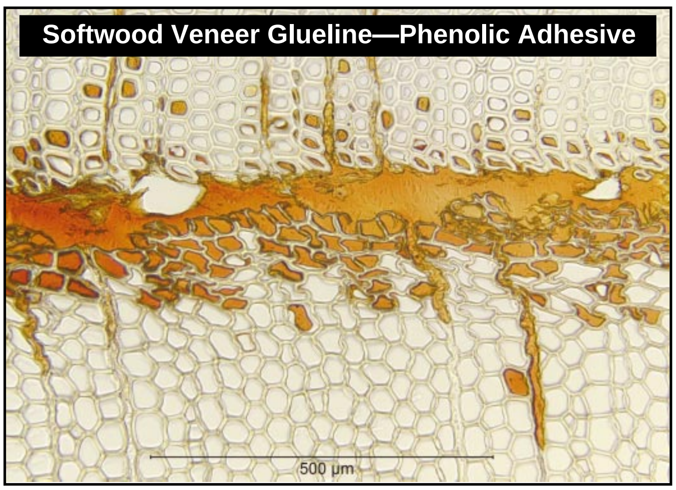
The purpose of this informational guide is to provide awareness to the fire service on the types of adhesives used in modern wood products in the construction of residential buildings. This publication is one in a series of eight Awareness Guides developed under a cooperative agreement between the Department of Homeland Security's United States Fire Administration and the American Wood Council.

Adhesives Used in Modern Engineered Wood Products

PURPOSE OF THIS GUIDE

The purpose of this Awareness Guide is to provide the fire service with information on the types and properties of adhesives used in modern engineered wood products (EWP) and structural wood panels (Figure 1). The guide also tells how these materials are used in residential construction.

Figure 1 Softwood Veneer Glue Line—Microscopic View



ADHESIVES AND A NEW GENERATION OF PRODUCTS

Getting the Most from Our Forest Resource

Wood adhesives have been important in helping use timber resources efficiently. As large trees become less available, the wood industry has developed new and innovative wood products as alternatives. Wood adhesives have made that possible. These new products use small logs, less desirable species of wood, and even wood that would otherwise be burned or land-filled. Modern engineered wood products are manufactured from wood and as such they have structural characteristics similar to that of solid-sawn lumber. Because the natural defects of solid wood are removed in the manufacturing process, the structural properties of these modern products are more uniform. The type of adhesive used to join the individual pieces could, however, affect their fire resistance characteristics.

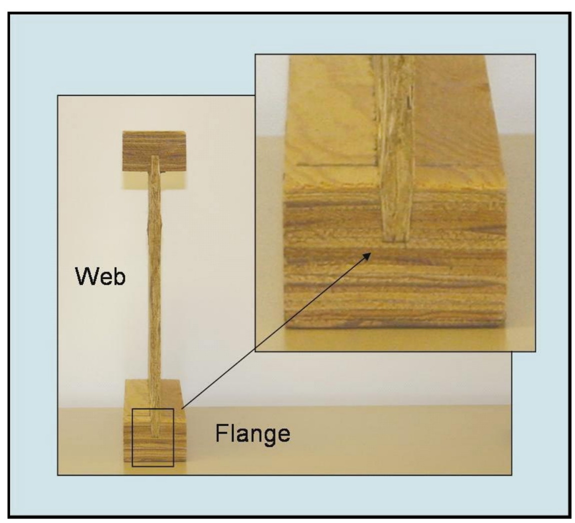
Examples of Modern Engineered Wood Products Using Adhesives

Building products manufactured with adhesives include:

- I-joists (Figure 2)
- End-jointed lumber
- Glued laminated timber (glulam)
- Structural Composite Lumber (e.g. LVL, PSL, LSL, and OSL)
- Oriented Strand Board (OSB)
- Plywood
- Particleboard
- Medium Density Fiberboard (MDF)
- Hardboard
- Architectural doors, windows, and frames
- Factory-laminated wood products

Other products using adhesives in the construction industry include panelized floor and wall systems and nonstructural applications such as floor coverings, countertops, cabinets, furniture, ceiling and wall tile, trim, and decorative accessories.

Figure 2 Glued Components of I-joists



The Laminated Veneer Lumber used for the I-joist flanges (horizontal components) and the Oriented Strand Board used for the web (vertical component) are glued products. The products are bonded together to create an I-joist.

What Adhesives Do

An adhesive is used to bond wood components such as veneer, strands, particles, and fibers, etc. The adhesive must provide the required strength immediately after manufacture as well as after long-term use. Some of the adhesives available for use in the manufacture of modern wood products are suitable for exterior exposures.

Adhesives Used in Wood Products

Natural Adhesives

Before synthetic adhesives were introduced in the 1930s, adhesives made from natural polymers found in plants and animals were used for bonding wood. These adhesives were made from animal blood, hide, casein, starch, soybean, dextrin, and cellulose. While natural adhesives are still being used in some non-structural products, they do not provide the necessary strength and durability required for todayÕs engineered wood products.

Synthetic Adhesives

To meet the needs of modern engineered wood products, polymer scientists have developed synthetic adhesives. These adhesives are designed to perform a variety of functions in product applications. As such, there are many types of wood adhesives used in the manufacture of wood products. The choice of an adhesive is based on many factors, such as cost, structural performance, fire performance, moisture resistance, adhesive curing needs, etc. Some of the early synthetic adhesives were similar in chemical structure to lignin, the natural adhesive in solid-sawn lumber that bonds wood fibers.

Two Adhesives Groups

Adhesives used in the North American wood products industry today fall into two primary groups:

Group 1: Adhesives for Structural Products

- This group of adhesives includes Phenolic (also called phenol formaldehyde or PF), resorcinol, phenol resorcinol, polymeric diphenylmethane diisocyanate (polymeric MDI), emulsion polymer isocyanate, polyurethane/emulsion polymer, polyurethane polymer, polyvinyl acetates (PVA), and melamine. These adhesives are generally used in wood products that require structural strength immediately after manufacture and after exposure to moisture (see Table 1).
- Examples of structural products: OSB, plywood, glued laminated timber (glulam), I-joists, end-jointed lumber, and structural composite lumber (Figure 3).

Group 2: Adhesives for Interior, Non-Structural Products

- This group of adhesives includes urea formaldehyde (also called urea or UF), hot melt, casein, blood, starch, and animal glues. Because of their low resistance to heat and moisture, these adhesives are generally used for indoor, non-structural wood products, such as particleboard, decorative wall paneling, medium density fiberboard (MDF) for furniture, and cabinets, interior doors, and architectural millwork.

Thermoplastic vs. Thermosetting Adhesives

Synthetic polymer adhesives can also be further classified as *thermosetting* and *thermoplastic.* In general, modern wood products made for structural applications use thermosetting adhesives. Thermosetting adhesives undergo a chemical change during application and curing. The bonds formed by thermosetting adhesives are generally moisture resistant, and support loads under normal use.

Thermoplastic adhesives do not undergo a chemical change during the application or the curing process. Such adhesives may soften when exposed to heat and therefore have a limited application where structural fire performance is desired. There are also adhesives that have both thermosetting and thermoplastic characteristics.

Thermosetting Polymers

Thermosetting polymers undergo irreversible chemical change when cured. While the method of curing depends on the specific adhesive, a typical method of curing involves the use of heat and pressure. During curing they form cross-linked polymers with high strength and resistance to moisture and other chemicals.

The degree of moisture resistance depends on the type of thermosetting adhesive used. Phenolic, resorcinol, phenol-resorcinol, polymeric MDI, emulsion polymer isocyanate, polyurethane/emulsion polymer, polyurethane polymer, and melamine adhesives have excellent moisture resistance. They are used in structural panels and structural wood products, since they are able to support long-term static loads without deforming. Urea, although a thermosetting resin, offers high strength when dry, but has poor moisture resistance and is used primarily in interior applications (floor underlayment, furniture, and cabinets, etc.) that are not generally exposed to moisture.

Bond Integrity:
Does the Glue Hold When Exposed to Fire?

A study conducted at the U.S. Department of Agriculture Forest Products Laboratory evaluated bond integrity of Douglas-fir and Southern Pine blocks after exposure to fire. For the test, the blocks were glued together with phenol resorcinol, polyvinyl acetate (PVA), urea, melamine, 60/40 blend of melamine and urea, and casein adhesives (Schaffer). The integrity of both the pyrolysis and normal wood zones were examined. (Pyrolysis is the decomposition of wood into simpler components when subjected to heat.) The author concluded that with both wood species:

- Phenol resorcinol and melamine adhesives maintained bond integrity throughout the pyrolysis and normal wood zones.
- Urea, a 60/40 melamine and urea blend, and casein adhesives had bond separation in the pyrolysis zone, but maintained bond integrity throughout the normal wood zone.
- Polyvinyl acetate adhesives had bond separation in both the pyrolysis and normal wood zones.

Thermoplastic Polymers

Thermoplastics are long-chain polymers that soften and flow on heating, and then re-harden upon cooling. They generally have less resistance to heat, moisture, and long-term static loading than do thermosetting polymers. Common wood adhesives based on thermoplastic polymers include: polyvinyl acetate emulsions, elastomerics, contacts, and hot-melts.

The fact that thermoplastic adhesives soften and flow when exposed to heat limits their use in modern wood products where fire resistance ratings are required. However, they are widely available for use in the manufacture of furniture, counter tops, laminating, and other applications not requiring a fire rating.

Many Adhesives, One I-joist

The efficient manufacture of some structural engineered wood products may require that different types of adhesives be used during the manufacturing process. Wood I-joists, for example, are typically fabricated with more than one type of adhesive. A phenolic or polymeric MDI adhesive (or both) may be used to manufacture the hot-press oriented strand board (OSB) or softwood plywood panels used for the web. The web might then be joined to the flange with resorcinol or polymeric isocyanate adhesives designed to cure in a warm room, or at ambient temperature. The flange could be laminated veneer lumber (LVL) or end-jointed lumber. LVL is typically bonded with phenolic adhesives in a hot press. I-joist end-jointed lumber flanges are assembled by bonding machined finger-shaped pieces end-to-end, typically with phenol resorcinol formaldehyde (PRF), polyurethane or melamine adhesives. PRF adhesive is usually cured by radio frequency (RFÑa process somewhat similar to heating food in a microwave oven), while end pressure is applied to obtain good contact between the fingers.

Figure 3 Examples of Engineered Wood Products Today

From left to right: I-joist, Oriented Strand Lumber (OSL), Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), and Parallel Strand Lumber (PSL).

Adhesive Performance During a Fire

Fire containment, fire growth, smoke density, and smoke toxicity are important issues to firefighters. It is important that firefighters know how modern wood products may perform in a fire.

Phenolic and resorcinol adhesives have been used to manufacture structural wood products since the 1950s. As such, most of the historical performance information is based on experiences with these adhesives.

Fire Performance of End-jointed Lumber

Recent fire resistance tests by Forintek Canada and American Wood Council (AWC) have shown that the type of adhesive used can affect the fire resistance rating of end-jointed lumber (Figure 4) used in stud wall assemblies.

The following table summarizes the full-scale fire-resistance test results.[1] All fire tests were conducted on the 1-hour rated wall assembly design specified in *2003 International Building Code* Table 720.1(2), Item Number 15-1.14 (identical to *2006 International Building Code* Table 720.1(2), Item Number 15-1.15).

End-jointed Lumber Adhesive	Fire Resistance Rating
Phenol Resorcinol Formaldehyde	1 hour
Polyurethane	51 minutes
Polyvinyl Acetate	49 minutes

To address this adhesive performance issue, a method has been developed to qualify adhesives for use in end-jointed lumber used in fire-rated assemblies.[2]

The American Lumber Standard Committee, the committee that develops rules for lumber grading, now requires that end-jointed lumber made with qualifying adhesives be marked ÒHRAÓ and others be marked ÒNon-HRA.Ó[3] End-jointed lumber, marked ÒHRA,Ó is interchangeable with solid-sawn lumber in 1-hour fire-rated assemblies, while those marked ÒNon-HRAÓ are not.

A Misconception

It is sometimes assumed that adhesives ignite more easily, and cause faster flame spread and more toxic smoke than wood alone. Available fire test data does not support this assumption and hence it is a misconception.

Figure 4 Example of 2x4 End-jointed Lumber

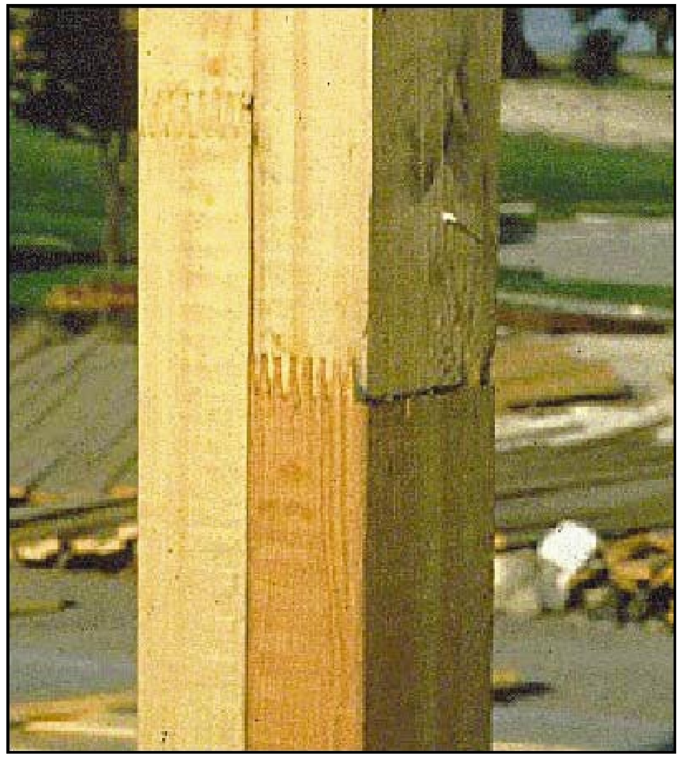


Table 1: Types of Adhesives Used in Modern Wood Products	
Engineered Wood Products	**Type of Thermosetting Adhesive Used**
Wood Structural Panels	
Oriented Strand Board (OSB)	Phenolic, Polymeric MDI
Softwood Plywood	Phenolic
Wood I-joists	
Web (OSB or Softwood Plywood)	Phenolic, Polymeric MDI
Flange (Finger-Jointed Lumber)	Melamine, Phenol resorcinol, Resorcinol, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive, Polyurethane/Emulsion polymer adhesive
Flange (Structural Composite Lumber)	Phenolic, Polymeric MDI
Web/Flange Joint	Phenol resorcinol, Polyurethane polymer adhesive, Polyurethane/ Emulsion polymer adhesive, Emulsion polymer isocyanate adhesive
Web/Web Joint	Phenol resorcinol, Polyurethane polymer adhesive, Polyurethane/ Emulsion polymer adhesive, Emulsion polymer isocyanate adhesive
Glued Laminated Timber (Glulam)	
Laminating	Melamine, Phenol resorcinol, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive
Finger Joint	Melamine, Phenol resorcinol, Resorcinol, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive, Polyurethane/Emulsion polymer adhesive
Structural Composite Lumber	
Laminated Veneer Lumber (LVL)	Phenolic, Polyurethane polymer adhesive, Emulsion polymer isocyanate adhesive, Polyurethane/ Emulsion polymer adhesive
Laminated Strand Lumber (LSL)	Phenolic, Polymeric MDI
Parallel Strand Lumber (PSL)	Phenolic
Oriented Strand Lumber (OSL)	Phenolic, Polymeric MDI
End-jointed Lumber	Polyvinyl acetate, Polyurethane, Phenol Resorcinol, Melamine

Note: The information above refers only to examples. Modern wood product manufacturers may use other types of adhesives or a combination of adhesives.

Combustibility

All organic materials will burn when subjected to sufficient heat in the presence of oxygen. Adhesives are no exception.

Charring

When wood is exposed to elevated temperatures, the surface of the wood undergoes thermal degradation resulting in the formation of a residual char layer.

A study conducted by the USDA Forest Products Laboratory evaluated the performance of several adhesive bondsÑin OSB, softwood plywood, Com-Ply¨, and LVLÑwhen exposed to the fire exposure specified in ASTM E119. Results showed that the linear charring rate ranged from 1.45 to 1.52 mm/min, which is similar to the 1.6 mm/min charring rate for some species of solid-sawn wood. The tested glued-wood products contained phenolic and/or polymeric MDI (White, 2003).

The rigid three-dimensional, cross-linked structure of a phenolic adhesive resists thermal stress without softening or melting. As the phenolic material is heated to ignition temperature, it is transformed into a char-forming material (Knop).

Smoke Obscuration and Toxicity

The amount of smoke released from wood burning has been measured for most wood products. Like flamespread, this index has a value of 100 for red oak. Most of the solid and engineered wood products tested did not exceed a smoke developed index of 450, a limiting value used in building codes.

The major chemical elements found in wood products are carbon, hydrogen, and oxygen. When burned, these elements primarily produce carbon monoxide, carbon dioxide, and water. Where nitrogen or halogens are present, the potential for production of hydrogen cyanide, nitrogen oxides, and hydrogen halide during the burning process exists.

Solid wood, as well as some of the adhesives used to manufacture modern engineered wood products, contain small amounts of nitrogen and thus have the potential to form and give off some quantity of hydrogen cyanide and nitrogen oxides when they burn.

Combustion toxicity research has shown there is no significant difference in the toxicity of the smoke from solid wood and modern engineered wood products. Because the adhesive is a minor component (usually 2-5%) of an engineered wood product and is mostly contained within the product, the effect on toxic combustion products is small, if any.

Studies on Toxicity

Phenolics

In *Phenolic Resins: Chemistry, Applications and Performance–Future Directions (Knop),* the following is reported:

- Phenolics are fire resistant materials with low smoke emission and low toxicity; hence, they exhibit favorable flame retardant characteristics under fire conditions.
- Since phenolics are mainly composed of carbon, hydrogen, and oxygen, their combustion products are water vapor, carbon dioxide, carbon char, and moderate amounts of carbon monoxide, depending on combustion conditions. The toxicity of the corresponding combustion products is, therefore, relatively low.

Other Adhesives

Morikawa reports that polymeric MDI (pMDI), polyurethane based adhesives, and melamine adhesives contain nitrogen, and thus when burned can give off some quantity of hydrogen cyanide and nitrogen oxides, as well as carbon monoxide and carbon dioxide.

A study conducted for Huntsman Polyurethanes by Warrington Fire Research in the United Kingdom (using the Tubular Furnace method,[4] compared the gaseous combustion products (carbon monoxide, carbon dioxide, hydrogen cyanide, and nitrogen oxide) from untreated wood to those from wood glued with 3% pMDI, 6% phenolic, and 8% UF[5] (urea formaldehyde). Results showed the following (ranked from lowest quantity to highest quantity):

- Carbon monoxide off-gassing
  - 3% pMDI (lowest)
  - 8% UF
  - Untreated wood
  - 6% PF (highest)
- Carbon dioxide off-gassing
  - 3% pMDI
  - Untreated wood
  - 8% UF
  - 6% PF
- Hydrogen cyanide
  - 6% PF
  - Untreated wood
  - 3% pMDI,
  - 8% UF
- Nitrogen oxide
  - 6% PF
  - 3% pMDI
  - Untreated wood
  - 8% UF

Ashland, a specialty chemical company, reports (Ashland, 2001) that there was no difference in thermal decomposition of products during the burning of samples of black spruce with and without finger joints bonded with a polyurethane polymer.

Fire Resistance of Structural Composite Lumber

Structural Composite Lumber (SCL) is a modern alternative to large-section solid-sawn and glulam timbers. In general, SCL and solid-sawn wood products burn similarly in a fire. As with solid-sawn wood, the size and mass of SCL has an effect on fire resistance. A study conducted at the USDA Forest Products Laboratory involving several types of SCL (laminated veneer lumber, parallel strand lumber, and laminated strand lumber), showed that charring of SCL products was comparable to solid-sawn wood and glulam.[6] These results support the use of fire resistance calculation design proceduresÑdeveloped for solid-sawn wood and glulamÑfor SCL as well. (White, 2000). The adhesives used in the SCL products tested in this study were polymeric MDI and phenolics.

General Thermal Degradation Information

Phenolic adhesives are temperature-resistant polymers and yield high amounts of char during pyrolysis (Knop).

The thermal degradation of phenolic adhesives can be divided into three stages (Knop):

- In the first stage, up to 300° C (572° F), the polymer remains virtually intact. The quantity of gaseous components released during this stage is relatively small (1-2%) and consists mainly of water and unreacted monomers (phenol and formaldehyde) that were entrapped during curing.
- During the second stage, from 300° C to 600° C (572° F to 1112° F), decomposition commences and gaseous components (mainly water, carbon monoxide, carbon dioxide, methane, phenol, cresols, and xylenols) are emitted. Random chain breakage begins to occur in both the adhesive and wood.
- In the third stage, above 600° C (1112° F), carbon dioxide, methane, water, benzene, toluene, phenol, cresols, and xylenols are liberated.

END NOTES

[1] ASTM E119, "Standard Test Methods for Fire Tests of Building Construction and Materials," American Society for Testing and Materials, 2005, http://www.astm.org

[2] *http://www.awc.org/Technical/Elevated-TemperatureAdhesiveQualificationProcedure.pdf*

[3] http://www.alsc.org/untreated_gluedlbr_mod.htm

[4] DIN 43436, 500° C, air flow rate 5 lpm.

[5] It is noted that UF resins are designed for use in interior, non-structural applications and are not used in structural engineered wood products.

[6] Several of these products are used in the top and bottom flanges of wood I-joists.

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Appendix A

Weyerhaeuser

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Report on:

LC_{50} VALUES OF WOOD PRODUCTS USING THE UNIVERSITY OF PITTSBURGH TOXICITY TEST APPARATUS

Conducted on:

EIGHTEEN WOOD PRODUCTS

Conducted for:

ROBERT W. GLOWINSKI
NATIONAL FOREST PRODUCTS ASSOCIATION
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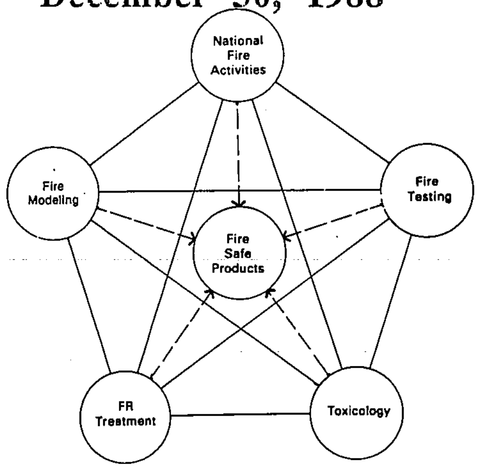
Completed on:
December 30, 1988



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NOTICE

This test method is intended to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or the fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.

INTRODUCTION

Wood products were received from various members of National Forest Products Association for testing. The toxic potency values or LC_{50} values for these wood products were determined using the University of Pittsburgh (UPITT) test procedure as described in Article 15 Part of the *New York State Uniform Fire Prevention and Building Code* [1].

This report includes dimensions of the wood products, test methodology, and the test results.

METHOD

The protocol used is published under Article 15 of the *New York State Uniform Fire Prevention and Building Code* [1]. The LC_{50} values and their confidence intervals were calculated by the Weil method [2].

The UPITT apparatus consisted of a Lindberg furnace (Pittsburgh, PA) connected to an animal exposure chamber. Within the furnace there was a weight load cell upon which the specimen was placed. There was an air flow of eleven (11) liters/minute proceeding from the furnace toward the animal exposure chamber. That air flow was mixed, cooled and diluted with nine (9) liters/minute of cold air (~15°C) before being presented to the animals. The furnace temperature was ramped 20° C/minute. The furnace, however, was not connected to the animals exposure chamber until the specimen had loss 1% of its weight as indicated by the weight load cell. The time at which this occurred was the beginning of the thirty (30)-minute animal exposure. The animal exposure chamber simultaneously housed four (4) male Swiss-Webster mice (Simenon Laboratories, Inc.; Gilroy, CA) in a head-only exposure mode. The decomposition products passed to gas analyzers (carbon monoxide, carbon dioxide and oxygen) after being presented to the animals. The apparatus and protocol were according to the methodology of New York State Protocol [1].

Procedurally, a ten (10)-gram quantity of the material was placed in the furnace after which the ramping of the furnace started. At the 1% weight loss, the animal exposure chamber was connected to the furnace. After the thirty (30)-minute exposure was completed, the animals were observed for an additional ten (10) minutes. Any deaths occurring during these forty (40) minutes were used in the determination of the LC_{50} value. If all the animals died with the ten (10) grams, the next experiment would be with a lower weight. If no animals died, then a higher weight would be used in the next experiment.

That next weight would be determined by a geometric factor. The geometric factor was necessary because of the statistical procedure [2] used for determining the LC_{50} values. This factor (for example, 1.1) would be multiplied by the weight to determine the next higher weight, or the weight would be divided by the factor to determine the next lower weight. Using this statistical procedure, four consequent weights (spaced by the geometric factor along with the corresponding deaths as required by the tables supplied in the reference) were needed to determine an LC_{50} value.

A program was written for a Macintosh® Plus Computer in conjunction with a Fluke 2400A (A/D and D/A measurement and control link) to specifically operate this apparatus. Ramping of the furnace was accomplished by the Macintosh® monitoring the furnace temperature and varying the power supply to the furnace. The specimen weight, the percent of weight loss, concentrations of carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2), time (from the initiation of ramping and from the 1% weight loss), temperatures of the furnace and chamber, and the difference between the actual and theoretical furnace temperatures were displayed on the computer monitor during the experiment as well as recorded on a diskette. The O_2 gas analyzer was a Servomex O_2 Analyzer OA 580 (Sybron/Taylor), and the CO/CO_2 analyzer was a Dual Gas Analyzer (Infrared Industries, Inc.)

In order to confirm that there were no leaks in the system and that the pump, air flow and flowmeters were operating properly, the flow rates of nine (9) and twenty (20) liters/minutes were tested prior to each test with a Mini-Buck Calibrator (A.P. Buck, Inc., Orlando, FL). This flowmeter is traceable to the National Institute of Standards and Technology (formerly National Bureau of Standards). Calibration of the CO and CO_2 analyzers was performed with calibration gases (CO - 0.9% and CO_2 - 5%) certified by Alphagaz Division (Tacoma, WA). The O_2 analyzer was calibrated with room air.

TEST RESULTS

The LC_{50} values and their confidence intervals are presented in Table 1. A number of parameters are reported in summary tables (Table 2-19), such as the minimum oxygen concentration, the maximum carbon monoxide and carbon dioxide concentrations, the maximum animal exposure chamber temperature, the maximum furnace temperature, and the percentage of the specimen weight. Tabulation of the data required by New York State is included (Table 20). These data are from a specimen weight close to the LC_{50} value. The concentration-time (Ct) products for carbon monoxide (Figures 1-18) and carbon dioxide (Figures 19-36) plotted vs the specimen weight are presented for each of the eighteen products. [This Ct product is a value calculated by multiplying the gas concentration, such as carbon monoxide, with the time of animal exposure to the gas concentration. In other words, it is the area under the curve of the gas concentrations vs time.]

REFERENCES

1. Article 15, Part 1120 -- New York State Fire Prevention and Building Code. New York Standards & Fire Information Network, Office of Fire Prevention and Control. Albany, NY.

2. Weil, C.S., Tables For Convenient Calculation Of Median-Effective Dose (LC_{50} or ED_{50}) And Instructions In Their Use. *Biometrics* 8: 249-263, 1952.

SAMPLE PREPARATION

These wood products were stored in a conditioning room (23.8 ± 2.8° C and 50 ± 10% Relative Humidity) for at least 48 hours prior to testing. Each specimen placed in the furnace was a piece of a wood product cut to a specific weight.

WOOD PRODUCT DIMENISONS

Wood Product	Length (inch)	Width (inch)	Thickness (inch)
Douglas Fir	37	7.1	1.50
Redwood	16.3	7.3	0.76
Southern Pine	>72	3.4	1.48
White Spruce	>72	3.5	1.50
Red Oak	~36	7.8	0.79
Yellow Poplar	~36	8.1	0.82
Douglas Fir Plywood	45.8	24	0.60
Southern Pine Plywood	46	24	0.60
Oriented Strandboard	48	24	0.46
Waferboard	48	24	0.43
Standard Hardboard	48	48	0.25
Tempered Hardboard	48	48	0.25
Fiberboard	24	24	0.75
Particleboard	24	24	0.76
Lauan Plywood	96	16	0.15
CCA-treated Southern Pine	24	3.5	1.47
AZCA-treated Douglas Fir	11.8	7.4	1.47
Fire Retardant-treated Southern Pine	23.8	3.5	1.50

Table 1: LC_{50} Values and their Confidence Intervals

Wood Product	LC50 Value	95% Confidence Interval	
	(grams)	Lower Value	High Value
Douglas Fir	25.38	22.60	28.50
Redwood	7.68	6.61	8.93
Southern Pine	12.39	10.70	14.35
White Spruce	7.47	6.53	8.54
Red Oak	15.75	11.12	22.31
Yellow Poplar	11.07	9.90	12.38
Douglas Fir Plywood	11.83	10.59	13.20
Southern Pine Plywood	11.64	9.30	14.56
Oriented Strandboard	12.40	9.95	15.45
Waferboard	13.64	9.63	19.31
Standard Hardboard	8.16	6.59	10.11
Tempered Hardboard	8.04	6.99	9.24
Fiberboard	10.11	7.25	14.10
Particleboard	8.94	7.70	10.37
Lauan Plywood	20.95	17.68	24.82
CCA-treated Southern Pine	24.16	20.30	28.76
AZCA-treated Douglas Fir	11.28	10.04	12.66
Fire Retardant-treated Southern Pine	15.74	14.71	16.83

SUMMARY TABLES

Table 2: Douglas Fir

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	30.69	27.92	25.38	23.07	20.97
Maximum Chamber Temperature (°C)	51.5	45.4	51.3	48.9	51.3
Maximum Furnace Temperature (°C)	791.9	823.0	834.2	827.2	829.5
Weight Loss (%)	80.45	73.07	87.16	71.65	69.43
Minimum Oxygen Concentration (%)	20.8	20.87	20.88	20.84	19.92
Maximum CO Concentration (ppm)	11518	11135	11567	8466	8495
Maximum CO2 Concentration (ppm)	59862	49012	49500	46960	41486
Number of Animals Exposed	4	4	4	4	4
Number of Dead Animals	4	2	3	1	0
Lethality (%)	100	50	75	25	0
Ct Product for CO (ppm x min)	36351	34783	33325	19953	22526
Ct Product for CO2 (ppm x min)	558741	456663	448379	442884	345227
T1% (°C)	199	233	245	232	236

Table 3: Redwood

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10	Test 11
Specimen Weight (grams)	14.32	13.02	13.02	11.84	10.76	9.77	8.88	8.07	7.33	6.66	6.66
Maximum Chamber Temperature (°C)	44	47.7	48.5	48	45	47.1	45.2	46.6	48.7	43.5	45.5
Maximum Furnace Temperature (°C)	826	816.6	830.7	832.4	864.8	831.9	823.6	829.5	837.7	833	836.6
Weight Loss (%)	86.5	79.5	92.2	85.1	82.4	not reliable	94.8	70.5	not reliable	not reliable	not reliable
Minimum Oxygen Concentration (%)	18.24	19.21	18.43	19.43	19.5	19.47	19.91	19.79	19.91	19.94	20.09
Maximum CO Concentration (ppm)	10860	9604	9997	8613	8809	7799	6337	6023	5090	5081	4963
Maximum CO2 Concentration (ppm)	18028	7863	17442	6788	6104	6837	5983	5908	5469	5713	5908
Number of Animals Exposed	4	4	4	4	4	4	4	4	4	4	4
Number of Dead Animals	3	4	4	4	3	4	3	3	1	3	1
Lethality (%)	75	100	100	100	75	100	75	75	25	75	25
Ct Product for CO (ppm x min)	63960	69789	55983	65394	65315	55178	48767	44512	42000	38213	38593
Ct Product for CO2 (ppm x min)	173619	154945	165693	129898	118521	103332	104647	97096	95120	82177	84225
T1% (°C)	231	225	234	237	274	235	231	237	244	237	244

Table 4: Southern Pine

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Specimen Weight (grams)	10.00	7.00	8.47	7.70	6.36	12.38	18.16	21.96	26.58	8.06
Maximum Chamber Temperature (°C)	46.0	49.0	44.8	46.0	45.7	44.4	42.9	44.9	37.7	38.0
Maximum Furnace Temperature (°C)	801.3	799.9	798.1	797	798.3	796.1	798.5	797.4	799.1	795.1
Weight Loss (%)	85	87	84	89.5	86	89.4	87.1	84.6	85	85.3
Minimum Oxygen Concentration (%)	17.97	20.09	18.16	19.93	20.11	17.57	17.06	16.09	16.1	18.11
Maximum CO Concentration (ppm)	7385	4759	6682	4624	3638	7185	11021	11276	10397	6176
Maximum CO2 Concentration (ppm)	21065	3993	12787	4733	4174	22014	26137	29662	39548	9567
Number of Animals Exposed	0	4	4	4	4	4	4	4	4	4
Number of Dead Animals	-	1	1	3	0	0	3	1	0	1
Lethality (%)	-	25	25	75	0	0	75	25	0	25
Ct Product for CO (ppm x min)	23343	29256	24398	29885	24447	21638	32059	28811	29201	26782
Ct Product for CO2 (ppm x min)	112837	59834	77072	69141	59388	132588	188749	127918	228286	68553
T1% (°C)	198	196	196	196	196	196	196	196	196	196

Test Sequence	Test 11	Test 12	Test 15	Test 16	Test 17	Test 18	Test 19	Test 20	Test 21	Test 22
Specimen Weight (grams)	7.34	6.67	32.16	38.92	10.24	26.58	29.24	24.17	12.40	9.32
Maximum Chamber Temperature (°C)	44.1	42.8	42.8	44.3	45.1	47.2	42.1	49.2	44.7	47.5
Maximum Furnace Temperature (°C)	798.3	796.3	797.2	796.8	800.7	797.9	795.2	799.4	818.1	800.4
Weight Loss (%)	89.9	88	84.3	82.9	89.2	10.5 ?	84.1	85.5	88.6	92.1
Minimum Oxygen Concentration (%)	19.91	20.24	14.69	6.48 ?	16.69	12.38	12.28	13.82	16.92	19.53
Maximum CO Concentration (ppm)	5369	4457	12433	14169	9911	13075	17010	15178	11790	8969
Maximum CO2 Concentration (ppm)	4527	3805	52773	80422	30565	74970	45455	35011	25364	7129
Number of Animals Exposed	4	4	4	4	4	4	4	4	4	4
Number of Dead Animals	2	0	3	1	0	3	3	4	2	2
Lethality (%)	50	0	75	25	0	75	75	100	50	50
Ct Product for CO (ppm x min)	32411	27750	36514	49383	31826	26333	46445	41556	29359	49560
Ct Product for CO2 (ppm x min)	67735	55802	373716	500558	148344	415552	340636	299702	152076	105848
T1% (°C)	196	196	196	196	196	196	196	196	196	196

Test Sequence	Test 23	Test 24	Test 25	Test 26	Test 27
Specimen Weight (grams)	15.01	16.51	13.64	11.27	13.64
Maximum Chamber Temperature (°C)	46.9	47.0	42.2	49.3	48.0
Maximum Furnace Temperature (°C)	797.6	798.7	798.8	804.3	810.5
Weight Loss (%)	87.4	86.2	83.9	87.5	88.8
Minimum Oxygen Concentration (%)	15.46	16.51	16.88	17.81	17.42
Maximum CO Concentration (ppm)	15693	14401	14717	11430	13696
Maximum CO2 Concentration (ppm)	27996	29751	25984	20244	23836
Number of Animals Exposed	4	4	4	4	4
Number of Dead Animals	4	1	0	3	2
Lethality (%)	100	25	0	75	50
Ct Product for CO (ppm x min)	48038	42740	46023	38885	49380
Ct Product for CO2 (ppm x min)	163313	222782	176999	121687	166137
T1% (°C)	196	196	196	196	196

Table 5: White Spruce

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Specimen Weight (grams)	10.00	7.00	8.47	7.70	10.24	5.79
Maximum Chamber Temperature (°C)	49.2	46.8	48.8	48.9	44.2	42.0
Maximum Furnace Temperature (°C)	773.9	775.4	774.5	773.7	771	773.2
Weight Loss (%)	94.5	94	93.6	89.1	91.3	91
Minimum Oxygen Concentration (%)	19.35	19.92	19.54	19.88	19.32	20.51
Maximum CO Concentration (ppm)	8226	5349	7366	5426	9324	4254
Maximum CO2 Concentration (ppm)	7929	5257	6663	5869	7992	5349
Number of Animals Exposed	0	4	4	4	4	4
Number of Dead Animals	-	1	4	0	3	0
Lethality (%)	-	25	100	0	75	0
Ct Product for CO (ppm x min)	46020	30804	38637	31298	46882	26128
Ct Product for CO2 (ppm x min)	115758	75571	90018	78318	108793	65658
T1% (°C)	172	172	172	172	172	172

Table 6: Red Oak

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Specimen Weight (grams)	25.40	23.08	20.98	19.07	17.34	15.76	14.32
Maximum Chamber Temperature (°C)	43.7	48.7	47.8	47.7	44.7	47.7	47.5
Maximum Furnace Temperature (°C)	730.8	829.5	833.0	827.2	803.6	833.0	811.9
Weight Loss (%)	83.03	70.02	86.7	92.61	82.64	4.12*	68.51
Minimum Oxygen Concentration (%)	13.89	19.89	20.98	14.62	14.72	14.79	15.64
Maximum CO Concentration (ppm)	10222	12587	10821	12077	8142	13127	12705
Maximum CO2 Concentration (ppm)	57711	54193	52922	49696	51602	46178	40460
Number of Animals Exposed	4	4	4	4	4	4	4
Number of Dead Animals	4	3	3	4	1	2	3
Lethality (%)	100	75	75	100	25	50	75
Ct Product for CO (ppm x min)	34796	41656	34881	38284	26807	30731	42812
Ct Product for CO2 (ppm x min)	341668	335828	329666	285181	288667	233861	198355
T1% (°C)	129	238	244	235	207	241	221

Table 7: Yellow Poplar

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Specimen Weight (grams)	19.05	17.32	15.75	14.32	13.02	11.83	10.74	9.76	9.75
Maximum Chamber Temperature (°C)	42.3	43.9	50.6	42.7	45.3	47.8	47.3	45.9	47.8
Maximum Furnace Temperature (°C)	817.8	857.7	814.2	810.7	822.5	823.6	830.7	822.5	826
Weight Loss (%)	80.1	not reliable	93.5	85.2	not reliable	81.2	87.5	81.4	80.0
Minimum Oxygen Concentration (%)	15.39	14.94	16.23	17.82	19.06	17.06	16.88	19.5	18.23
Maximum CO Concentration (ppm)	12548	13245	13725	10585	11567	9290	7710	8505	8741
Maximum CO2 Concentration (ppm)	46960	43050	33862	39727	7668	27705	29953	7228	19152
Number of Animals Exposed	4	4	4	4	4	4	4	4	4
Number of Dead Animals	4	4	4	3	4	2	2	4	1
Lethality (%)	100	100	100	75	100	50	50	100	25
Ct Product for CO (ppm x min)	46242	48073	data can not be	37829	66639	36460	30102	50889	33127
Ct Product for CO2 (ppm x min)	254541	243162	read again	212712	119846	180248	159722	93605	126918
T1% (°C)	221	268		219	.228	231	237	228	231

Table 8: Douglas Fir Plywood

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Specimen Weight (grams)	10.00	10.25	12.40	13.64	15.01	12.40	11.27
Maximum Chamber Temperature (°C)	41.3	36.91	43.09	44.5	38.2	39.38	42.42
Maximum Furnace Temperature (°C)	831.2	854.7	834.6	846.9	836.3	833.9	835.0
Weight Loss (%)	not reliable	82.1	84.6	79.6	82.4	77.0	84.1
Minimum Oxygen Concentration (%)	19.22	19.08	19.26	16.36	15.90	20.75	19.42
Maximum CO Concentration (ppm)	9518	8636	4946	11361	11052	13204	11669
Maximum CO2 Concentration (ppm)	7501	6600	4002	24586	28841	8288	7963
Number of Animals Exposed	0	4	4	4	4	4	4
Number of Dead Animals	-	0	0	2	0	1	4
Lethality (%)	-	0	0	50	0	25	100
Ct Product for CO (ppm x min)	53564	54248	34885	38655	30682	77719	68838
Ct Product for CO2 (ppm x min)	99675	108050	58663	157739	173121	119296	114947
T1% (°C)	230	230	230	230	230	230	230

Table 9: Southern Pine Plywood

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Specimen Weight (grams)	10.00	12.40	10.25	8.47	9.32	11.27	13.64	11.27	15.01
Maximum Chamber Temperature (℃)	46.4	41.5	45.1	42.6	43.7	48.3	42.6	42.4	45.5
Maximum Furnace Temperature (℃)	880.6	835.9	836.1	835.4	836.9	833.1	836.1	831.8	832.2
Weight Loss (%)	79.2	74.8	74.5	70.6	72.0	79.9	76.2	73.7	77.3
Minimum Oxygen Concentration (%)	19.08	19.34	19.77	19.83	19.66	19.28	15.81	19.34	15.82
Maximum CO Concentration (ppm)	8467	13739	9092	8232	9146	11669	14612	13055	15315
Maximum CO2 Concentration (ppm)	6912	7993	6207	6527	7766	9906	36170	8074	40010
Number of Animals Exposed	0	4	4	4	4	4	4	4	4
Number of Dead Animals	-	2	2	0	0	1	1	0	3
Lethality (%)	-	50	50	0	0	25	25	0	75
Ct Product for CO (ppm x min)	41627	64453	46747	38791	44069	55258	37602	57003	44378
Ct Product for CO2 (ppm x min)	107241	105639	98745	90523	113082	129634	176697	109175	200152
T1% (℃)	275	230	230	230	230	230	230	230	230

Table 10: Oriented Strandboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Specimen Weight (grams)	10.00	7.00	8.47	10.25	12.39	15.00
Maximum Chamber Temperature (°C)	45.1	43.6	41.6	46.2	44.5	43.9
Maximum Furnace Temperature (°C)	801.3	801.2	800.7	801.6	799.9	797.6
Weight Loss (%)	86.4	91	84.7	86	84	83.3
Minimum Oxygen Concentration (%)	19.8	20.15	20.09	20.01	19.69	19.48
Maximum CO Concentration (ppm)	6082	3503	4230	5292	7406	9350
Maximum CO2 Concentration (ppm)	5844	3257	4228	4899	6210	7693
Number of Animals Exposed	0	4	4	4	4	4
Number of Dead Animals	-	2	2	0	2	4
Lethality (%)	-	50	50	0	50	100
Ct Product for CO (ppm x min)	31021	18737	24022	27489	36468	43220
Ct Product for CO2 (ppm x min)	77970	53270	67179	75088	81156	96628
T1% (°C)	198	198	198	198	198	198

Table 11: Waferboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Specimen Weight (grams)	10.00	11.27	10.25	13.64	16.51	15.01	12.40	18.16	12.40	13.64
Maximum Chamber Temperature (°C)	45.5	45.5	41.7	44.5	41.6	40.9	45.2	37.5	49.6	48.1
Maximum Furnace Temperature (°C)	831.6	917.5	914.8	898.3	898.2	895.6	897.2	900.5	899.1	901.7
Weight Loss (%)	not reliable	84.6	77.5	80.3	83.8	88.2	81.7	81.4	82.9	87.3
Minimum Oxygen Concentration (%)	19.09	19.13	19.06	19.01	15.09	15.67	19.11	13.72	19.19	18.67
Maximum CO Concentration (ppm)	9773	13050	13647	15925	17912	17175	14115	14347	13360	17713
Maximum CO2 Concentration (ppm)	8554	9718	9889	11929	41835	33485	9504	60248	9697	12454
Number of Animals Exposed	0	4	4	4	4	4	4	4	4	4
Number of Dead Animals	-	1	1	2	1	2	1	0	0	3
Lethality (%)	-	25	25	50	25	50	25	0	0	75
Ct Product for CO (ppm x min)	44498	58841	55509	72472	49973	49031	66541	35337	62605	74128
Ct Product for CO2 (ppm x min)	96103	119225	109747	144697	211721	195553	128689	281878	137745	147258
T1% (°C)	230	310	310	290	290	290	290	290	290	290

Table 12: Standard Hardboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	14.99	7.68	9.21	11.05	6.40
Maximum Chamber Temperature (°C)	50.1	52.5	52.2	47.5	46.7
Maximum Furnace Temperature (°C)	823.6	814.2	823.0	824.8	820.1
Weight Loss (%)	82.1	79.3	not reliable	not reliable	not reliable
Minimum Oxygen Concentration (%)	19.32	20.06	19.97	19.6	20.25
Maximum CO Concentration (ppm)	10693	5208	6189	7563	4031
Maximum CO2 Concentration (ppm)	9134	4442	5126	6886	3465
Number of Animals Exposed	0	4	4	4	4
Number of Dead Animals	-	2	2	4	1
Lethality (%)	-	50	50	100	25
Ct Product for CO (ppm x min)	62881	30632	37699	45643	25856
Ct Product for CO2 (ppm x min)	154560	67539	76713	102369	57758
T1% (°C)	228	223	228	228	225

Table 13: Tempered Hardboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Specimen Weight (grams)	7.68	9.21	11.05	6.40	11.05	11.04	19.79	34.40	28.52	23.75
Maximum Chamber Temperature (℃)	48.2	48.2	41.2	51.4	52.5	53.3	45.5	42.3	43.3	45.7
Maximum Furnace Temperature (℃)	827.2	827.2	823.6	829.5	835.4	822.5	824.8	824.2	824.8	818.9
Weight Loss (%)	not reliable	67.86	73.85	65.47	80.36	83.24	86.71	82.89	not reliable	88.72
Minimum Oxygen Concentration (%)	20.16	19.23	19.92	20.38	19.75	19.66	18.79	12.28	13.33	18.54
Maximum CO Concentration (ppm)	5208	5679	5041	4266	8221	8701	14501	15923	21144	16895
Maximum CO2 Concentration (ppm)	4149	5726	4296	4100	7277	8010	11919	67687	61816	13679
Number of Animals Exposed	4	4	4	4	4	4	4	4	4	4
Number of Dead Animals	3	2	1	0	1	4	4	4	4	4
Lethality (%)	75	50	25	0	25	100	100	100	100	100
Ct Product for CO (ppm x min)	28279	33972	31449	24460	45624	47738	82280	96199	85492	95396
Ct Product for CO2 (ppm x min)	69868	92434	89262	76409	122013	121417	188537	419264	318155	223692
TI% (℃)	232	235	232	232	234	230	228	228	228	225

Table 14: Fiberboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	7.02	10.11	12.13	8.42	14.56
Maximum Chamber Temperature (°C)	32.6	51.4	51.1	52.9	46.8
Maximum Furnace Temperature (°C)	829.5	823.6	827.2	818.9	829.5
Weight Loss (%)	not reliable	not reliable	94.97	not reliable	89.9
Minimum Oxygen Concentration (%)	18.23	19.99	19.7	20.16	19.27
Maximum CO Concentration (ppm)	1980	4933	6729	4060	9526
Maximum CO2 Concentration (ppm)	4540	5517	7032	5078	9769
Number of Animals Exposed	4	4	4	4	4
Number of Dead Animals	0	3	2	1	3
Lethality (%)	0	75	50	25	75
Ct Product for CO (ppm x min)	13287	33493	40995	27034	53205
Ct Product for CO2 (ppm x min)	94392	114129	141464	107431	171765
T1% (°C)	233	232	230	229	230

Table15: Particleboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	9.79	11.75	14.10	8.16	6.80
Maximum Chamber Temperature (℃)	48.1	48	46.8	47.8	48
Maximum Furnace Temperature (℃)	829.5	822.5	824.8	823.6	829.5
Weight Loss (%)	85.5	90.2	89.7	88.9	not reliable
Minimum Oxygen Concentration (%)	19.89	19.58	19.43	20	20.09
Maximum CO Concentration (ppm)	6562	6857	8858	4305	4256
Maximum CO2 Concentration (ppm)	6641	6982	8059	5322	5908
Number of Animals Exposed	4	4	4	4	4
Number of Dead Animals	2	4	4	2	0
Lethality (%)	50	100	100	50	0
Ct Product for CO (ppm x min)	36355	38259	51744	27143	23775
Ct Product for CO2 (ppm x min)	122904	120542	153872	101522	97313
T1% (℃)	230	231	229	232	231

Table 16: Lauan Plywood

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Specimen Weight (grams)	10.00	9.32	10.25	13.64	16.51	19.97	21.97	18.16	24.17
Maximum Chamber Temperature (°C)	34.4	40.31	42.38	40.1	35.61	32.99	33.01	41.88	39.54
Maximum Furnace Temperature (°C)	798.6	803.2	791.7	798.2	798.1	797.3	796.3	799.3	791.5
Weight Loss (%)	79.9	83.6	84.6	77.3	80.9	82.5	83.6	81.8	88.0
Minimum Oxygen Concentration (%)	17.35	19.28	19.76	15.99	15.12	14.62	14.28	11.76	13.56
Maximum CO Concentration (ppm)	3979	4075	4179	4409	5788	7883	7196	6338	11732
Maximum CO2 Concentration (ppm)	6762	5504	6636	7375	9684	11361	11587	14121	17349
Number of Animals Exposed	4	4	4	4	4	4	4	4	4
Number of Dead Animals	1	0	0	0	0	2	2	1	3
Lethality (%)	25	0	0	0	0	50	50	25	75
Ct Product for CO (ppm x min)	34388	31219	37176	37759	43370	49087	48995	49847	72803
Ct Product for CO2 (ppm x min)	110369	98905	117159	136202	163392	179356	191424	185720	279274
T1% (°C)	187	193	190	190	190	190	190	190	190

Table 17: CCA-Treated Southern Pine

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Specimen Weight (grams)	10.00	13.64	18.16	16.51	21.97	19.97	24.17	26.58	29.24	32.16
Maximum Chamber Temperature (℃)	44.82	36.38	46.58	41.5	40.15	37.38	38.21	47.47	38.32	36.73
Maximum Furnace Temperature (℃)	881.2	863.3	857.3	852.1	851.9	862.7	859.4	859.3	867.2	854.7
Weight Loss (%)	75.4	77.2	80.3	85.8	79.4	76.3	78.8	80.3	77.9	76.3
Minimum Oxygen Concentration (%)	20.35	17.42	13.02	17.31	14.19	15.93	13.54	11.69	13.90	13.66
Maximum CO Concentration (ppm)	6570	6543	8768	7371	10348	8186	10595	12759	12626	12996
Maximum CO2 Concentration (ppm)	7813	20846	30411	31954	39393	33749	34323	38774	43724	41432
Number of Animals Exposed	4	4	4	4	4	4	4	4	4	4
Number of Dead Animals	0	0	1	0	3	0	1	1	2	1
Lethality (%)	0	0	25	0	75	0	25	25	50	25
Ct Product for CO (ppm x min)	44477	30745	27726	30246	34064	28498	38599	38931	39787	45657
Ct Product for CO2 (ppm x min)	129761	160054	205811	228041	262532	254023	269821	328396	355292	361273
T1% (℃)	273	255	250	250	250	250	250	250	250	250

Test Sequence	Test 11	Test 12
Specimen Weight (grams)	35.38	26.58
Maximum Chamber Temperature (℃)	36.5	38.4
Maximum Furnace Temperature (℃)	859.6	861.8
Weight Loss (%)	76.7	76
Minimum Oxygen Concentration (%)	15.87	15.43
Maximum CO Concentration (ppm)	14413	11291
Maximum CO2 Concentration (ppm)	45867	38036
Number of Animals Exposed	4	4
Number of Dead Animals	1	0
Lethality (%)	25	0
Ct Product for CO (ppm x min)	48535	38939
Ct Product for CO2 (ppm x min)	314017	306230
T1% (℃)	250	250

Table 18: AZCA-Treated Douglas Fir

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Specimen Weight (grams)	10.00	10.25	12.40	13.64	15.01	16.51	19.97	24.17	32.16	35.38
Maximum Chamber Temperature (°C)	44.1	41.01	45.16	43.9	39.27	39.43	47.74	44.8	40.41	42.24
Maximum Furnace Temperature (°C)	906.8	829.6	894.2	893.2	897.4	888.8	865.0	897.1	862.1	888.5
Weight Loss (%)	83.5	78.4	77.3	76.9	77.2	78.0	81.5	78.6	79.5	78.1
Minimum Oxygen Concentration (%)	19.56	19.57	19.39	19.00	15.05	15.22	11.80	11.81	15.06	14.70
Maximum CO Concentration (ppm)	9528	8888	9977	14082	12950	13683	14396	12364	12493	11290
Maximum CO2 Concentration (ppm)	7793	8129	9344	11296	43196	35073	43120	48880	52957	57367
Number of Animals Exposed	0	4	4	4	4	4	4	4	4	4
Number of Dead Animals	-	0	1	0	0	0	0	0	0	0
Lethality (%)	-	0	25	0	0	0	0	0	0	0
Ct Product for CO (ppm x min)	43661	42119	50718	65467	29125	35389	36647	31708	31223	26854
Ct Product for CO2 (ppm x min)	111394	103951	130683	133969	201656	193742	245588	309778	384345	507765
T1% (°C)	300	227	286	285	286	285	262	286	260	279

Test Sequence	Test 11	Test 12	Test 13	Test 14	Test 15	Test 16	Test 17	Test 18	Test 19
Specimen Weight (grams)	47.09	56.98	68.91	8.47	9.32	11.27	10.25	13.64	12.40
Maximum Chamber Temperature (°C)	47.54	43.2	46.94	50.4	35.29	46.6	41.9	42.3	41.39
Maximum Furnace Temperature (°C)	887.5	887.0	887.9	886.6	890.4	891.0	884.6	893.5	885.1
Weight Loss (%)	76.8	75.02	76.01	95.7	75.7	77.7	80.3	76.2	79.2
Minimum Oxygen Concentration (%)	13.13	12.45	12.42	19.70	19.87	19.01	19.56	19.11	18.73
Maximum CO Concentration (ppm)	12938	12360	10580	9683	8713	13232	8439	12440	15570
Maximum CO2 Concentration (ppm)	68750	76267	82740	6628	7597	9871	7665	10940	11752
Number of Animals Exposed	4	4	4	4	4	4	4	4	4
Number of Dead Animals	1	0	1	0	0	2	1	1	3
Lethality (%)	25	0	25	0	0	50	25	25	75
Ct Product for CO (ppm x min)	30969	34670	30347	41043	39930	56081	44435	57772	72446
Ct Product for CO2 (ppm x min)	569199	718114	886956	74921	117155	112911	107981	133675	159967
T1% (°C)	280	279	280	280	280	280	280	280	280

Table 19: Fire Retardant-Treated Southern Pine

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	10.00	13.64	15.01	16.51	18.16
Maximum Chamber Temperature (°C)	43.09	43.55	42.55	42.0	39.47
Maximum Furnace Temperature (°C)	894.1	861.2	858.1	862.5	862.5
Weight Loss (%)	66.4	68.2	65.6	68.6	65.3
Minimum Oxygen Concentration (%)	19.73	20.10	20.08	19.89	19.74
Maximum CO Concentration (ppm)	2190	6213	7023	8238	8280
Maximum CO2 Concentration (ppm)	4831	5696	6186	6588	6515
Number of Animals Exposed	4	4	4	4	4
Number of Dead Animals	0	0	3	1	4
Lethality (%)	0	0	75	25	100
Ct Product for CO (ppm x min)	20314	40854	48328	53965	50098
Ct Product for CO2 (ppm x min)	89193	96360	115380	118378	117869
T1% (°C)	286	250	250	250	250

Table 20: New York State Data

	Douglas Fir	Redwood	Southern Pine	White Spruce	Red Oak	Yellow Poplar	Douglas Fir Plywood
Number of Samples Tested	5	11	27	6	7	9	7
Furnace Temperature at 1% Sample Mass Loss (°C)	233	235	196	172	223	231	230
Maximal Concentration of Carbon Monoxide in the Exposure Chamber (ppm)	11567	8022	5369	5426	12195	9290	11669
Furnace Temperature at the Point of Maximal Carbon Monoxide (°C)	503	503	487	468	514	482	496
Maximal Concentration of Carbon Dioxide in the Exposure Chamber (%)	4.95	0.61	0.45	0.59	3.32	2.77	0.8
Furnace Temperature at the Point of Maximal Carbon Dioxide (°C)	486	539	532	523	517	458	495
Minimal Concentration of Oxygen in the Exposure Chamber (%)	Not reliable	19.5	19.9	19.9	16.7	17.1	19.4
Furnace Temperature at the Point of Minimal Oxygen (°C)	Not reliable	535	503	473	516	463	496
Number of Times the Exposure Chamber Temperature Exceeded 45°C	4	1	0	1	1	3	0
Average Duration of Exposure Chamber Temperature in Excess of 45°C (sec)	121	103	0	348	998	67	0
Eye Condition of Test Animals: (1) All apparently normal, (2) Some appparent damage, (3) Some severe damage	1	1	1	1	1	1	1

	Southern Pine Plywood	Oriented Strandboard	Waferboard	Standard Hardboard	Tempered Hardboard	Fiberboard	Particleboard
Number of Samples Tested	9	6	10	5	10	5	5
Furnace Temperature at 1% Sample Mass Loss (°C)	230	198	290	223	232	232	232
Maximal Concentration of Carbon Monoxide in the Exposure Chamber (ppm)	13055	7406	17713	5028	5208	4933	4305
Furnace Temperature at the Point of Maximal Carbon Monoxide (°C)	477	467	477	430	404	437	422
Maximal Concentration of Carbon Dioxide in the Exposure Chamber (%)	0.81	0.62	1.25	0.44	0.41	0.49	0.53
Furnace Temperature at the Point of Maximal Carbon Dioxide (°C)	485	472	477	430	485	435	419
Minimal Concentration of Oxygen in the Exposure Chamber (%)	19.3	19.7	18.7	20.1	20.2	20	20
Furnace Temperature at the Point of Minimal Oxygen (°C)	479	472	477	425	498	437	424
Number of Times the Exposure Chamber Temperature Exceeded 45°C	0	0	2	1	2	3	2
Average Duration of Exposure Chamber Temperature in Excess of 45°C (sec)	0	0	121	629	138	174	112
Eye Condition of Test Animals: (1) All apparently normal, (2) Some appparent damage, (3) Some severe damage	1	1	1	1	1	1	1

	Lauan Plywood	CCA-Treated Southern Pine	AZCA-Treated Douglas Fir	Fire Retardant-Treated Southern Pine
Number of Samples Tested	9	12	19	5
Furnace Temperature at 1% Sample Mass Loss (°C)	190	250	280	250
Maximal Concentration of Carbon Monoxide in the Exposure Chamber (ppm)	7883	10595	13232	7023
Furnace Temperature at the Point of Maximal Carbon Monoxide (°C)	409	489	472	492
Maximal Concentration of Carbon Dioxide in the Exposure Chamber (%)	1.14	3.43	0.99	0.62
Furnace Temperature at the Point of Maximal Carbon Dioxide (°C)	409	510	474	722
Minimal Concentration of Oxygen in the Exposure Chamber (%)	14.6	13.5	19	20.1
Furnace Temperature at the Point of Minimal Oxygen (°C)	465	561	474	474
Number of Times the Exposure Chamber Temperature Exceeded 45°C	0	0	1	0
Average Duration of Exposure Chamber Temperature in Excess of 45°C (sec)	0	0	336	0
Eye Condition of Test Animals: (1) All apparently normal, (2) Some appparent damage, (3) Some severe damage	1	1	1	1

Carbon Monoxide Ct Product

vs

Specimen Weight

Figure 1: Douglas Fir

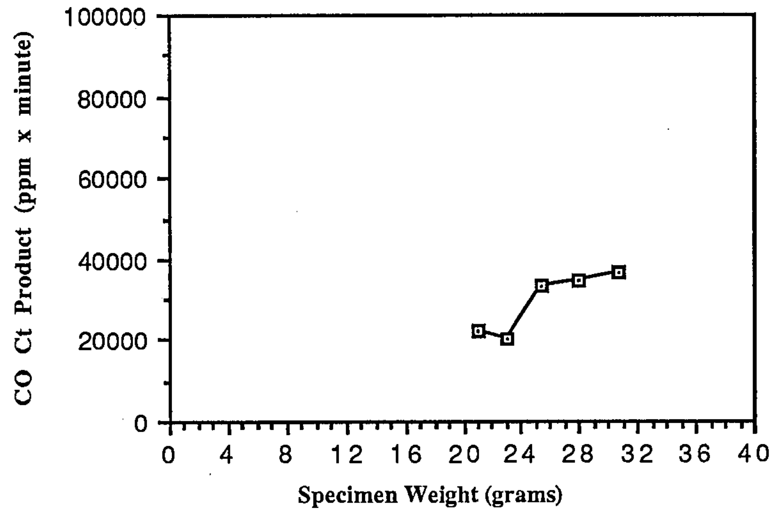


Figure 2: Redwood

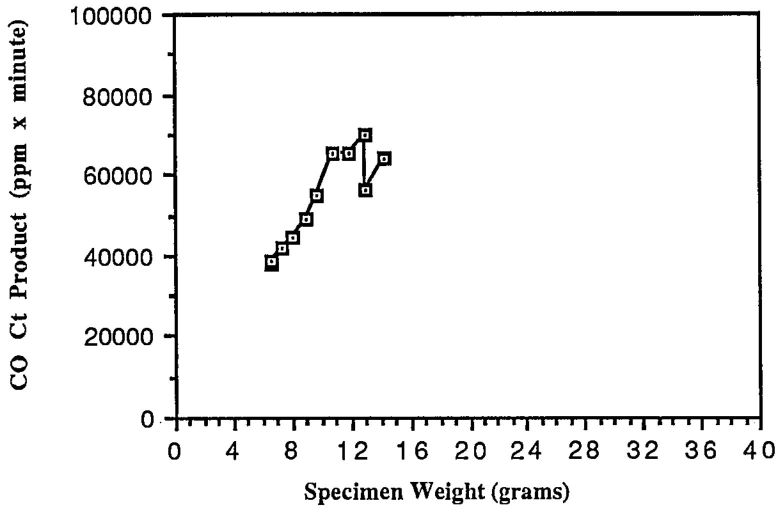


Figure 3: Southern Pine

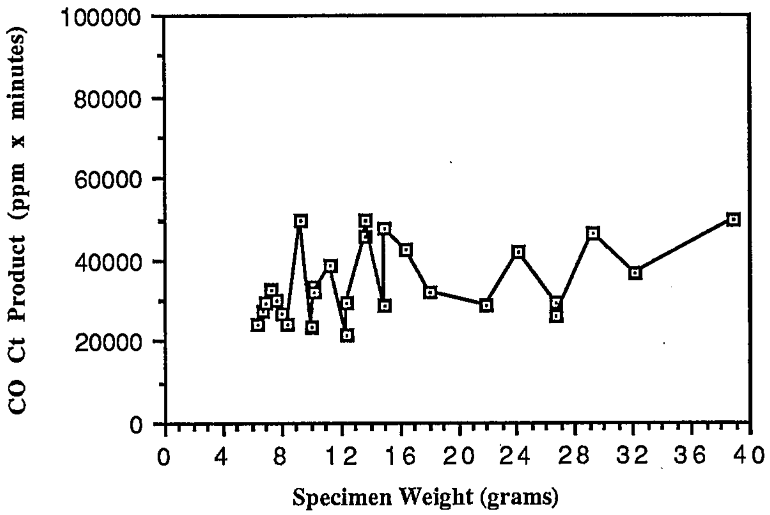


Figure 4: White Spruce

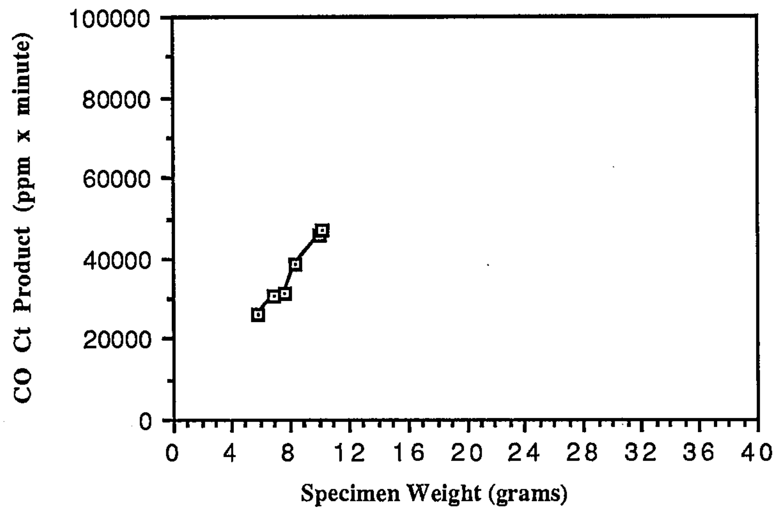


Figure 5: Red Oak

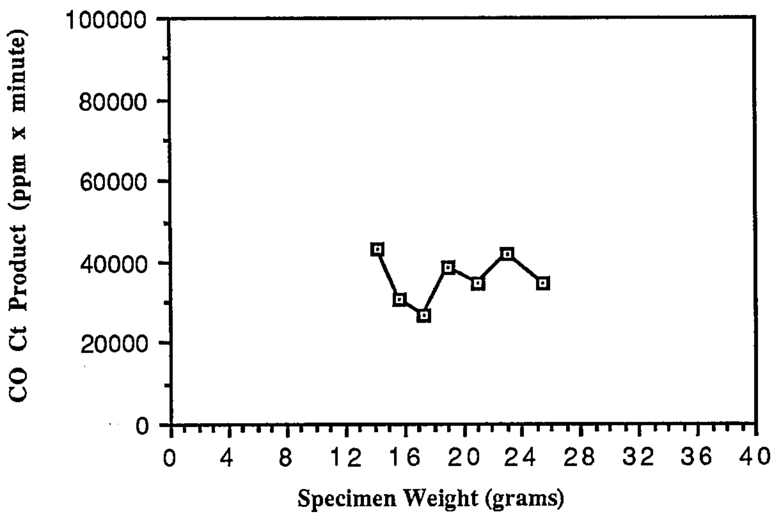


Figure 6: Yellow Poplar

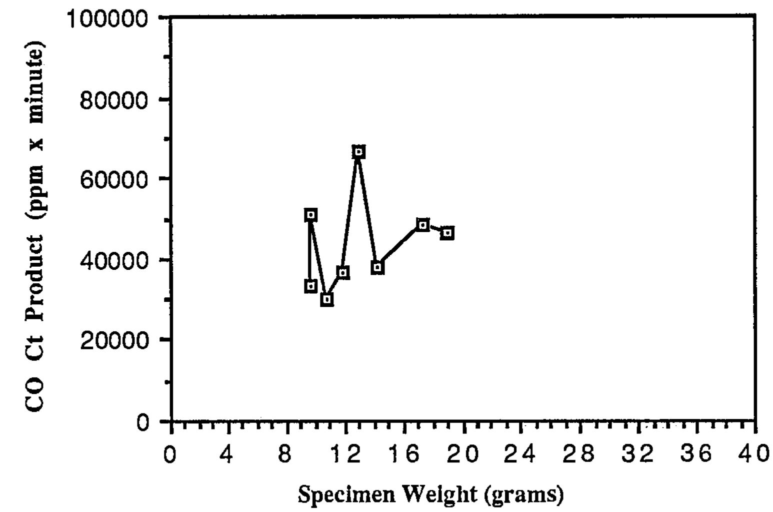


Figure 7: Douglas Fir Plywood

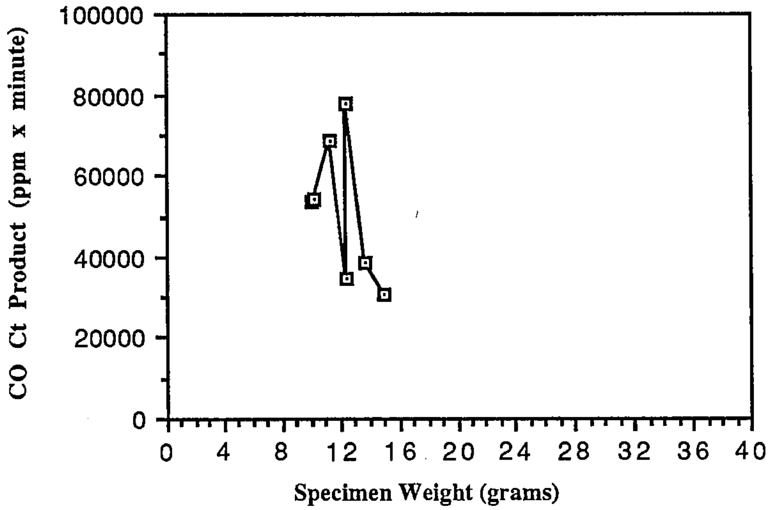


Figure 8: Southern Pine Plywood

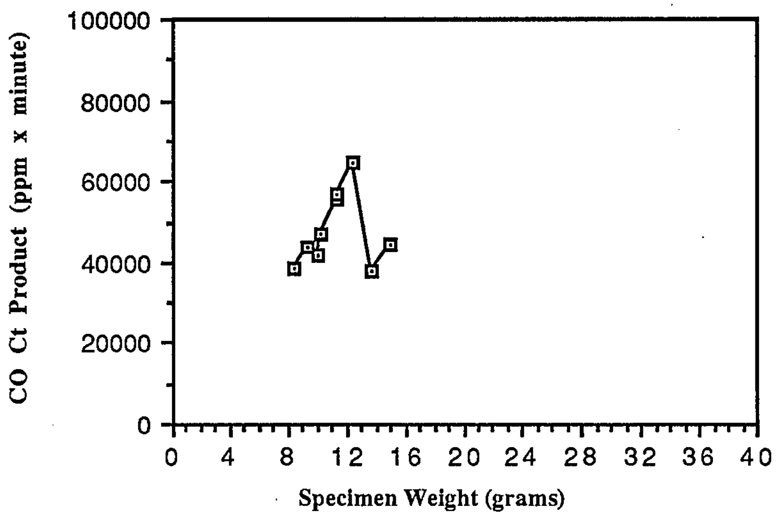


Figure 9: Oriented Strandboard

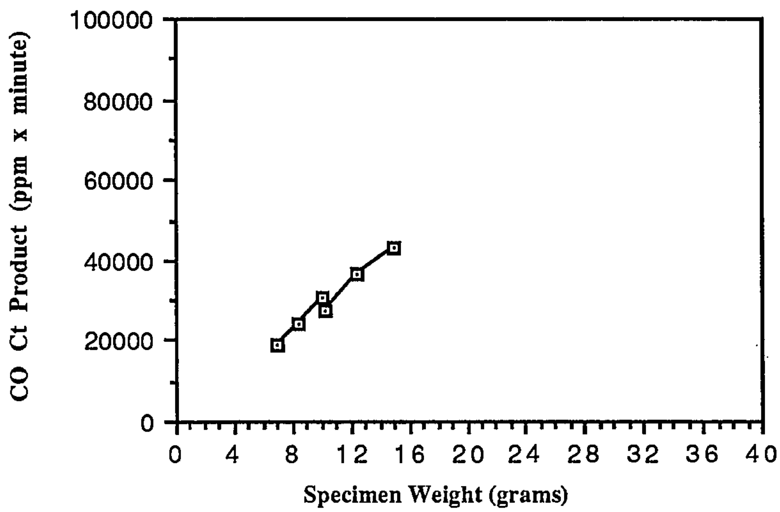


Figure 10: Waferboard

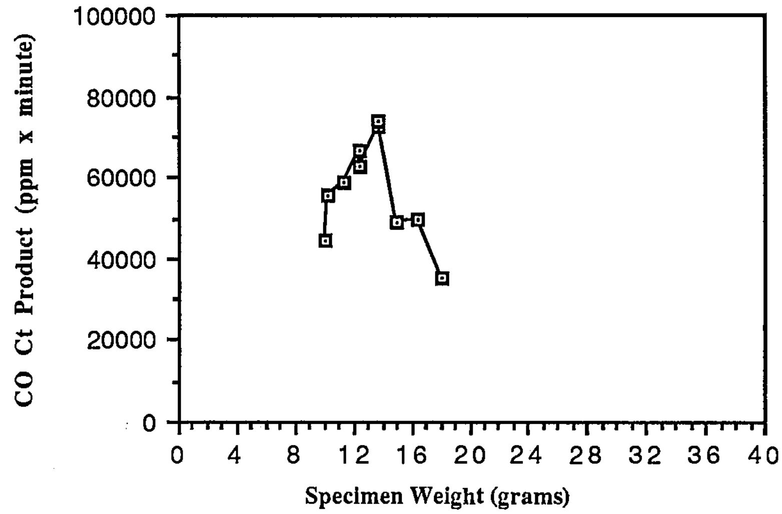


Figure 11: Standard Hardboard

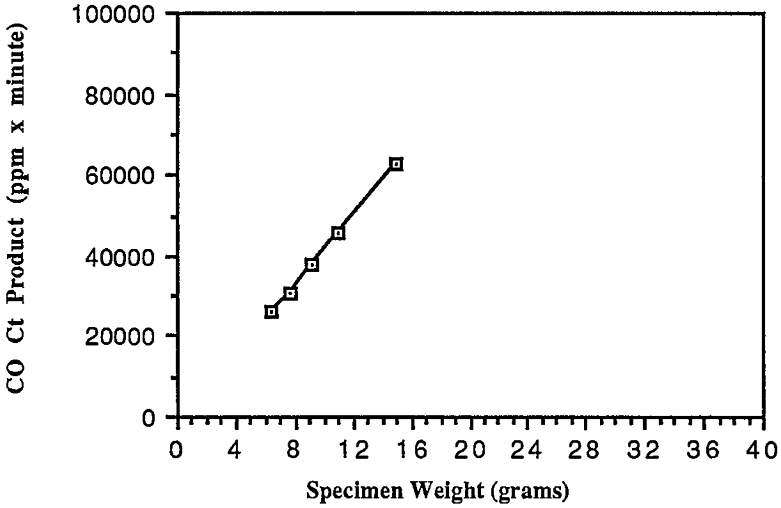


Figure 12: Tempered Hardboard

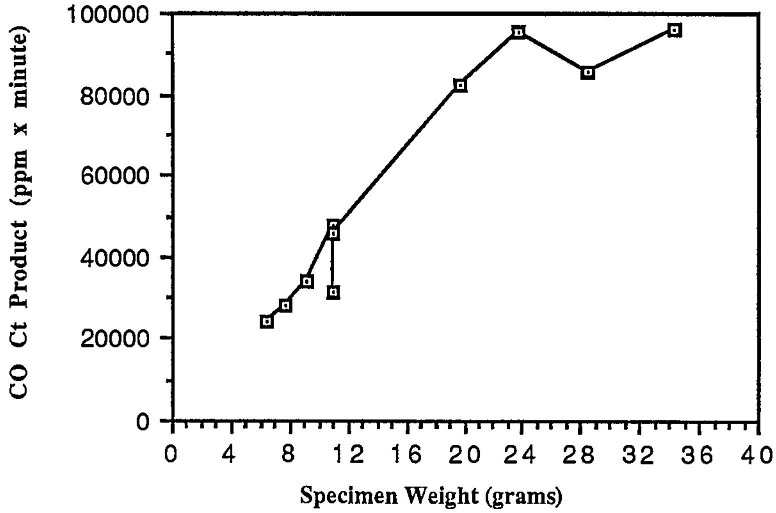


Figure 13: Fiberboard

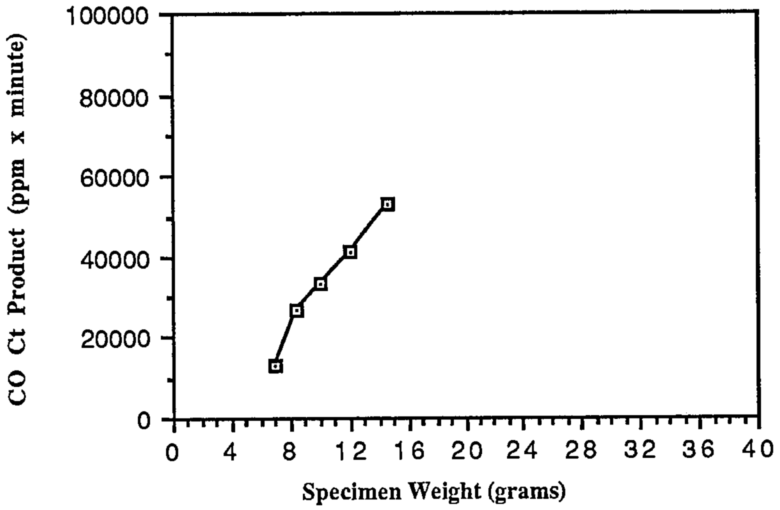


Figure 14: Particleboard

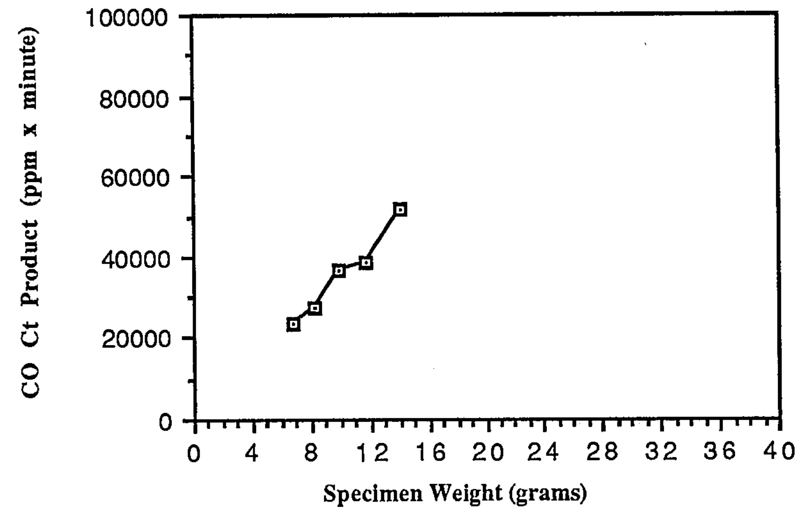


Figure 15: Lauan Plywood

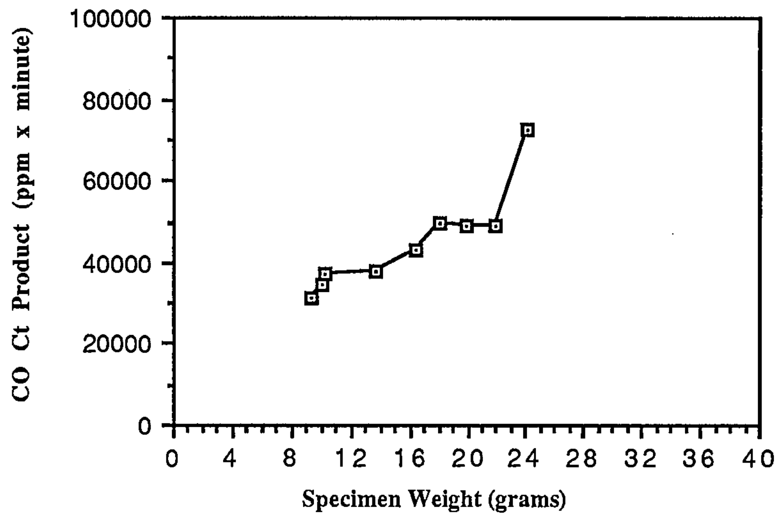


Figure 16: CCA-Treated Southern Pine

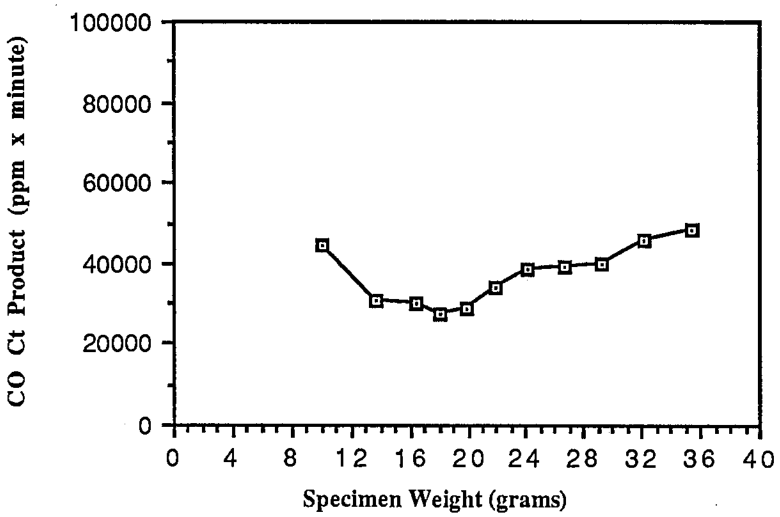


Figure 17: AZCA-Treated Douglas Fir

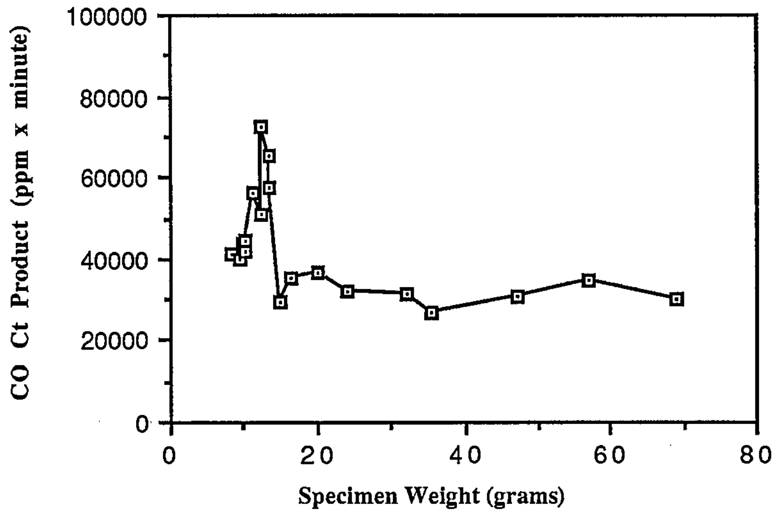
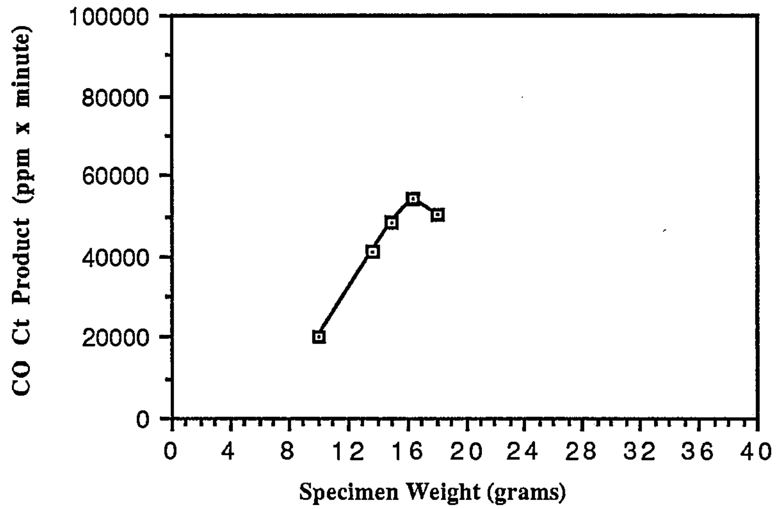


Figure 18: Fire Retardant-Treated Southern Pine



Carbon Dioxide Ct Product

vs

Specimen Weight

Figure 19: Douglas Fir

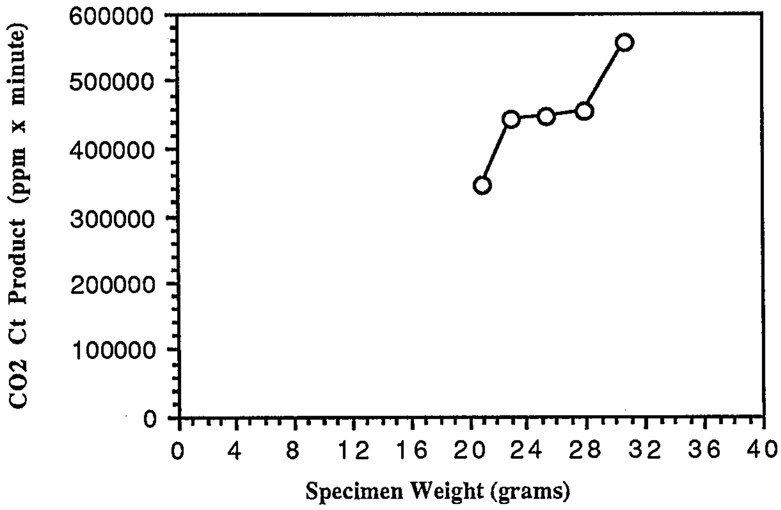


Figure 20: Redwood

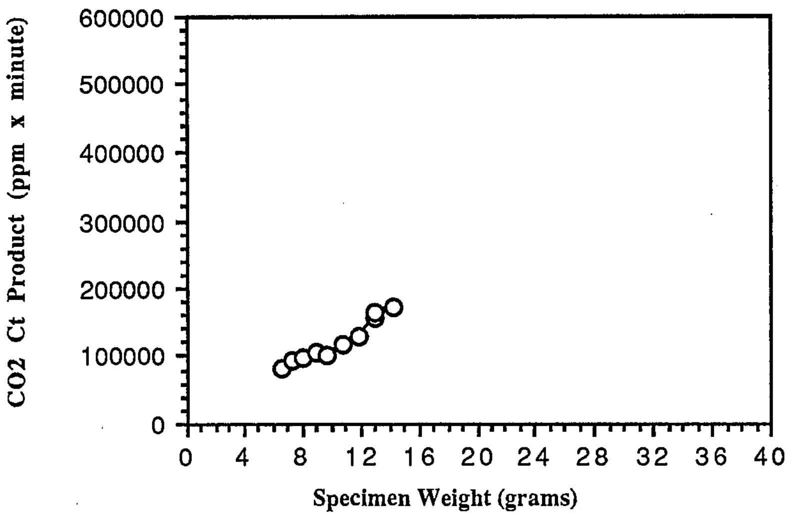


Figure 21: Southern Pine

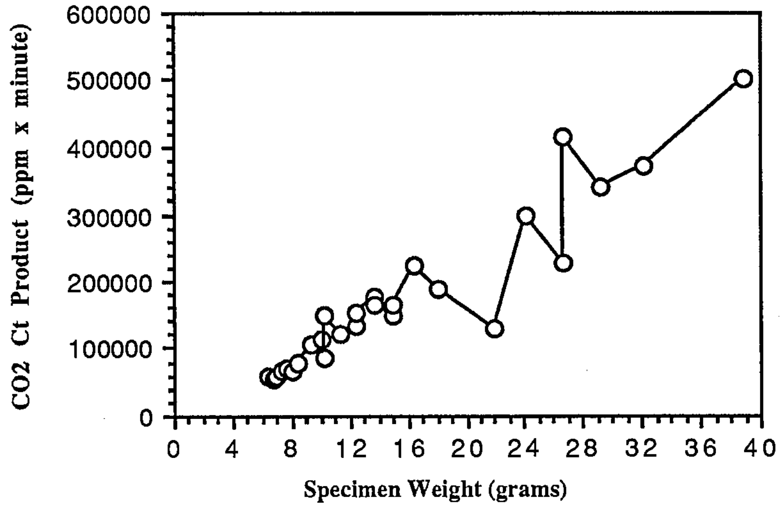


Figure 22: White Spruce

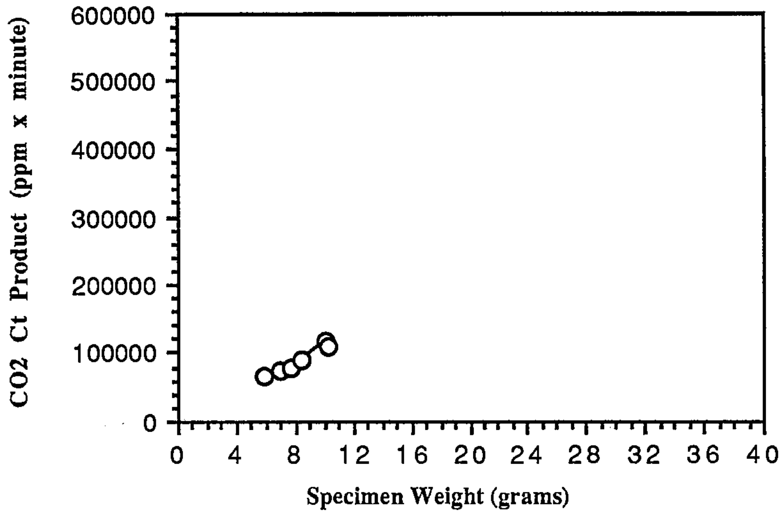


Figure 23: Red Oak

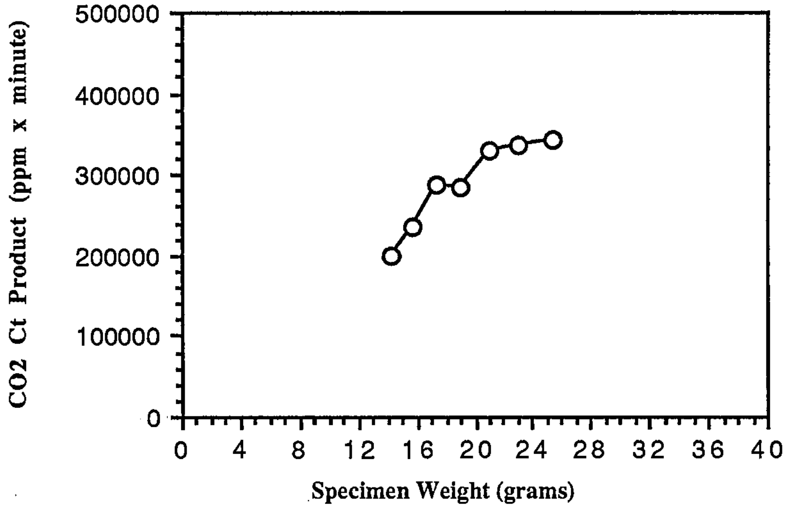


Figure 24: Yellow Poplar

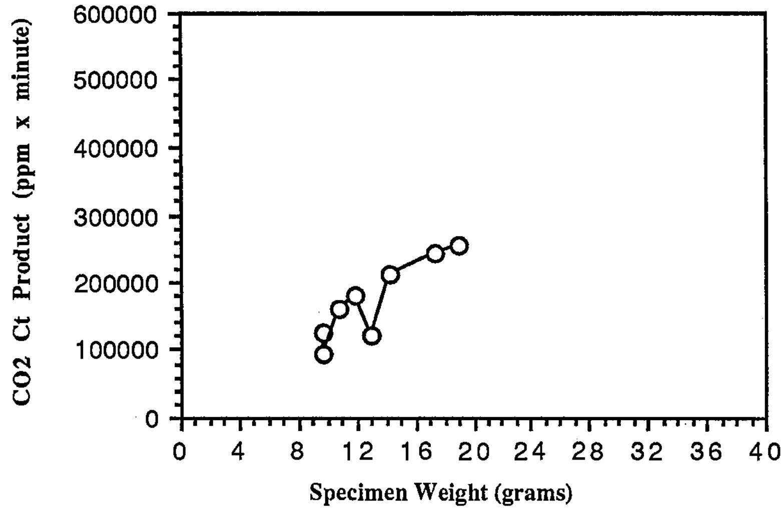


Figure 25: Douglas Fir Plywood

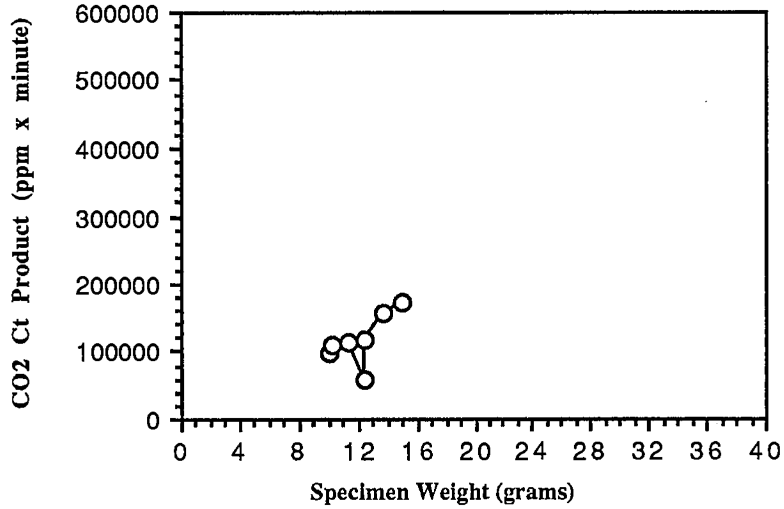


Figure 26: Southern Pine Plywood

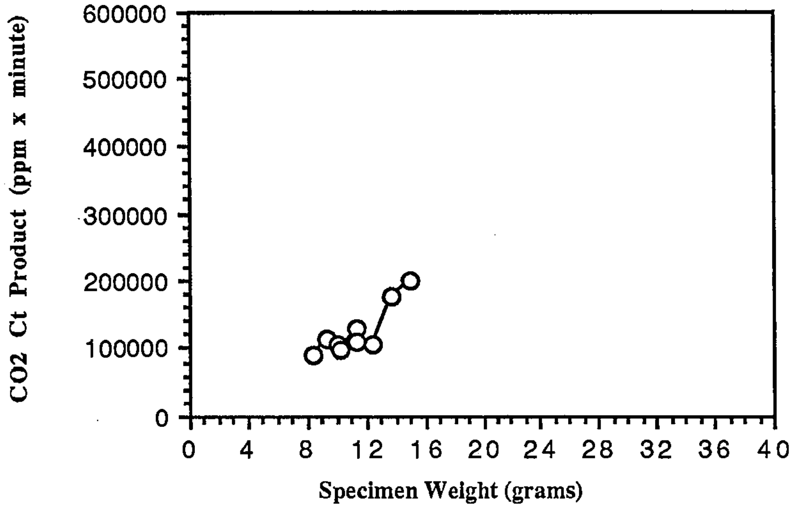


Figure 27: Oriented Strandboard

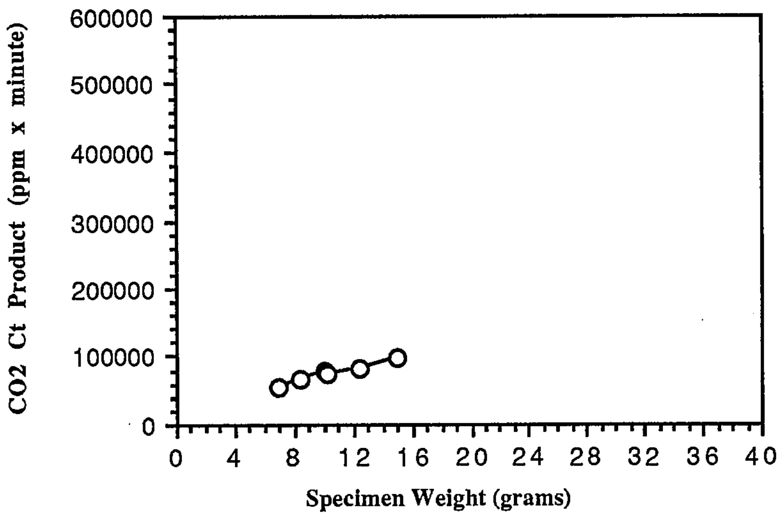


Figure 28: Waferboard

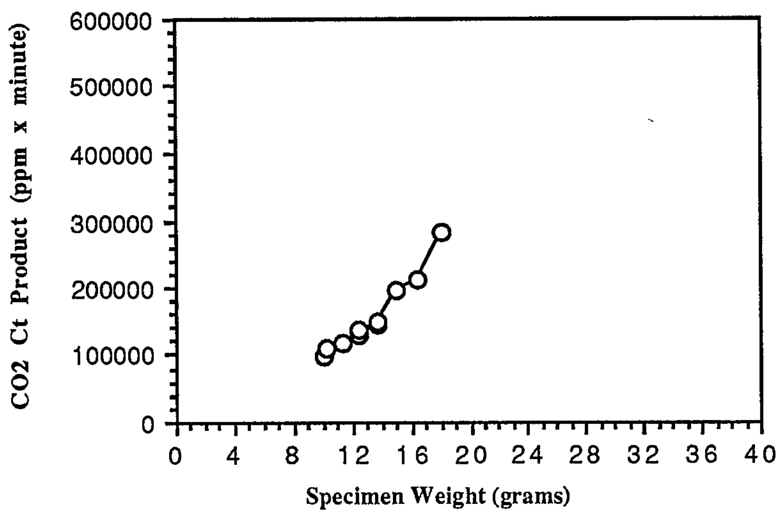


Figure 29: Standard Hardboard

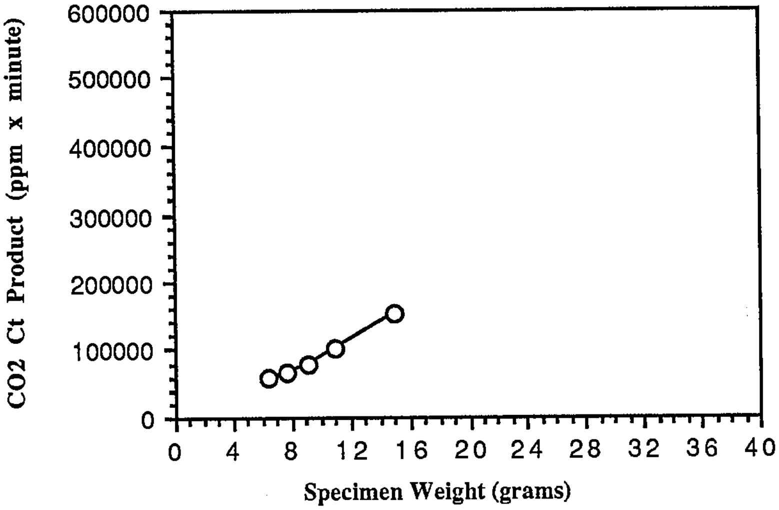


Figure 30: Tempered Hardboard

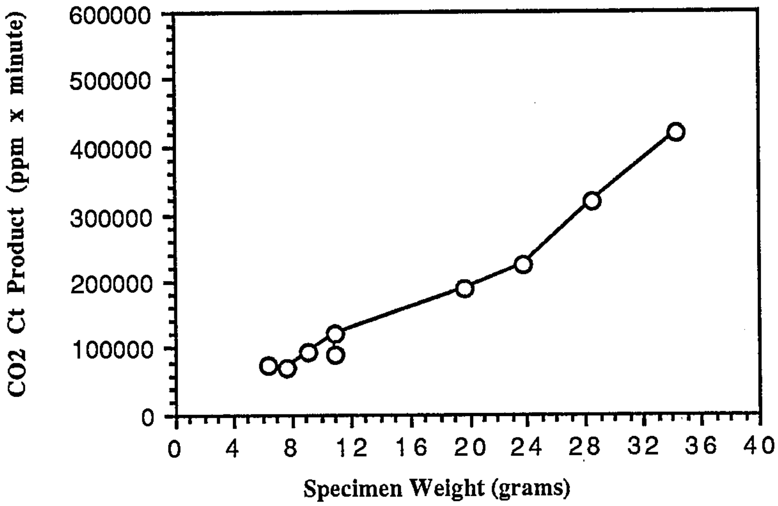


Figure 31: Fiberboard

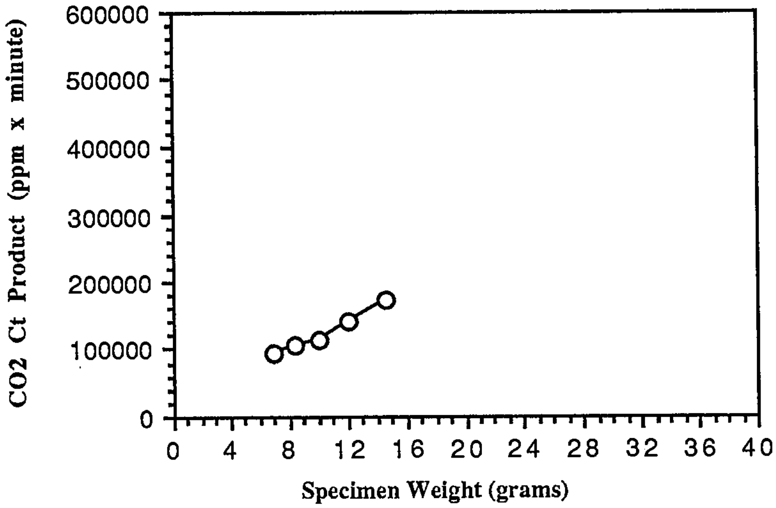


Figure 32: Particleboard

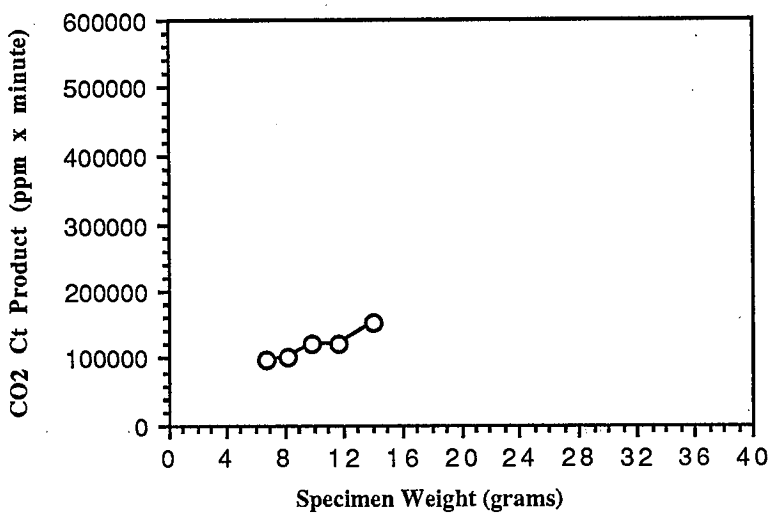


Figure 33: Lauan Plywood

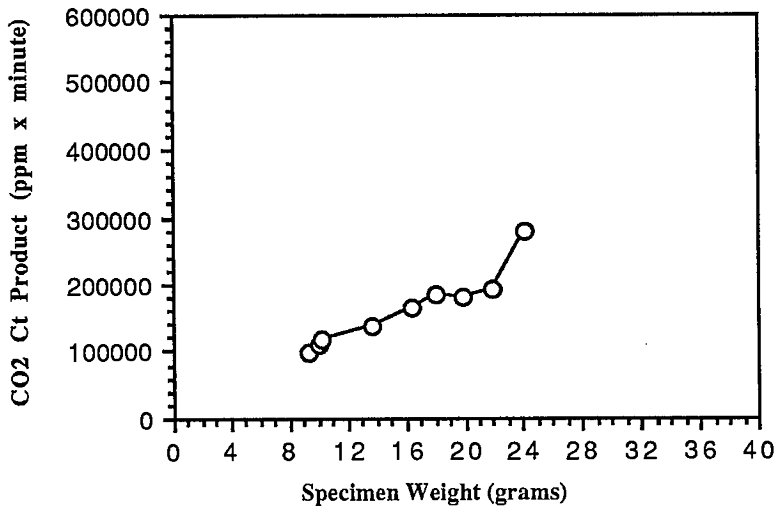


Figure 34: CCA-Treated Southern Pine

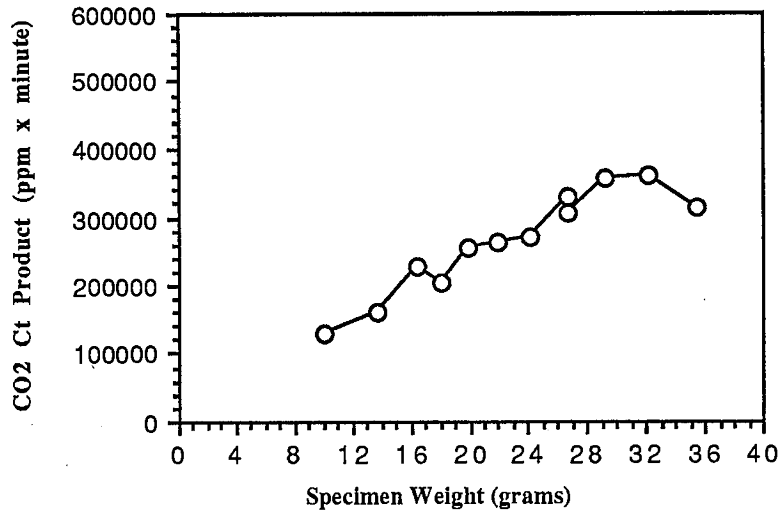


Figure 35: AZCA-Treated Douglas Fir

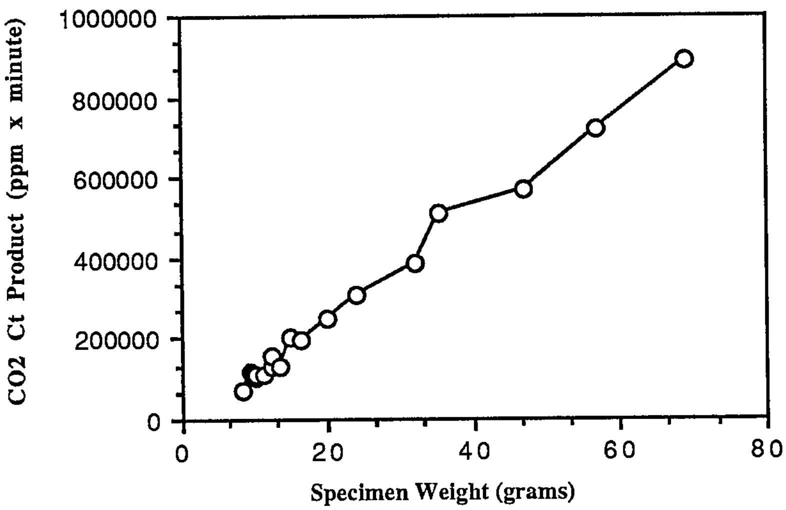
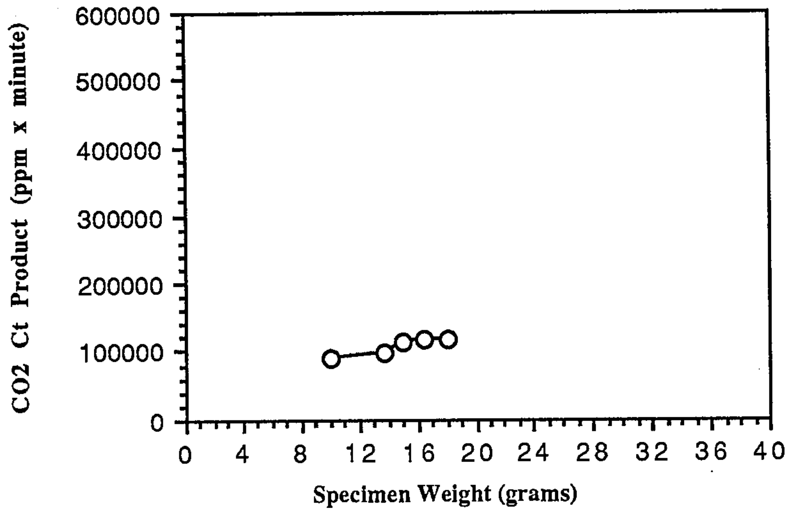


Figure 36: Fire Retardant-Treated Southern Pine



SIGNATURE PAGE

Prepared by,

James C. Norris, Ph.D.
Toxicologist

James R. [illegible]
Director

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APPENDIX C

LC_{50} VALUES OF A LAUAN PLYWOOD USING THE UNIVERSITY OF PITTSBURGH TOXICITY TEST APPARATUS

LAUAN PLYWOOD WITH A PVC LAMINATE

Appendix B

Weyerhaeuser

FIRE TECHNOLOGY LABORATORY

P.O. BOX 188 LAB B
LONGVIEW, WA 98632

Report on:

LC_{50} VALUE OF A LAUAN PLYWOOD USING THE UNIVERSITY OF PITTSBURGH TOXICITY TEST APPARATUS

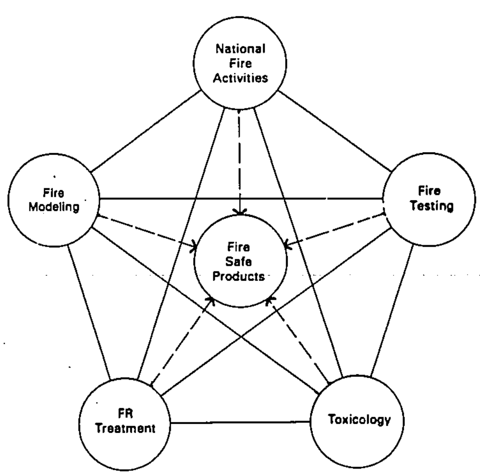
Conducted on:

LAUAN PLYWOOD WITH A POLYVINYL CHLORIDE LAMINATE

Conducted for:

WILLIAM J. GROAH
HARDWOOD PLYWOOD MANUFACTURERS ASSOCIATION
1825 MICHAEL FARADAY DRIVE
RESTON, VA 22090

Completed on:
June 27, 1989



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NOTICE

This test method is intended to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or the fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.

INTRODUCTION

For this report, a Lauan plywood with a polyvinyl chloride (PVC) laminate was received from the Hardwood Plywood Manufacturers Association. Testing of this plywood was in accordance to the University of Pittsburgh Test Methodology as described in Article 15 Part 1120 of the *New York State Uniform Fire Prevention and Building Code* [1].

This report includes dimensions of the particleboards, test methodology, and the test results.

METHOD

The protocol used is published under Article 15 of the *New York State Uniform Fire Prevention and Building Code* [1]. The LC_{50} values and their confidence intervals were calculated by the Weil method [2].

The UPITT apparatus consisted of a Lindberg furnace (Pittsburgh, PA) connected to an animal exposure chamber. Within the furnace there was a weight load cell upon which the specimen was placed. There was an air flow of eleven (11) liters/minute proceeding from the furnace toward the animal exposure chamber. That air flow was mixed, cooled and diluted with nine (9) liters/minute of cold air (~15°C) before being presented to the animals. The furnace temperature was ramped 20° C/minute. The furnace, however, was not connected to the animals exposure chamber until the specimen had loss 1% of its weight as indicated by the weight load cell. The time at which this occurred was the beginning of the thirty (30)-minute animal exposure. The animal exposure chamber simultaneously housed four (4) male Swiss-Webster mice (Simenon Laboratories, Inc.; Gilroy, CA) in a head-only exposure mode. The decomposition products passed to gas analyzers (carbon monoxide, carbon dioxide and oxygen) after being presented to the animals. The apparatus and protocol were according to the methodology of New York State Protocol [1].

Procedurally, a ten (10)-gram quantity of the material was placed in the furnace after which the ramping of the furnace started. At the 1% weight loss, the animal exposure chamber was connected to the furnace. After the thirty (30)-minute exposure was completed, the animals were observed for an additional ten (10) minutes. Any deaths occurring during these forty (40) minutes were used in the determination of the LC_{50} value. If all the animals died with the ten (10) grams, the next experiment would be with a lower weight. If no animals died, then a higher weight would be used in the next experiment.

That next weight would be determined by a geometric factor. The geometric factor was necessary because of the statistical procedure [2] used for determining the LC_{50} values. This factor (for example, 1.1) would be multiplied by the weight to determine the next higher weight, or the weight would be divided by the factor to determine the next lower weight. Using this statistical procedure, four consequent weights (spaced by the geometric factor along with the corresponding deaths as required by the tables supplied in the reference) were needed to determine an LC_{50} value.

A program was written for a Macintosh® Plus Computer in conjunction with a Fluke 2400A (A/D and D/A measurement and control link) to specifically operate this apparatus. Ramping of the furnace was accomplished by the Macintosh® monitoring the furnace temperature and varying the power supply to the furnace. The specimen weight, the percent of weight loss, concentrations of carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2), time (from the initiation of ramping and from the 1% weight loss), temperatures of the furnace and chamber, and the difference between the actual and theoretical furnace temperatures were displayed on the computer monitor during the experiment as well as recorded on a diskette. The O_2 gas analyzer was a Servomex O_2 Analyzer OA 580 (Sybron/Taylor), and the CO/CO_2 analyzer was a Dual Gas Analyzer (Infrared Industries, Inc.)

In order to confirm that there were no leaks in the system and that the pump, air flow and flowmeters were operating properly, the flow rates of nine (9) and twenty (20) liters/minutes were tested prior to each test with a Mini-Buck Calibrator (A.P. Buck, Inc., Orlando, FL). This flowmeter is traceable to the National Institute of Standards and Technology (formerly National Bureau of Standards). Calibration of the CO and CO_2 analyzers was performed with calibration gases (CO - 0.9% and CO_2 - 5%) certified by Alphagaz Division (Tacoma, WA). The O_2 analyzer was calibrated with room air.

TEST RESULTS

The LC_{50} values and their confidence intervals are presented. A number of parameters are reported in a summary table, such as the minimum oxygen concentration, the maximum carbon monoxide and carbon dioxide concentrations, the maximum animal exposure chamber temperature, the maximum furnace temperature, and the percentage of the specimen weight. Tabulation of the data required by New York State is included. These data are from a specimen weight close to the LC_{50} value. The concentration-time (Ct) products for carbon monoxide and carbon dioxide plotted with the specimen weight are presented. [This Ct product is a value calculated by multiplying the gas concentration, such as carbon monoxide, with the time of animal exposure to the gas concentration. In other words, it is the area under the curve of the gas concentrations vs time.]

REFERENCES

1. Article 15, Part 1120 -- New York State Fire Prevention and Building Code. New York Standards & Fire Information Network, Office of Fire Prevention and Control. Albany, NY.

2. Weil, C.S., Tables For Convenient Calculation Of Median-Effective Dose (LC_{50} or ED_{50}) And Instructions In Their Use. *Biometrics* 8: 249-263, 1952.

SAMPLE PREPARATION

This plywood was stored in a conditioning room (23.8 ± 2.8° C and 50 ± 10% Relative Humidity) for at least 48 hours prior to testing. Each specimen placed in the furnace was a piece of a wood product cut to a specific weight.

WOOD PRODUCT DIMENSIONS

Wood Product	Length (inch)	Width (inch)	Thickness (inch)
Lauan Plywood- PVC Laminate	48	12	0.23

LC_{50} Value and its Confidence Interval

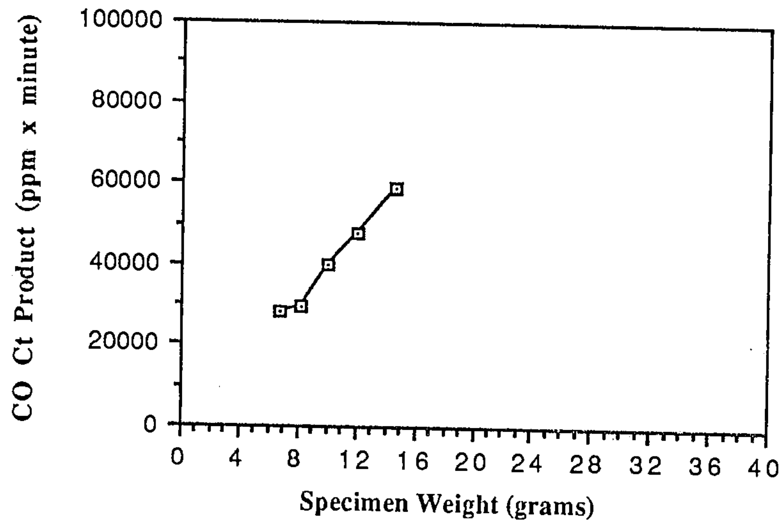
Wood Product	LC50 Value (grams)	95% Confidence Interval	
		Low Value	High Value
Lauan Plywood- PVC Laminate	9.5	8.7	10.5

Lauan Plywood - PVC Laminate

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	10.00	12.10	8.26	6.83	14.64
Maximum Chamber Temperature (°C)	37.98	46.23	40.6	36.3	39.78
Maximum Furnace Temperature (°C)	837.9	830.5	829.8	841.3	830.3
Weight Loss (%)	73.1	76.9	77.3	72.8	75.3
Minimum Oxygen Concentration (%)	19.80	19.73	20.19	20.16	19.61
Maximum CO Concentration (ppm)	6118	7830	4108	3966	9613
Maximum CO2 Concentration (ppm)	6057	7678	5486	5199	7327
Number of Animals Exposed	4	4	4	4	4
Number of Dead Animals	3	4	0	0	4
Lethality (%)	75	100	0	0	100
Ct Product for CO (ppm x min)	39648	47996	29358	27817	58780
Ct Product for CO2 (ppm x min)	85411	112245	70833	68466	113514
T1% (°C)	240	230	230	235	230

New York State Data

	Lauan Plywood - PVC Laminate
Number of Samples Tested	5
Furnace Temperature at 1% Sample Mass Loss (°C)	230
Maximal Concentration of Carbon Monoxide in the Exposure Chamber (ppm)	6118
Furnace Temperature at the Point of Maximal Carbon Monoxide (°C)	483
Maximal Concentration of Carbon Dioxide in the Exposure Chamber (%)	0.61
Furnace Temperature at the Point of Maximal Carbon Dioxide (°C)	676
Minimal Concentration of Oxygen in the Exposure Chamber (%)	19.8
Furnace Temperature at the Point of Minimal Oxygen (°C)	484
Number of Times the Exposure Chamber Temperature Exceeded 45°C	0
Average Duration of Exposure Chamber Temperature in Excess of 45°C (sec)	0
Eye Condition of Test Animals: (1) All apparently normal, (2) Some appparent damage, (3) Some severe damage	2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60000
40000
20000
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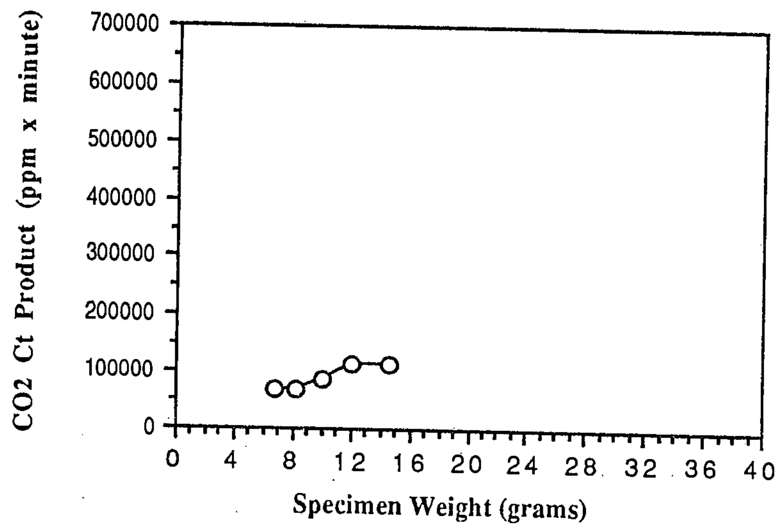
Specimen Weight (grams)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600000
500000
400000
300000
200000
100000
0
0 4 8 12 16 20 24 28 32 36 40
Specimen Weight (grams)

SIGNATURE PAGE

Prepared by,

James C. Norris

James C. Norris, Ph.D.
Toxicologist

James R. Shen
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APPENDIX D

LC_{50} VALUES OF PARTICLEBOARDS USING THE UNIVERSITY OF PITTSBURGH TOXICITY TEST APPARATUS

FIVE PARTICLEBOARDS

Weyerhaeuser

FIRE TECHNOLOGY LABORATORY

P.O. BOX 188 LAB B
LONGVIEW, WA 98632

Report on:

LC_{50} VALUES OF PARTICLEBOARDS USING THE UNIVERSITY OF PITTSBURGH TOXICITY TEST APPARATUS

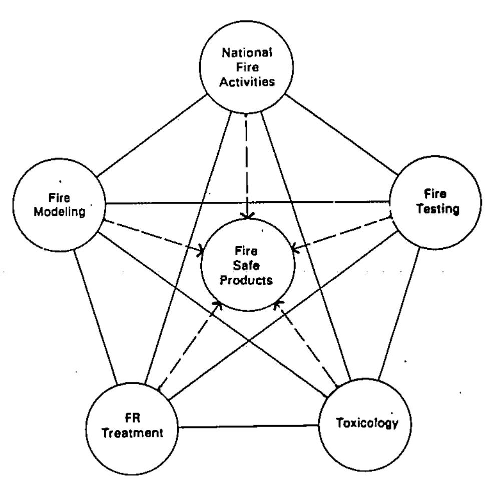
Conducted on:

FIVE PARTICLEBOARDS

Conducted for:

RICH MARGOSIAN
NATIONAL PARTICLEBOARD ASSOCIATION
18928 PREMIERE COURT
GAITHERSBURG, MD 20879

Completed on:
December 30, 1988



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NOTICE

This test method is intended to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or the fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.

INTRODUCTION

Five particleboards were received from various members of National Particleboard Association for testing. The toxic potency values or LC_{50} values for these wood products were determined using the University of Pittsburgh (UPITT) test procedure as described in Article 15 Part of the *New York State Uniform Fire Prevention and Building Code* [1].

This report includes dimensions of the particleboards, test methodology, and the test results.

METHOD

The protocol used is published under Article 15 of the *New York State Uniform Fire Prevention and Building Code* [1]. The LC_{50} values and their confidence intervals were calculated by the Weil method [2].

The UPITT apparatus consisted of a Lindberg furnace (Pittsburgh, PA) connected to an animal exposure chamber. Within the furnace there was a weight load cell upon which the specimen was placed. There was an air flow of eleven (11) liters/minute proceeding from the furnace toward the animal exposure chamber. That air flow was mixed, cooled and diluted with nine (9) liters/minute of cold air (~15°C) before being presented to the animals. The furnace temperature was ramped 20° C/minute. The furnace, however, was not connected to the animals exposure chamber until the specimen had loss 1% of its weight as indicated by the weight load cell. The time at which this occurred was the beginning of the thirty (30)-minute animal exposure. The animal exposure chamber simultaneously housed four (4) male Swiss-Webster mice (Simenon Laboratories, Inc.; Gilroy, CA) in a head-only exposure mode. The decomposition products passed to gas analyzers (carbon monoxide, carbon dioxide and oxygen) after being presented to the animals. The apparatus and protocol were according to the methodology of New York State Protocol [1].

Procedurally, a ten (10)-gram quantity of the material was placed in the furnace after which the ramping of the furnace started. At the 1% weight loss, the animal exposure chamber was connected to the furnace. After the thirty (30)-minute exposure was completed, the animals were observed for an additional ten (10) minutes. Any deaths occurring during these forty (40) minutes were used in the determination of the LC_{50} value. If all the animals died with the ten (10) grams, the next experiment would be with a lower weight. If no animals died, then a higher weight would be used in the next experiment.

That next weight would be determined by a geometric factor. The geometric factor was necessary because of the statistical procedure [2] used for determining the LC_{50} values. This factor (for example, 1.1) would be multiplied by the weight to determine the next higher weight, or the weight would be divided by the factor to determine the next lower weight. Using this statistical procedure, four consequent weights (spaced by the geometric factor along with the corresponding deaths as required by the tables supplied in the reference) were needed to determine an LC_{50} value.

A program was written for a Macintosh® Plus Computer in conjunction with a Fluke 2400A (A/D and D/A measurement and control link) to specifically operate this apparatus. Ramping of the furnace was accomplished by the Macintosh® monitoring the furnace temperature and varying the power supply to the furnace. The specimen weight, the percent of weight loss, concentrations of carbon monoxide (CO), carbon dioxide (CO_2)

and oxygen (O_2), time (from the initiation of ramping and from the 1% weight loss), temperatures of the furnace and chamber, and the difference between the actual and theoretical furnace temperatures were displayed on the computer monitor during the experiment as well as recorded on a diskette. The O_2 gas analyzer was a Servomex O_2 Analyzer OA 580 (Sybron/Taylor), and the CO/CO_2 analyzer was a Dual Gas Analyzer (Infrared Industries, Inc.)

In order to confirm that there were no leaks in the system and that the pump, air flow and flowmeters were operating properly, the flow rates of nine (9) and twenty (20) liters/minutes were tested prior to each test with a Mini-Buck Calibrator (A.P. Buck, Inc., Orlando, FL). This flowmeter is traceable to the National Institute of Standards and Technology (formerly National Bureau of Standards). Calibration of the CO and CO_2 analyzers was performed with calibration gases (CO - 0.9% and CO_2 - 5%) certified by Alphagaz Division (Tacoma, WA). The O_2 analyzer was calibrated with room air.

TEST RESULTS

The LC_{50} values and their confidence intervals are presented in Table 1. A number of parameters are reported in summary tables (Table 2-6), such as the minimum oxygen concentration, the maximum carbon monoxide and carbon dioxide concentrations, the maximum animal exposure chamber temperature, the maximum furnace temperature, and the percentage of the specimen weight. Tabulation of the data required by New York State is included (Table 7). These data are from a specimen weight close to the LC_{50} value. The concentration-time (Ct) products for carbon monoxide (Figures 1-5) and carbon dioxide (Figures 6-10) plotted vs the specimen weight are presented for each of the five products. [This Ct product is a value calculated by multiplying the gas concentration, such as carbon monoxide, with the time of animal exposure to the gas concentration. In other words, it is the area under the curve of the gas concentrations vs time.]

REFERENCES

1. Article 15, Part 1120 -- New York State Fire Prevention and Building Code. New York Standards & Fire Information Network, Office of Fire Prevention and Control. Albany, NY.

2. Weil, C.S., Tables For Convenient Calculation Of Median-Effective Dose (LC_{50} or ED_{50}) And Instructions In Their Use. *Biometrics* 8: 249-263, 1952.

SAMPLE PREPARATION

These wood products were stored in a conditioning room (23.8 ± 2.8° C and 50 ± 10% Relative Humidity) for at least 48 hours prior to testing. Each specimen placed in the furnace was a piece of a wood product cut to a specific weight.

WOOD PRODUCT DIMENSIONS

Wood Product	Length (inch)	Width (inch)	Thickness (inch)
"A" Particleboard	24	24	0.75
"B" Particleboard	24	24	1.50
"C" Particleboard	24	24	0.75
"D" Particleboard	24	24	0.63
"E" Medium Density Fiberboard	24	24	0.75

Table 1: LC_{50} Values and their Confidence Intervals

Wood Product	LC50 Value	95% Confidence Interval	
	(grams)	Low Value	High Value
"A" Particleboard	9.79	7.93	12.09
"B" Particleboard	15.00	13.11	17.17
"C" Particleboard	12.40	8.47	18.16
"D" Particleboard	11.07	9.73	12.59
"E" Medium Density Fiberboard	13.21	11.96	14.59

SUMMARY TABLES

"A" Particleboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	14.99	8.16	9.79	11.74	14.09
Maximum Chamber Temp (°C)	49.3	47.2	44	54.9	48.8
Maximum Furnace Temp (°C)	803.6	850.7	817.8	815.4	823.6
Weight Loss (%)	79.79	76.1	80.08	92.5	65.22
Minimum Oxygen (%)	19.38	20.15	19.81	19.77	19.58
Maximum CO Concentration (ppm)	8888	4188	4482	6425	8152
Maximum CO2 Concentration (ppm)	8401	4735	5420	6641	7619
Number of Animals Exposed	0	4	4	4	4
Number of Dead Animals	-	0	2	4	2
% Lethality	-	0	50	100	50
Ct Product for CO (ppm x min)	51655.44	26070.52	29490.41	36883	46510.56
Ct Product for CO2 (ppm x min)	154052.25	103538.88	100604.13	122544.77	138721.95
T1% (°C)	211.2	255.8	221.2	221.8	228.8

"B" Particleboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Specimen Weight (grams)	10.00	12.40	13.64	11.27	13.64	15.01	16.51
Maximum Chamber Temp (°C)	42.7	43.5	41.7	39.8	46.2	39.8	39.7
Maximum Furnace Temp (°C)	881.1	877.2	875.9	875.4	848.9	843.9	846.2
Weight Loss (%)	76.1	83.2	84.4	88.3	81.4	83.0	80.0
Minimum Oxygen (%)	19.99	19.55	19.59	17.54?	19.66	18.23	18.67
Maximum CO Concentration (ppm)	5095	6803	5986	5414	6693	6449	8816
Maximum CO2 Concentration (ppm)	6671	8288	10201	8022	7807	9344	11084
Number of Animals Exposed	0	4	4	4	4	4	4
Number of Dead Animals	-	1	3	1	0	3	3
% Lethality	-	25	75	25	0	75	75
Ct Product for CO (ppm x min)	33572	43402	44799	35126	41763	45440	54410
Ct Product for CO2 (ppm x min)	137686	171398	224024	153730	152282	177176	188365
T1% (°C)	269	270	270	270	240	240	240

"C" Particleboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Specimen Weight (grams)	10.00	12.40	10.25	15.01	13.64	11.27
Maximum Chamber Temp (°C)	44.46	45.74	40.21	42.15	40.02	44.07
Maximum Furnace Temp (°C)	908.6	918.7	918.6	911.01	913.4	912.9
Weight Loss (%)	79.1	84	80.1	79.27	81.1	75.9
Minimum Oxygen (%)	18.81	19.48	19.76	19.2	19.29	19.62
Maximum CO Concentration (ppm)	6147	9317	6718	12483	11329	9048
Maximum CO2 Concentration (ppm)	6052	9124	6426	10945	10176	8994
Number of Animals Exposed	0	4	4	4	4	4
Number of Dead Animals	-	2	1	4	2	2
% Lethality	-	50	25	100	50	50
Ct Product for CO (ppm x min)	30934	47481	37346	57880	51570	42898
Ct Product for CO2 (ppm x min)	110734	152599	134359	186380	171233	142330
T1% (°C)	300	310	310	310	310	310

"D" Particleboard

Test Sequence	Test 1	Test 2	Test 3	Test 4
Specimen Weight (grams)	8.42	10.06	12.07	14.43
Maximum Chamber Temp (°C)	35.8	45.7		45.0
Maximum Furnace Temp (°C)	846.0	837.7		827.2
Weight Loss (%)	72.8	78.0		not reliable
Minimum Oxygen (%)	20.04	19.89		19.36
Maximum CO Concentration (ppm)	4874	5718	data not saved	9045
Maximum CO2 Concentration (ppm)	6837	6104		8645
Number of Animals Exposed	4	4	4	4
Number of Dead Animals	1	0	4	3
% Lethality	25	0	100	75
Ct Product for CO (ppm x min)	32578	34441		53358
Ct Product for CO2 (ppm x min)	141835	118154		157221
T1% (°C)	250	243	232	230

"E" Medium Density Fiberboard

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Specimen Weight (grams)	10.00	10.25	12.40	15.01	13.64	11.27
Maximum Chamber Temp (°C)	41.53	43.67	42.6	34.65000	40.65	40.06
Maximum Furnace Temp (°C)	895.2	896.6	898.2	896.40000	900.8	899.98
Weight Loss (%)	79.6	75.3	81.3	81.20000	80.4	78.8
Minimum Oxygen (%)	19.68	20.18	19.62	19.59	19.56	19.76
Maximum CO Concentration (ppm)	5140	5646	7277	8448	8176	6657
Maximum CO2 Concentration (ppm)	5983	6814	10061	10063	9662	7679
Number of Animals Exposed	0	4	4	4	4	4
Number of Dead Animals	-	0	1	4	2	1
% Lethality	-	0	25	100	50	25
Ct Product for CO (ppm x min)	27862	28396	35019	42521	38759	32461
Ct Product for CO2 (ppm x min)	123524	134888	174940	183770	167141	156285
T1% (°C)	292	290	290	290	290	290

Table 7: New York State Data

	"A" Particleboard	"B" Particleboard	"C" Particleboard	"D" Particleboard	"E" Medium Density Fiberboard
Number of Samples Tested	5	7	6	4	6
Furnace Temperature at 1% Sample Mass Loss (°C)	221	240	310	243	290
Maximal Concentration of Carbon Monoxide in the Exposure Chamber (ppm)	4482	6449	9317	5718	8176
Furnace Temperature at the Point of Maximal Carbon Monoxide (°C)	451	457	482	429	488
Maximal Concentration of Carbon Dioxide in the Exposure Chamber (%)	0.6	0.93	0.91	0.61	0.97
Furnace Temperature at the Point of Maximal Carbon Dioxide (°C)	534	444	482	426	485
Minimal Concentration of Oxygen in the Exposure Chamber (%)	19.8	18.2	19.5	19.9	19.6
Furnace Temperature at the Point of Minimal Oxygen (°C)	485	469	480	426	488
Number of Times the Exposure Chamber Temperature Exceeded 45°C	0	0	1	2	0
Average Duration of Exposure Chamber Temperature in excess of 45°C (sec)	0	0	74	14	0
Eye Condition of Test Animals: (1) All apparently normal, (2) Some appparent damage, (3) Some severe damage	1	1	1	1	1

GRAPHS

CARBON MONOXIDE CT PRODUCT

VS

THE SPECIMEN WEIGHT

Figure 1: "A" Particleboard

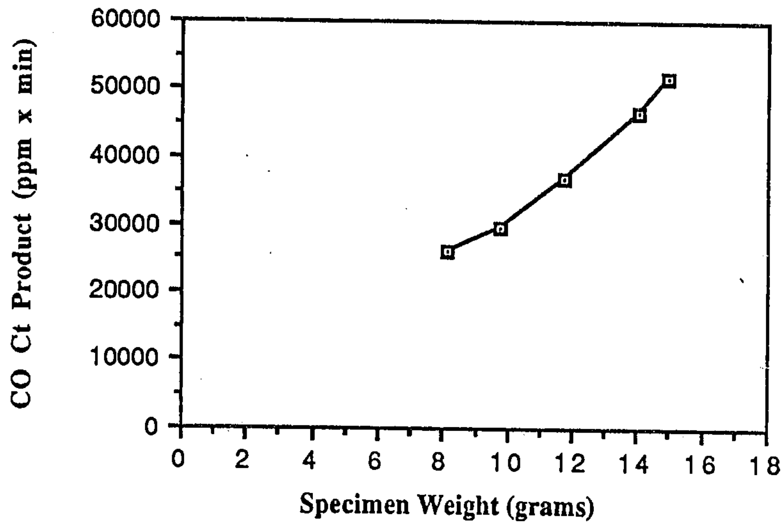


Figure 2: "B" Particleboard

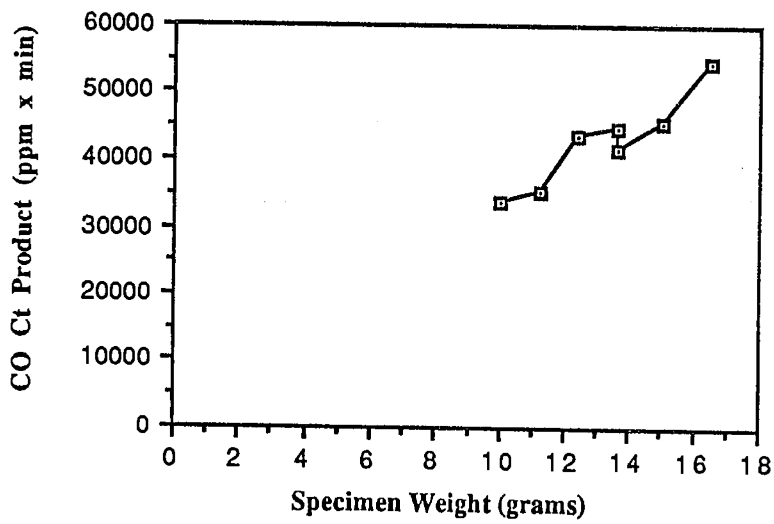


Figure 3: "C" Particleboard

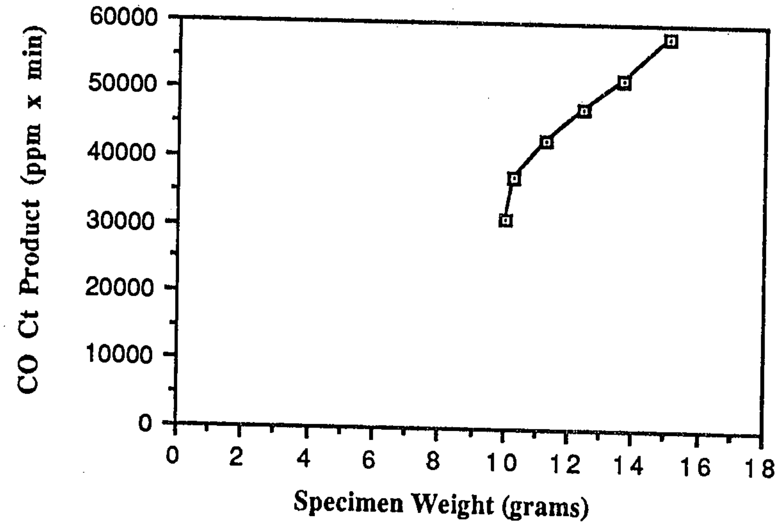


Figure 4: "D" Particleboard

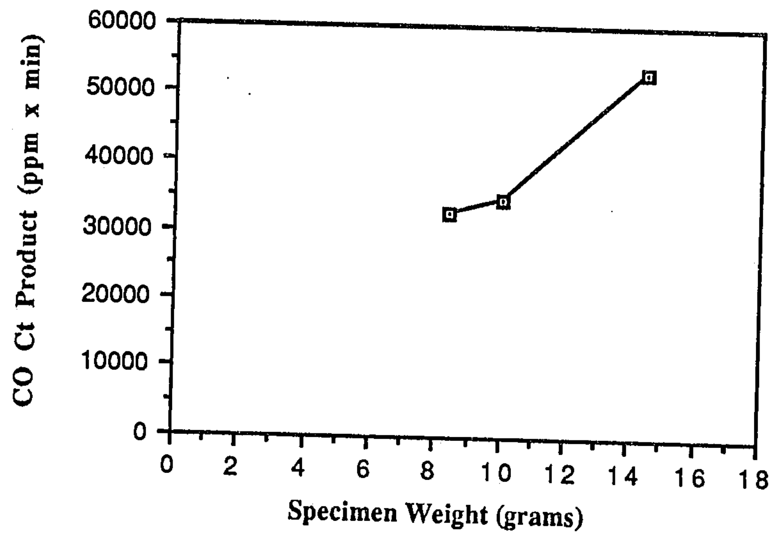
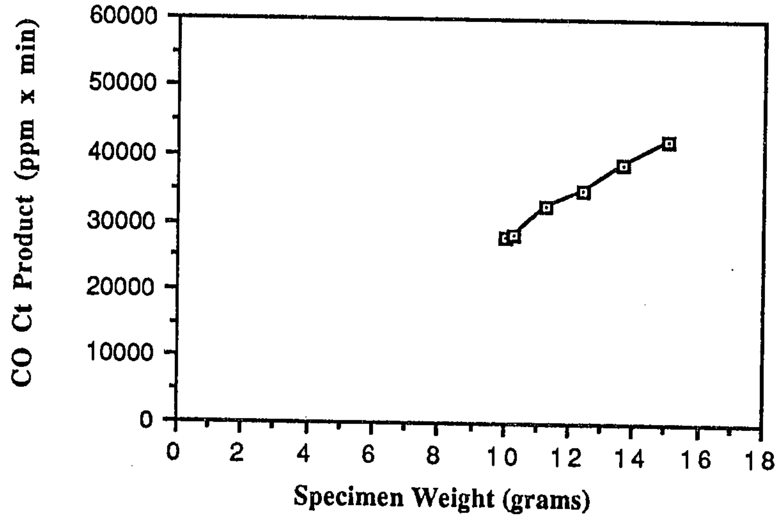


Figure 5: "E" Medium Density Fiberboard



GRAPHS

CARBON DIOXIDE CT PRODUCT

VS

THE SPECIMEN WEIGHT

Figure 6: "A" Particleboard

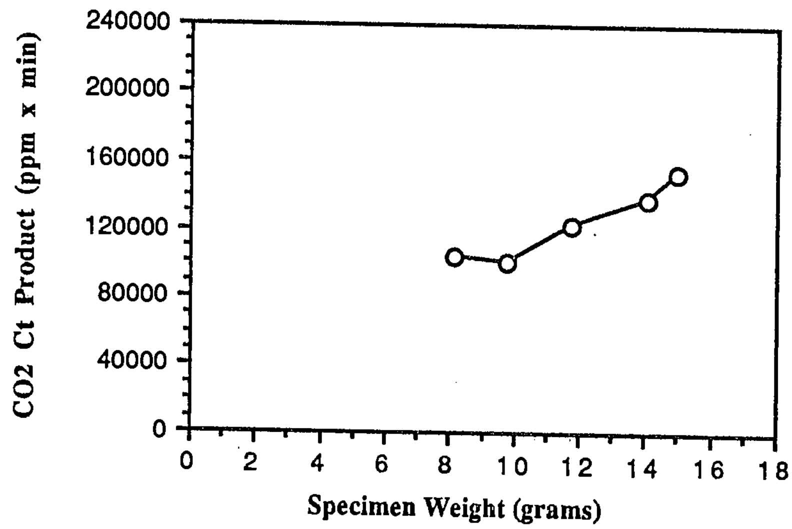


Figure 7: "B" Particleboard

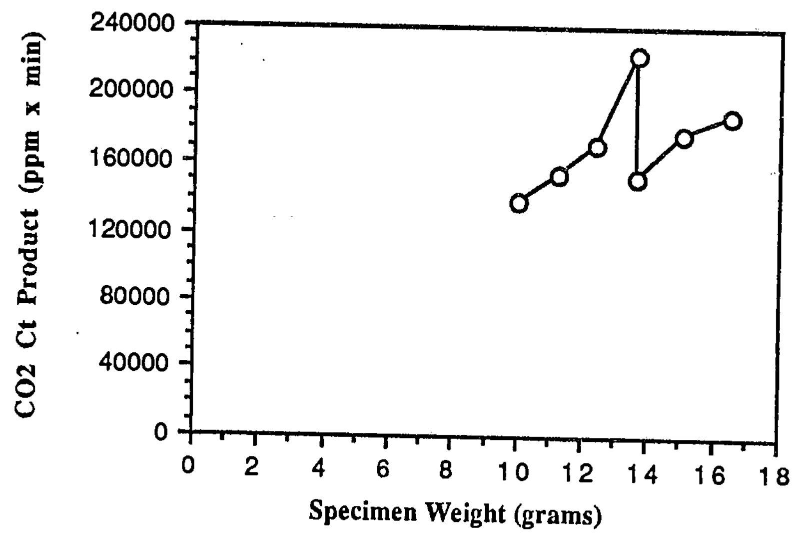


Figure 8: "C" Particleboard

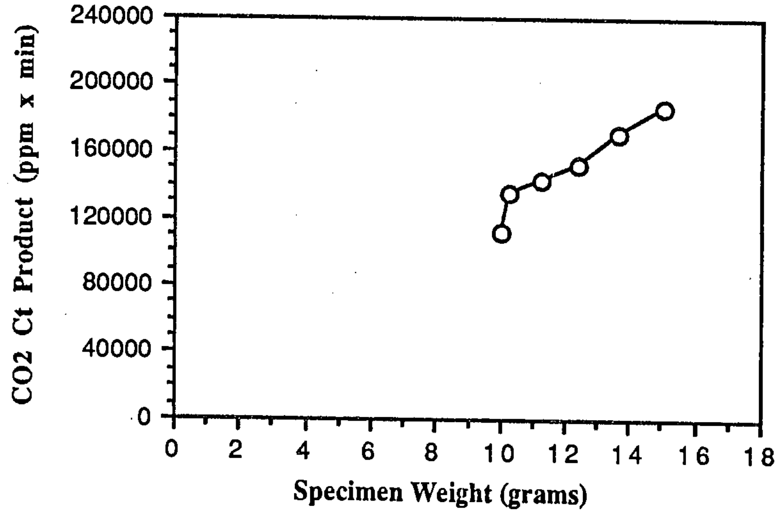


Figure 9: "D" Particleboard

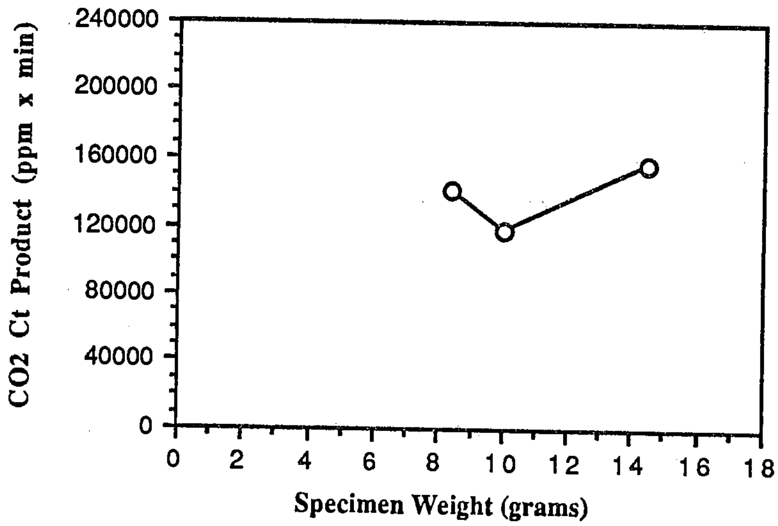
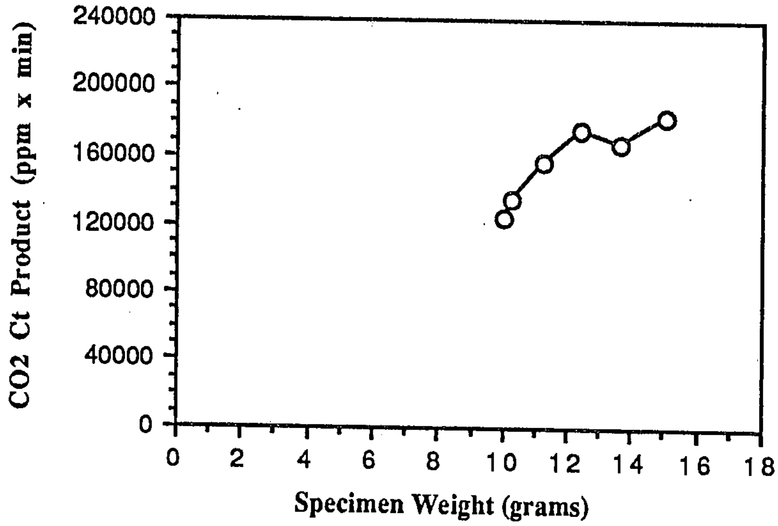


Figure 10: "E" Medium Density Fiberboard



SIGNATURE PAGE

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APPENDIX E

LC_{50} VALUES OF WOOD PRODUCTS USING THE UNIVERSITY OF PITTSBURGH TOXICITY TEST APPARATUS

FOUR WOOD PRODUCTS

Weyerhaeuser

FIRE TECHNOLOGY LABORATORY

P.O. BOX 188 LAB B
LONGVIEW, WA 98632

Report on:

LC_{50} VALUES OF WOOD PRODUCTS USING THE UNIVERSITY OF PITTSBURGH TOXICITY TEST APPARATUS

Conducted on:

FOUR WOOD PRODUCTS FOR GENERIC CLASSIFICATION

Conducted for:

**ROBERT W. GLOWINSKI
NATIONAL FOREST PRODUCTS ASSOCIATION
1250 CONNECTICUT AVENUE
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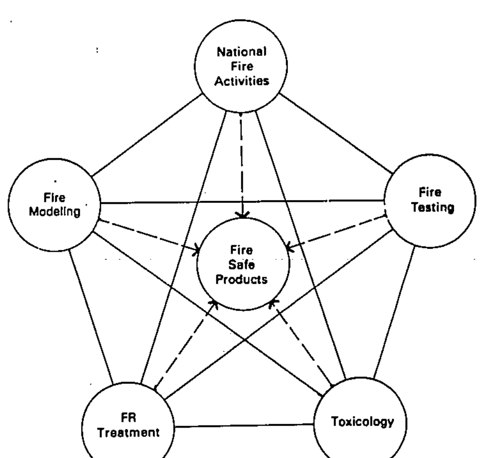
Completed on:
June 27, 1989



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NOTICE

This test method is intended to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or the fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.

INTRODUCTION

Wood products were received from members of National Forest Products Association for testing. These wood products do not necessarily represent any one product, but were made for a generic classification scheme for presentation to the state of New York. (The abbreviations, CCA, PVC and UF representing chromium/copper/arsenic, polyvinyl chloride, and urea formaldehyde, respectively, are used in conjunction with the wood products.) The toxic potency values or LC_{50} values for these wood products were determined using the University of Pittsburgh (UPITT) test procedure as described in Article 15 Part of the *New York State Uniform Fire Prevention and Building Code* [1].

This report includes dimensions of the wood products, test methodology, and the test results.

METHOD

The protocol used is published under Article 15 of the *New York State Uniform Fire Prevention and Building Code* [1]. The LC_{50} values and their confidence intervals were calculated by the Weil method [2].

The UPITT apparatus consisted of a Lindberg furnace (Pittsburgh, PA) connected to an animal exposure chamber. Within the furnace there was a weight load cell upon which the specimen was placed. There was an air flow of eleven (11) liters/minute proceeding from the furnace toward the animal exposure chamber. That air flow was mixed, cooled and diluted with nine (9) liters/minute of cold air (~15°C) before being presented to the animals. The furnace temperature was ramped 20° C/minute. The furnace, however, was not connected to the animals exposure chamber until the specimen had loss 1% of its weight as indicated by the weight load cell. The time at which this occurred was the beginning of the thirty (30)-minute animal exposure. The animal exposure chamber simultaneously housed four (4) male Swiss-Webster mice (Simenon Laboratories, Inc.; Gilroy, CA) in a head-only exposure mode. The decomposition products passed to gas analyzers (carbon monoxide, carbon dioxide and oxygen) after being presented to the animals. The apparatus and protocol were according to the methodology of New York State Protocol [1].

Procedurally, a ten (10)-gram quantity of the material was placed in the furnace after which the ramping of the furnace started. At the 1% weight loss, the animal exposure chamber was connected to the furnace. After the thirty (30)-minute exposure was completed, the animals were observed for an additional ten (10) minutes. Any deaths occurring during these forty (40) minutes were used in the determination of the LC_{50} value. If all the animals died with the ten (10) grams, the next experiment would be with a lower weight. If no animals died, then a higher weight would be used in the next experiment.

That next weight would be determined by a geometric factor. The geometric factor was necessary because of the statistical procedure [2] used for determining the LC_{50} values. This factor (for example, 1.1) would be multiplied by the weight to determine the next higher weight, or the weight would be divided by the factor to determine the next lower weight. Using this statistical procedure, four consequent weights (spaced by the geometric factor along with the corresponding deaths as required by the tables supplied in the reference) were needed to determine an LC_{50} value.

A program was written for a Macintosh® Plus Computer in conjunction with a Fluke 2400A (A/D and D/A measurement and control link) to specifically operate this apparatus. Ramping of the furnace was accomplished by the Macintosh® monitoring the furnace temperature and varying the power supply to the furnace. The specimen weight, the percent of weight loss, concentrations of carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2), time (from the initiation of ramping and from the 1% weight loss), temperatures of the furnace and chamber, and the difference between the actual and theoretical furnace temperatures were displayed on the computer monitor during the experiment as well as recorded on a diskette. The O_2 gas analyzer was a Servomex O_2 Analyzer OA 580 (Sybron/Taylor), and the CO/CO_2 analyzer was a Dual Gas Analyzer (Infrared Industries, Inc.)

In order to confirm that there were no leaks in the system and that the pump, air flow and flowmeters were operating properly, the flow rates of nine (9) and twenty (20) liters/minutes were tested prior to each test with a Mini-Buck Calibrator (A.P. Buck, Inc., Orlando, FL). This flowmeter is traceable to the National Institute of Standards and Technology (formerly National Bureau of Standards). Calibration of the CO and CO_2 analyzers was performed with calibration gases (CO - 0.9% and CO_2 - 5%) certified by Alphagaz Division (Tacoma, WA). The O_2 analyzer was calibrated with room air.

TEST RESULTS

The LC_{50} values and their confidence intervals are presented in Table 1. A number of parameters are reported in summary tables (Table 2-5), such as the minimum oxygen concentration, the maximum carbon monoxide and carbon dioxide concentrations, the maximum animal exposure chamber temperature, the maximum furnace temperature, and the percentage of the specimen weight. Tabulation of the data required by New York State is included (Table 6). These data are from a specimen weight close to the LC_{50} value. The concentration-time (Ct) products for carbon monoxide (Figures 1-4) and carbon dioxide (Figures 5-8) plotted vs the specimen weight are presented for each of the four products. [This Ct product is a value calculated by multiplying the gas concentration, such as carbon monoxide, with the time of animal exposure to the gas concentration. In other words, it is the area under the curve of the gas concentrations vs time.]

REFERENCES

1. Article 15, Part 1120 -- New York State Fire Prevention and Building Code. New York Standards & Fire Information Network, Office of Fire Prevention and Control. Albany, NY.

2. Weil, C.S., Tables For Convenient Calculation Of Median-Effective Dose (LC_{50} or ED_{50}) And Instructions In Their Use. *Biometrics* 8: 249-263, 1952.

SAMPLE PREPARATION

These wood products were stored in a conditioning room (23.8 ± 2.8° C and 50 ± 10% Relative Humidity) for at least 48 hours prior to testing. Each specimen placed in the furnace was a piece of a wood product cut to a specific weight.

WOOD PRODUCT DIMENSIONS

Wood Product	Length (inch)	Width (inch)	Thickness (inch)
Southern Pine Lumber- 20% Fire Retardant	12	5.5	1.5
Southern Pine Lumber- 2.7% CCA	48	24	1.53
Southern Pine Particleboard- 10% PVC	20.5	12.5	0.21
Southern Pine Particleboard- 15% UF	21	13	0.51

Table 1: LC_{50} Values and their Confidence Intervals

Wood Product	LC50 Value (grams)	95% Confidence Interval	
		Low Value	High Value
Southern Pine Lumber- 20% Fire Retardant	71.7	57.3	89.7
Southern Pine Lumber- 2.7% CCA	45.9	40.2	52.6
Southern Pine Particleboard- 10% PVC	12.1	9.6	15.3
Southern Pine Particleboard- 15% UF	15.0	13.7	16.4

SUMMARY TABLES

Table 2: Southern Pine Lumber - 20% Fire Retardant

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Specimen Weight (grams)	10.00	17.72	14.64	8.26	12.10	55.60	98.49	81.40	67.27	21.44
Maximum Chamber Temperature (°C)	39.3	38.6	41.5	43.3	36.2	41.5	45.8	44.2	45.5	37.0
Maximum Furnace Temperature (°C)	853.5	849.6	851.3	849.8	850.3	854.0	853.4	848.1	850.0	848.5
Weight Loss (%)	63.5	59.2	55.5	59.3	59.4	59.3	61.7	61.7	64.5	61.7
Minimum Oxygen Concentration (%)	20.17	19.11	20.22	20.58	20.21	17.91	17.51	17.33	17.29	18.85
Maximum CO Concentration (ppm)	4109	4417	4730	2836	4489	6622	5822	7417	9724	5951
Maximum CO2 Concentration (ppm)	3893	14374	5203	3144	4283	27025	32775	30280	33101	15232
Number of Animals Exposed	4	4	4	4	4	4	4	4	4	4
Number of Dead Animals	0	0	0	0	0	1	4	2	2	0
Lethality (%)	0	0	0	0	0	25	100	50	50	0
Ct Product for CO (ppm x min)	30965	14788	26663	22364	29424	24914	34267	24079	30012	20442
Ct Product for CO2 (ppm x min)	61080	93626	62930	46901	59391	324518	446726	426488	400901	116958
T1% (°C)	250	250	250	250	250	250	250	250	250	250

Test Sequence	Test 11	Test 12	Test 13	Test 14
Specimen Weight (grams)	25.94	31.38	37.97	45.95
Maximum Chamber Temperature (°C)	37.8	38.0	36.5	37.6
Maximum Furnace Temperature (°C)	846.4	850.9	849.2	849.3
Weight Loss (%)	64.2	64.2	59.1	58.9
Minimum Oxygen Concentration (%)	18.46	18.47	19.41	18.9
Maximum CO Concentration (ppm)	5217	7053	3429	3490
Maximum CO2 Concentration (ppm)	19735	20879	14158	16289
Number of Animals Exposed	4	4	4	4
Number of Dead Animals	0	1	0	0
Lethality (%)	0	25	0	0
Ct Product for CO (ppm x min)	19092	24230	18402	18321
Ct Product for CO2 (ppm x min)	149875	166578	158422	184628
T1% (°C)	250	250	250	250

Table 3: Southern Pine Lumber - 2.7% CCA*

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
Specimen Weight (grams)	10.00	17.71	25.94	45.95	55.60	37.97	31.38
Maximum Chamber Temperature (°C)	40.25	35.7	36.5	40.6	40.75	40.5	36.89
Maximum Furnace Temperature (°C)	851.0	850.9	853.2	848.4	853.8	848.3	851.3
Weight Loss (%)	76.2	79.6	77.8	77.5	76.2	76.8	77.5
Minimum Oxygen Concentration (%)	18.34	16.75	16.28	14.77	13.93	15.20	15.46
Maximum CO Concentration (ppm)	5618	8343	8804	9899	12015	10284	8737
Maximum CO2 Concentration (ppm)	16135	33507	39128	55822	59291	50266	48003
Number of Animals Exposed	4	4	4	4	4	4	4
Number of Dead Animals	0	0	0	1	4	1	0
Lethality (%)	0	0	0	25	100	25	0
Ct Product for CO (ppm x min)	20851	22942	24120	29222	48417	26523	22045
Ct Product for CO2 (ppm x min)	125050	246807	353471	574571	686644	487653	429265
T1% (°C)	250	250	250	250	250	250	250

*CCA - chromium / copper / arsenic

Table 4: Southern Pine Particleboard - 10% PVC*

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5
Specimen Weight (grams)	10.00	12.10	14.64	17.72	8.26
Maximum Chamber Temperature (°C)	37.4	47.4	49.9	40.0	44.4
Maximum Furnace Temperature (°C)	821.2	827.5	820.5	820.0	816.2
Weight Loss (%)	70.6	78.3	79.3	75.6	75.5
Minimum Oxygen Concentration (%)	19.71	19.65	19.74	19.05	20.19
Maximum CO Concentration (ppm)	5346	7001	5967	10764	3720
Maximum CO2 Concentration (ppm)	5082	6427	6909	8063	4611
Number of Animals Exposed	4	4	4	4	4
Number of Dead Animals	1	2	3	3	0
Lethality (%)	25	50	75	75	0
Ct Product for CO (ppm x min)	32237	40538	42857	58792	25504
Ct Product for CO2 (ppm x min)	77047	103820	124814	123427	71468
T1% (°C)	220	230	220	220	220

*PVC - polyvinyl chloride

Table 5: Southern Pine Particleboard - 15% UF*

Test Sequence	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Specimen Weight (grams)	10.00	11.27	15.01	13.64	16.51	12.40
Maximum Chamber Temperature (°C)	32.0	37.6	40.6	42.2	41.4	38.1
Maximum Furnace Temperature (°C)	826.8	826.7	827.4	818.7	819.2	818.8
Weight Loss (%)	84.4	75.3	79.6	80.8	77.9	80.0
Minimum Oxygen Concentration (%)	20.03	18.26	19.45	19.48	17.13	19.4
Maximum CO Concentration (ppm)	5215	7609	9642	8327	11284	7930
Maximum CO2 Concentration (ppm)	8824	8267	10022	9477	12850	7786
Number of Animals Exposed	4	4	4	4	4	4
Number of Dead Animals	1	0	3	0	3	0
Lethality (%)	25	0	75	0	75	0
Ct Product for CO (ppm x min)	29179	38570	47427	40071	53008	38622
Ct Product for CO2 (ppm x min)	117670	133017	142731	131283	160919	114892
T1% (°C)	220	220	220	220	220	220

*UF = Urea Formaldehyde

Table 6: New York State Data

	Southern Pine Lumber - 20% Fire Retardant	Southern Pine Lumber - 2.7% CCA
Number of Samples Tested	14	7
Furnace Temperature at 1% Sample Mass Loss (°C)	250	250
Maximal Concentration of Carbon Monoxide in the Exposure Chamber (ppm)	9724	9899
Furnace Temperature at the Point of Maximal Carbon Monoxide (°C)	525	501
Maximal Concentration of Carbon Dioxide in the Exposure Chamber (%)	3.31	5.58
Furnace Temperature at the Point of Maximal Carbon Dioxide (°C)	549	552
Minimal Concentration of Oxygen in the Exposure Chamber (%)	17.3	14.8
Furnace Temperature at the Point of Minimal Oxygen (°C)	551	518
Number of Times the Exposure Chamber Temperature Exceeded 45°C	1	0
Average Duration of Exposure Chamber Temperature in Excess of 45°C (sec)	98	0
Eye Condition of Test Animals: (1) All apparently normal, (2) Some appparent damage, (3) Some severe damage	1	1

	Southern Pine Particleboard - 10% PVC	Southern Pine Particleboard - 15% UF
Number of Samples Tested	5	6
Furnace Temperature at 1% Sample Mass Loss (°C)	220	220
Maximal Concentration of Carbon Monoxide in the Exposure Chamber (ppm)	7001	9642
Furnace Temperature at the Point of Maximal Carbon Monoxide (°C)	450	501
Maximal Concentration of Carbon Dioxide in the Exposure Chamber (%)	0.64	1
Furnace Temperature at the Point of Maximal Carbon Dioxide (°C)	452	496
Minimal Concentration of Oxygen in the Exposure Chamber (%)	19.7	19.5
Furnace Temperature at the Point of Minimal Oxygen (°C)	451	504
Number of Times the Exposure Chamber Temperature Exceeded 45°C	1	0
Average Duration of Exposure Chamber Temperature in Excess of 45°C (sec)	415	0
Eye Condition of Test Animals: (1) All apparently normal, (2) Some appparent damage, (3) Some severe damage	2	2

Carbon Monoxide Ct Product

vs

Specimen Weight

Figure 1: Southern Pine Lumber - 20% Fire Retardant

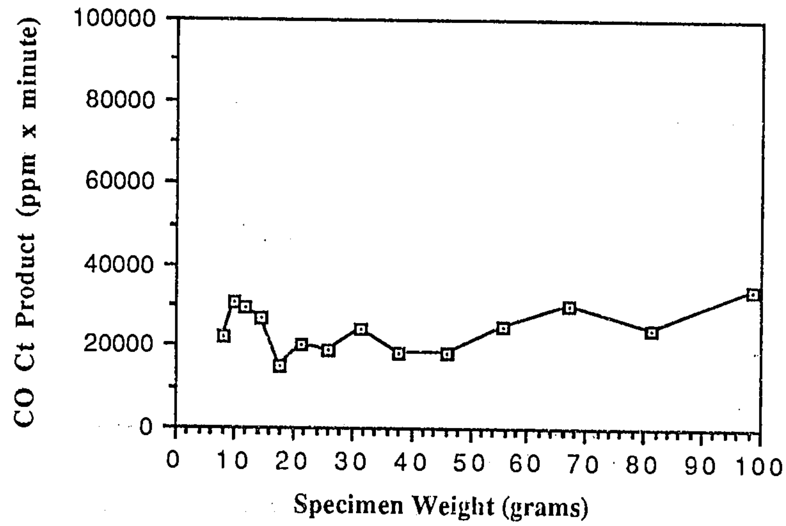


Figure 2: Southern Pine Lumber - 2.7% CCA

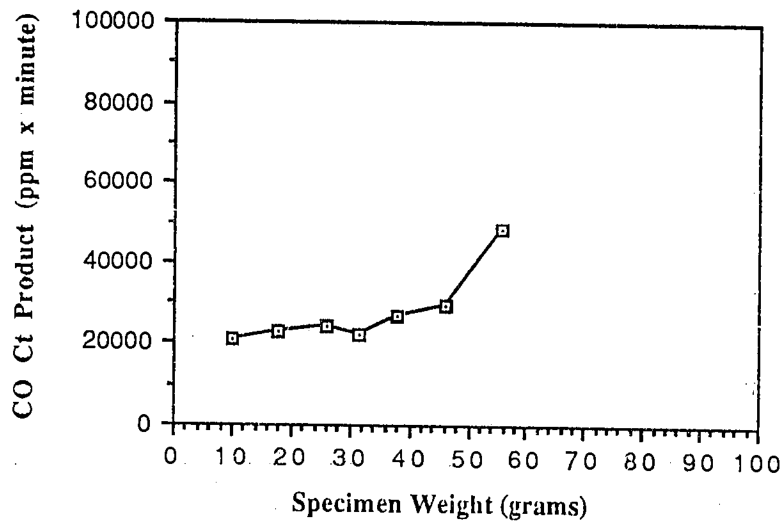


Figure 3: Southern Pine Particleboard - 10% PVC

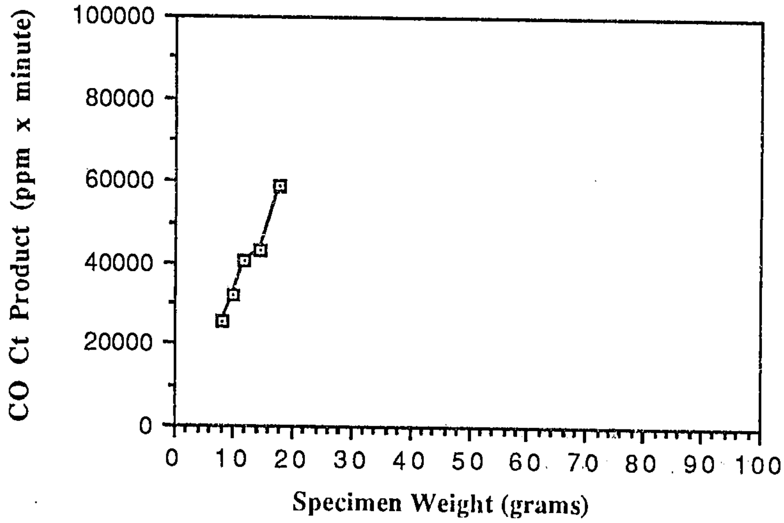
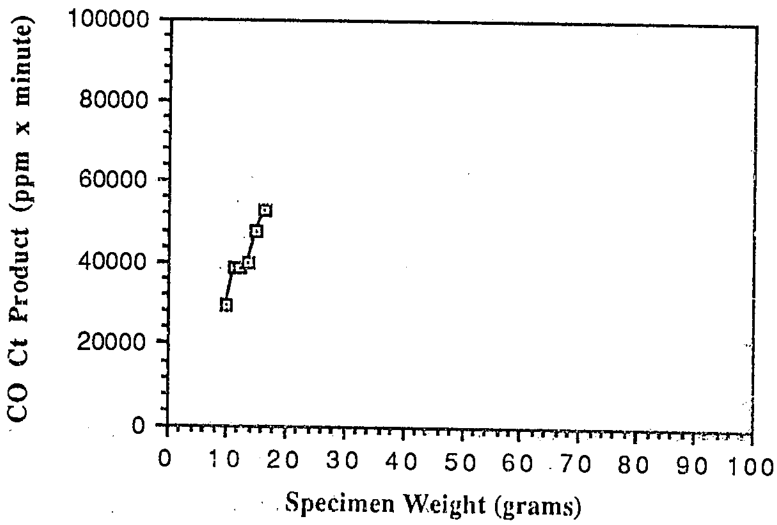


Figure 4: Southern Pine Particleboard - 15% UF



Carbon Dioxide Ct Product

vs

Specimen Weight

Figure 5: Southern Pine Lumber - 20% Fire Retardant

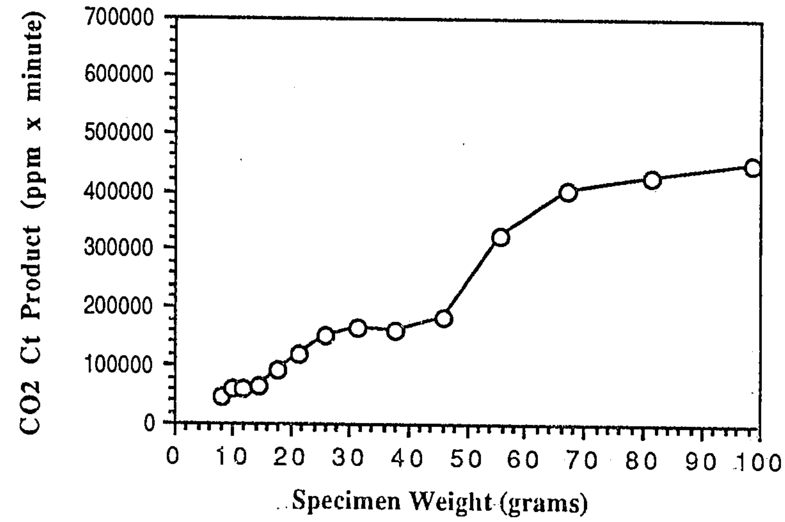


Figure 6: Southern Pine Lumber - 2.7% CCA

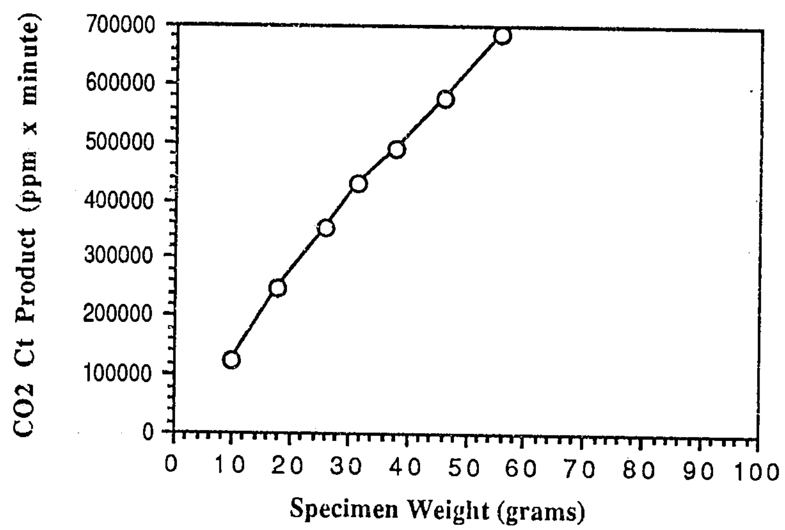


Figure 7: Southern Pine Particleboard - 10% PVC

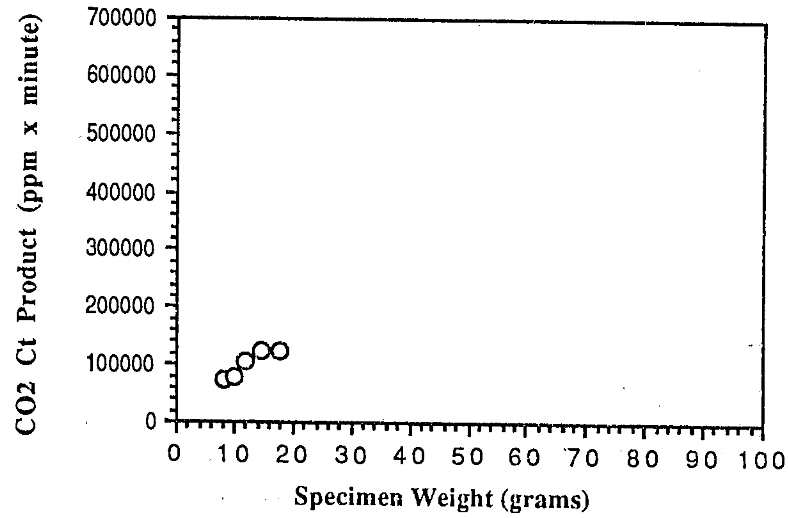
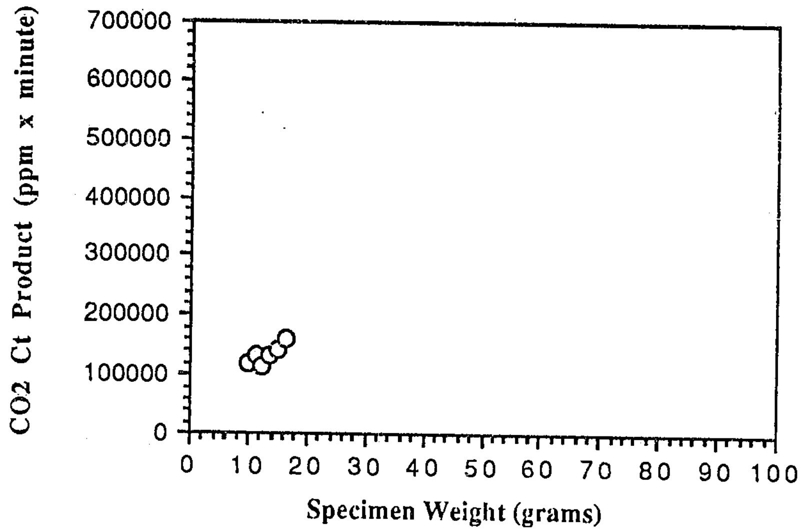


Figure 8: Southern Pine Particleboard - 15% UF



SIGNATURE PAGE

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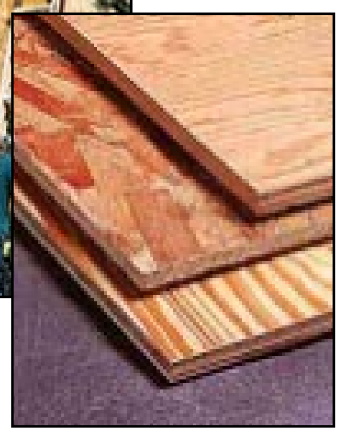
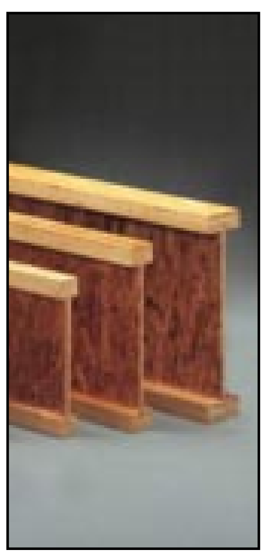
ENGINEERED WOOD PRODUCTS PRIMER AWARENESS GUIDE





American Wood Council

American
Wood
Council

ENGINEERED WOOD PRODUCTS PRIMER AWARENESS GUIDE

The American Wood Council (AWC) is the voice of North American traditional and engineered wood products, representing over 75% of the industry. From a renewable resource that absorbs and sequesters carbon, the wood products industry makes products that are essential to everyday life and employs over one-third of a million men and women in well-paying jobs. AWC's engineers, technologists, scientists, and building code experts develop state-of-the-art engineering data, technology, and standards on structural wood products for use by design professionals, building officials, and wood products manufacturers to assure the safe and efficient design and use of wood structural components. For more wood awareness information, see www.woodaware.info.

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www.woodaware.info

This guide reviews the history and development of engineered wood products (EWP) in the marketplace and provides definitions that enable a fire service instructor to identify these lightweight products as they are used in building construction. This publication is one in a series of eight Awareness Guides developed under a cooperative agreement between the Department of Homeland Security's United States Fire Administration, and the American Wood Council.

Engineered Wood Products Primer

MEETING THE NEEDS OF THE FIRE SERVICE

The level of training and technical support available from the building industry has increased dramatically in the past twenty years. Engineered wood product specialists are now common in the construction industry and software has helped to communicate the intricacies of the many new products. Until now, however, the available information has not been uniformly provided to the fire service. This series of *Awareness Guides* has therefore been prepared to "train the trainer" and begin to inform the fire service in a uniform manner about new wood product construction materials and methods being used in the marketplace.

The wood products industry is committed to delivering educational material to the fire service with the goal of reducing risk of injury from structural collapse in fires. These *Awareness Guides* will address questions raised by the fire service during a series of industry visits to a number of state fire academies.

PURPOSE OF THIS GUIDE

This guide reviews the history and development of engineered wood products in the marketplace and provides definitions that enable a fire service instructor to identify these lightweight products as they are used in building construction.

BACKGROUND

As noted above, the past fifty years have seen unprecedented changes in building construction. The changes in wood frame construction during this period have also been significant, paralleling the numerous changes within the fire service. The wood industry has adapted to a number of opportunities and constraints. As a result, there are many lightweight structural products and construction techniques for building residential wood frame houses.

After World War II, the explosive growth of American suburbs was unlike any other time in history. In the 1950s, most homes were constructed with solid sawn lumber framing, with diagonal board sheathing placed on floors, walls, and roof. Hardwood plank flooring was commonplace. In the 1960s, plywood sheathing had become common for floors, roofs, and walls, and the use of trusses in roofs had replaced rafters throughout the homebuilding industry. Additionally, carpeting had become the preferred flooring choice.

Transition to Engineered Lightweight Construction

In the 1980s, both environmental limitations and consumer demand spurred the transition to engineered lightweight wood construction. Environmental constraints reduced the size of trees delivered to saw mills. With larger-diameter logs unavailable, the wood industry developed technology to "disassemble" smaller logs and glue them back together lighter and stronger. It had become impossible to make a 20-foot long 2x12 floor joist out of a 9-inch diameter tree, or plywood out of 6-inch tree tops that were full of knots. The choice was clear to the wood industry—either use smaller diameter trees or witness a significant decline in the use of dimensional lumber and panels in residential construction.

At the same time, coupled with environmental constraints, consumers expected the forest products industry to use fewer trees with greater efficiency and less waste. Meanwhile, the square footage of residential homes was increasing, along with demand for deep, long, and straight building materials.

New Design Standards

Design and material standards for new structural products also began to change. Previous standards had been prescriptive. For example, by this cookbook approach, plywood or another panel product would have to be manufactured according to a strict recipe designating adhesives to be used and type and dimension of materials. The newer standards developed were instead based

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simply on performance. A product could be manufactured with any adhesive, as well as type or dimension of material, as long as it performed in accordance with the requirements of manufacturing standards and the building code.

The evolution of performance-based standards created the ideal opportunity for product innovation in the marketplace. Building code organizations, in turn, developed evaluation services to manage approval of the influx of newer products offered as alternatives to those already listed in the building code.

(See www.woodaware.info for a link to the International Code Council's Evaluation Services.)

DEFINING ENGINEERED WOOD PRODUCTS

In response to consumer demands, the wood industry developed technologies to use smaller trees more efficiently. These technologies moved homebuilding to a new era of more fiber-efficient and lightweight engineered materials—thus the term "engineered wood products."

There are different opinions as to what is an engineered wood product (EWP). From the fire service perspective, any product consisting of a combination of smaller components into a structural member and designed using engineering methodologies should be considered engineered. Engineered products are developed to use materials efficiently. Therefore, many engineered wood products are lighter in weight than the conventional product they are designed to replace.

For the sake of definition here, engineered wood products are structural components or assemblies that are offered as alternatives to solid sawn lumber. Structural composite lumber, I-joists, and wood trusses are examples.

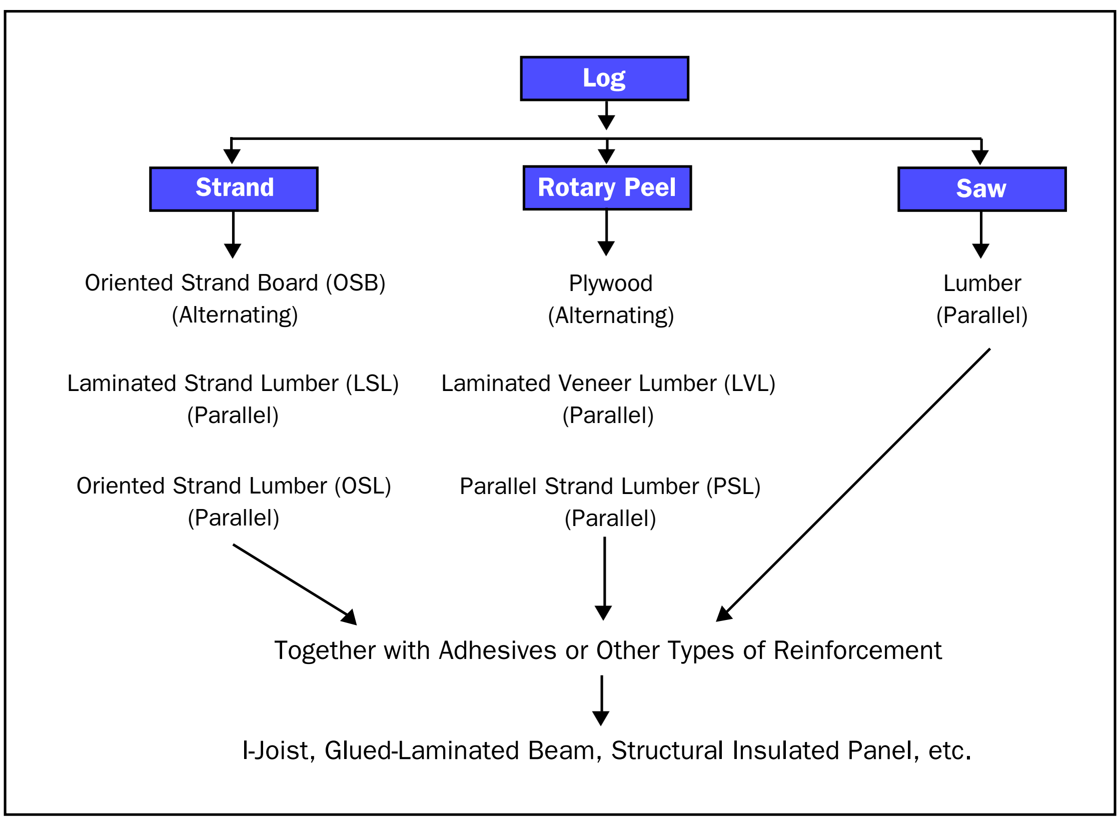
Most of these products are proprietary (uniquely designed from a specific manufacturer) and are marketed under different trade names. Each of these products, however, has to comply with building code requirements before its use in structural applications.

HOW ENGINEERED WOOD PRODUCTS ARE MANUFACTURED

There are three primary manufacturing methods to dismantle a log and reassemble it into an engineered wood product—stranding, peeling, and sawing—as shown in Figure 1.

Figure 1 EWP Manufacturing Methods

There are three primary manufacturing methods to dismantle a log and reassemble it into an engineered wood product—stranding, peeling, and sawing.



Stranding

Stranding involves slicing a log into 1-inch to 12-inch strands, similar to a cheese grater. The strands are dried in a large rotary drum, where resin is applied. The strands are then dropped into a forming bin and pressed together to form the product. These products can be thin and flat, like plywood, or long and wide, like lumber.

Stranding is the most efficient method to convert a log into an engineered wood product, because it uses the smallest pieces (Figure 2). Smaller strands pack more efficiently into rectangular sections. The net result is increased utilization of a tree and less waste delivered to the landfill. For example, a 100 cubic foot log produces only 40 cubic feet of solid lumber, but 76 cubic feet of engineered wood products. More efficient conversion of the natural resource results in benefits to the industry, consumer, and the environment.

Peeling

Rotary peeling involves placing a long knife parallel to the outside edge of a spinning log. The knife peels slices off the log like paper towels off a roll. The wood slices are then clipped into individual sheets (called veneer), which are dried, glued, and pressed together to form the product. Peeling the log is not as efficient as stranding (Figure 2), but is still attractive to facilities that were established to peel logs but now want to manufacture engineered wood products.

Sawing

Sawing involves cutting a log into common rectangular sections, such as 2x3 or 2x4. The lumber is dried and cut to length before assembly as an engineered wood product, such as trusses or I-joist flanges.

Conversion Efficiency of Engineered Wood Products

The forest products industry is constantly looking for innovative ways to use more and more of each log, thereby reducing waste. How well manufacturers are able to use the fiber in a log when they convert it to a product is called "conversion efficiency" (Figure 2).

TYPES OF ENGINEERED WOOD COMPONENTS

There are many generic names and acronyms to describe engineered wood products. As a result, popular trade names are most familiar. (See www.woodaware.info for links to individual manufacturers' websites.) Whether stranded, peeled, or sawn, EWPs are designed to meet specific stiffness and strength criteria, so that an engineer can reliably design a structure with the lightweight component.

Figure 2 Conversion Efficiency of Engineered Wood Products

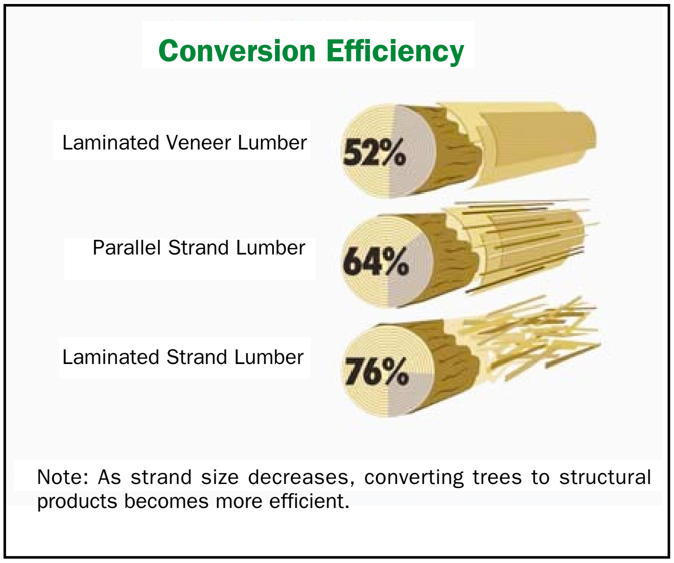


Figure 2 above shows the conversion efficiency of laminated veneer lumber (LVL), parallel strand lumber (PSL), and laminated strand lumber (LSL). These are examples of structural composite lumber (SCL).

Strand Products

There are three primary types of wood products manufactured from strands: oriented strand board (OSB), laminated strand lumber (LSL), and oriented strand lumber (OSL).

- OSB most often is used as panels and as a lumber substitute. OSB is formed by alternating the layers of strands perpendicular to the previous layer, which provides bending support in two directions. The strands are up to three inches long (see more information on this product in the *Wood Structural Panel Awareness Guide* in this series).
- LSL most often is used as a lumber substitute and as flanges in I-joists. The strands used are up to 12 inches long and in manufacture are placed parallel to each other.
- OSL has uses similar to LSL. It is fabricated with shorter strands, up to six inches long.

Peel Products

There are three primary wood products manufactured using peeling technology: plywood, laminated veneer lumber (LVL), and parallel strand lumber (PSL).

- Plywood most often is used as structural panels. Plywood is manufactured by alternating veneer perpendicular to the previous layer, which provides bending support in two directions (see more information on this product in the *Wood Structural Panel Awareness Guide* in this series).
- LVL most often is used as a lumber substitute and as flanges for I-joists. The layers of veneer are staggered to disperse the joints between veneer segments.
- PSL is manufactured from veneer clippings that are too narrow for LVL or plywood. The PSL process involves clipping the veneer to less than one inch wide, coating the clippings with resin, and forming them into large dimension cross-sections similar in size to heavy timber.

Engineered Wood Products with Multiple Components

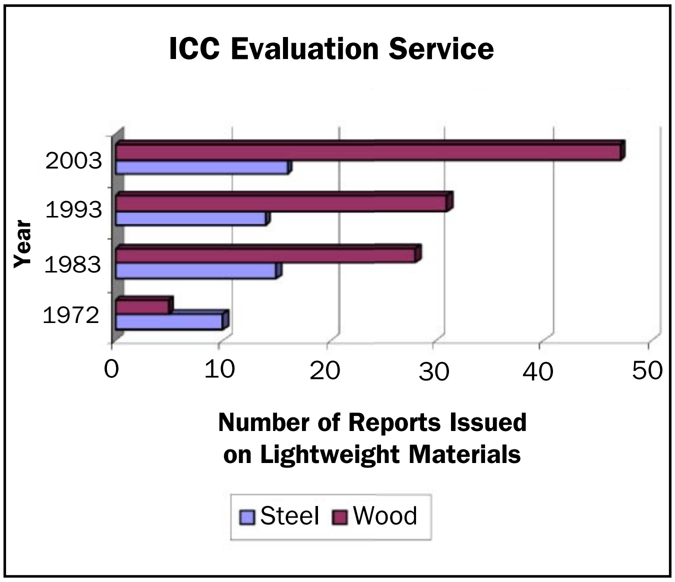
An engineered wood product may consist of multiple engineered components. For example, an I-joist can have OSB as the web, and lumber or structural composite lumber as the flanges. A glued-laminated timber beam is an engineered assembly of specially graded lumber. A truss is an engineered assembly often comprised of sawn lumber chords and wood or metal webs.

SOME ADVANTAGES OF ENGINEERED WOOD PRODUCTS

One of the most attractive features of these engineered components and assemblies is that they can be produced to longer lengths than their sawn lumber counterparts. EWPs can be cut to exact lengths prior to delivery, thereby eliminating job site waste. They also eliminate any problems related to natural defects present in sawn lumber.

EWP technology did not come without a cost. It is more expensive to peel, strand, glue, and press together a 2x12 than to cut that dimension directly from a log. Added costs, coupled with certain environmental expectations to reduce harvesting, fueled development and the resulting popularity of lightweight engineered materials. Products such as I-joists use 50% less fiber than a rectangular piece of lumber of the same width.

Figure 3 Lightweight Materials Enter Marketplace



The number of evaluation reports issued by the International Code Council Evaluation Service reflects the upsurge in use of lightweight innovative products for both wood and light gauge steel over the past thirty years.

INNOVATION IN ENGINEERED WOOD PRODUCTS

As represented by the number of evaluation reports issued by the ICC ES, Figure 3 illustrates the upsurge in use of innovative products for both wood and light gauge steel over the past thirty years. While some of these products have a larger market share than others, the overall trend in their use is in increasingly complex configurations. For example, there are new construction practices such as floor and roof assemblies (see structural insulated panels in Figure 4), new connection details (hangers, straps, staples), new resources (lesser known species, hardwoods, offshore species), and new adhesives and composites (various blend of materials, plastics, and glass fiber reinforcement).

The Changing Marketplace

Lightweight components have made a significant market impact in the United States. For example, I-joists have grown from a small percentage to over a 50% market share in residential floors over the last twenty years, and can be projected to reach 70% by 2020, based on housing starts (Figure 5). The I-joist industry has already expanded manufacturing capacity to meet this anticipated demand. It is estimated that currently over 6.5 million homes contain an I-joist floor or roof system.

Figure 4 Structural Insulated Panel Roof Assembly

Structural Insulated Panels (SIPs) are composites of foam plastic [usually expanded polystyrene (EPS)] sandwiched between wood structural panels. Here, a SIP is used to build a roof.

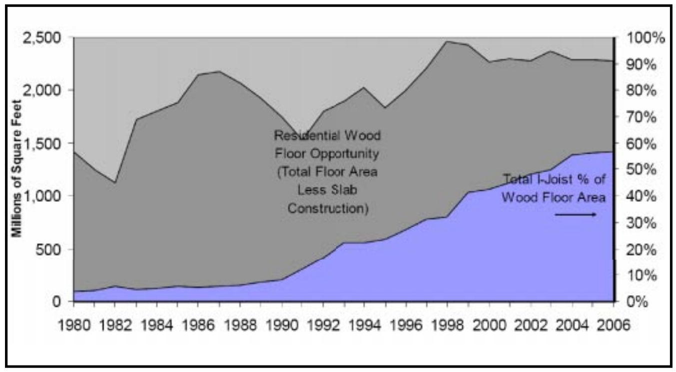
Metal-plate-connected wood trusses were introduced in the mid-1950s. These trusses are designed by engineers with specialized training in structural building component design for floors and roofs. The most common application is in a roof assembly. Trusses used to form traditional sloped roof assemblies are referred to as "pitch chord." Parallel chord trusses can also be used to form flat roof assemblies, but they are more commonly used in the construction of floors.

PERFORMANCE REQUIREMENTS FOR ENGINEERED WOOD PRODUCTS

To qualify for use in the marketplace, an engineered wood product must be classified under one or more test standards, listed on www.woodaware.info.

Typically, a new product must also meet ICC ES (International Code Council Evaluation Service) acceptance criteria. Once a product meets established acceptance criteria, ICC ES issues an evaluation report as evidence of compliance.

Figure 5 I-Joist Market Share of Wood Floors



FIRE PERFORMANCE OF ENGINEERED WOOD PRODUCTS

Fire testing of engineered wood products is required to satisfy building code provisions. For one- and two-family dwellings, there are no structural fire performance requirements. However, for multi-family housing and commercial structures, one- or two-hour fire rated assemblies may be required. To comply, a manufacturer would need to supply qualifying ASTM E119 test reports on wall or floor assemblies as proof of compliance to applicable code provisions.

BUILDING CODE CERTIFICATION OF ENGINEERED WOOD PRODUCTS

Role of Certification Agencies

Model building codes require that engineered wood products be certified by an independent third-party certification agency. That independent agency must confirm that products meet the strict performance criteria required by building codes. Before submitting samples to a certification agency for testing and certification, engineered wood products manufacturers conduct regular, extensive, and monitored performance testing.

Through regular and unannounced random audits at manufacturing facilities, certification agencies implement and closely monitor a rigorous quality control program. During the auditing process, certification agency personnel review and verify quality control test results. They also collect and test samples (small and/or large) to ensure that the engineered wood product meets required performance criteria.

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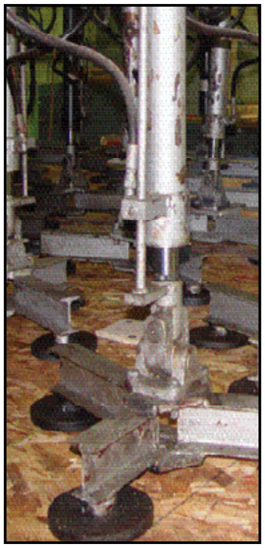
FIRE PERFORMANCE OF WOOD PRODUCTS AWARENESS GUIDE



American Wood Council

FIRE PERFORMANCE OF WOOD PRODUCTS

The American Wood Council (AWC) is the voice of North American traditional and engineered wood products, representing over 75% of the industry. From a renewable resource that absorbs and sequesters carbon, the wood products industry makes products that are essential to everyday life and employs over one-third of a million men and women in well-paying jobs. AWC's engineers, technologists, scientists, and building code experts develop state-of-the-art engineering data, technology, and standards on structural wood products for use by design professionals, building officials, and wood products manufacturers to assure the safe and efficient design and use of wood structural components. For more wood awareness information, see www.woodaware.info.

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This publication is one in a series of eight Awareness Guides developed by the American Wood Council for the fire service. This series of guides is intended to contribute to the knowledge base of developers of fire service training curriculum and publications. These guides were developed under a cooperative agreement with the Department of Homeland Security's United States Fire Administration.

Fire Performance of Wood Products

There are approximately 1.1 million firefighters in the United States who respond to approximately 2 million fire calls each year. Tragically, in 2001, seventeen fire fighter Line of Duty Deaths (LODD) occurred in residential construction [1]. In response, an essential objective of the United States Fire Administration is to reduce firefighter fatalities[2]. Additionally, the National Fallen Firefighters Foundation's goal is to make sure "Everyone Goes Home."

The National Fire Protection Association (NFPA) has determined that less than 5% of fires originate within concealed spaces where structural wood products are located [3]. Building contents, such as furniture, cabinets, drapes, or electronic equipment, are often the first items ignited and are the primary fuel source in fires. However, when not suppressed, these fires can eventually compromise the structural system of a building and may lead to collapse. If the structure itself becomes involved in fire, the fire service must understand the nature of the structural products used as well as their fire performance characteristics, to reduce risk of death or injury.

The Changing Homebuilding Industry

At the same time, the homebuilding industry is changing in response to resource constraints and market demands. Notably, the availability of large-diameter trees is on the decline. At the same time, homeowners are clamoring for homes with open ceilings and larger rooms. To meet this demand, a large number of new products have entered the market.

FIRE PERFORMANCE OF WOOD

Fire professionals all agree that each fire is unique. There is no fool-proof method to predict how a fire will develop in a specific room and what thermal effects will develop on the surrounding structure. However, for purposes of comparison, fire scientists have agreed upon the use of standard fire exposures, developed from data derived from many fires.

It is well established that building contents (furniture, cabinets, drapes, electronic equipment, etc.) are the primary fuel source in fires. The fire intensity and rate of fire growth are influenced by the types, volume, and configuration of these contents. Given the infinite possible variations, it is not possible to accurately predict how any particular fire will grow. Hence each fire scenario is unique.

Fire performance characteristics of building products are dependent on fire intensity and rate of fire growth. The following discussion on combustibility, ignition temperatures, flame spread, heat release rate, char rate, smoke, and fire endurance is presented in terms of standardized test methods, allowing comparison between materials, but is not intended to represent any specific fire scenario.

Combustibility and How Wood Burns

Wood will burn when exposed to high enough temperatures and in the presence of oxygen. Thermal degradation of wood occurs in stages. The degradation process and the exact products of thermal degradation depend upon the rate of heating as well as temperatures. This is what happens to wood in a fire:

- As the surface temperature of wood increases due to fire exposure, flammable vapors are produced and a char layer (burnt wood) is formed on the external surfaces.
- In the presence of fire, these flammable vapors ignite and contribute to the fire.
- As the char layer gets thicker, it insulates the remaining unburned wood and slows the rate of vapor production, thereby slowing the charring process.

Ignition Temperature of Materials

In the absence of an open flame, wood typically ignites at temperatures above 550^{o}F [4,5] depending on species, moisture content, and time of exposure to an elevated temperature. In the presence of a flame, ignition temperatures are lower.

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Flame Spread

The standard fire test used to evaluate flame spread characteristics of building materials in the United States is *ASTM E-84*, *Standard Test Method for Surface Burning Characteristics of Building Materials[6]*. To provide standard conditions for each specimen, the test is conducted in a standard dimension tunnel, calibrated to a benchmark index of 0 for noncombustible materials and 100 for nominal one-inch red oak flooring.

Based on the resulting flame spread index, building materials are classified into three classes: Class A = 0 to 25; Class B = 26 to 75; and Class C = 76 to 200. Untreated wood products typically fall into either Class B or C. Fire retardant treatments, typically required to be by pressure impregnation, can lower the flame spread rate of wood products to Class A. Table 1 lists the flame spread indices of several wood products. A comprehensive list is available in *Flame Spread Performance of Wood Products[11]*.

Lumber, plywood, and other wood-based materials, including the components of I-joists and trusses, exhibit a relatively narrow range of flame spread. Flame spread rates for LVL, PSL and LSL are within the same range as solid wood materials. Differences result from factors such as density, thickness, surface characteristics, and coatings or other chemicals applied, if any. Typically, at thicknesses greater than 1/4", flame spread is almost independent of material thickness.

Table 1: Flame Spread Indices of Wood Products

Wood Material	Flame Spread Index	
Yellow Poplar Lumber	185	Class C
Doug Fir Plywood	155	
Walnut Lumber	140	
Oriented Strand Board	138	
Yellow Birch Lumber	110	
Southern Pine Plywood	110	
Maple Lumber	104	
Douglas Fir Lumber	100	
Red or White Oak Lumber	100	
Eastern White Pine Lumber	85	
Western White Pine Lumber	75	Class B
Red Cedar Lumber	73	
Redwood Lumber	70	
White Fir Lumber	65	
Fire Retardant Treated Lumber/Plywood	Less than 25	Class A

Glued Laminated Lumber (Glulam), Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL), and Laminated Strand Lumber (LSL) are wood products made for structural applications in a process similar to that of making plywood (for details on these products, see other Guides available in this series). These wood products react to fire much the same as comparable sizes of solid sawn lumber. Several types of adhesives may be used in the manufacture of these man-made structural lumbers. One commonly used adhesive, phenol-formaldehyde resin, is inert once cured and does not contribute to the fire load. Furthermore, the strength of the bond is not adversely affected by heat. Accordingly, their flame spread indices are representative of the wood species from which they are manufactured.

Smoke Developed

Smoke developed (sometimes referred to as smoke obscuration) has been measured for some wood products. The index for this criterion also has an established value of 100 for red oak. None of the wood products tested exceeded 450, a limiting value commonly used in building code regulations.

Charring

Wood exposed to fire develops an insulating layer of char that further slows wood degradation (see Figure 1 on next page). The char layer contributes no strength to the remaining cross-section, but acts to insulate the underlying wood from further charring, thus retarding the char rate. The structural capacity of a wood member exposed to fire depends upon its unburned-wood cross-section. Accordingly, char rate is a major factor in the determination of the fire endurance of wood products.

In laboratory experiments, the char rate of wood is measured by burning a test specimen for a measured time period. In the test, a wood specimen is exposed to a radiant heat source (example: electric coil heater or gas burners) for a chosen time period, then the remaining uncharred section is measured after extinguishment. Char rate is calculated by dividing the loss of wood due to char by time. A lower char rate indicates a slower burn rate.

Across all species of wood, charring begins at an approximate rate of 1.9 inches/hour for a short period of time, and then slows to about 1.4 inches/hour due to the insulating effect of the initial char layer. For calculations and estimates, the average char rate is assumed to be 1.5 inches/hour. Moisture content in wood significantly affects char rate. Other factors, such as wood density and anatomical features (grain direction, species, etc.), also affect the rate of the char layer formation[5].

Heat Release Rate

Another measure of how fast or "hot" a material burns is its total heat release (THR) and peak heat release rate (PHR). These measurements are useful to assess the relative heat contribution of materials—thick, thin, untreated, or treated—under fire exposure. The cone calorimeter (ASTM E1354) is the most commonly used bench-scale THR and PHR apparatus. An advanced test method, it estimates the heat release rate based on how much oxygen is consumed during burning. This method, called the *oxygen depletion method*, provides better accuracy than the traditional method of assessing heat release rate by measuring temperature rise in the exhaust gas stream. This is because the fraction of heat released through radiant emission varies with the type of material being burned, and not all radiant energy contributes to temperature rise.

Table 2 lists Total Heat Release and Peak Heat Release data from the Cone Calorimeter for several wood products. The test specimens were exposed to an external heat flux of 75 kW/m^2, representing post-flashover conditions, for 15 minutes. Total heat released during the 15-minute test and the peak heat release rate during this period is shown[12].

Table 2: Total Heat Release From Cone Calorimeter

Material	THR (MJ/m^2)	PHR (kW/m^2)
Red Oak	139	272
Oriented Strand Board	107	331
Spruce, Pine Fir (SPF)	109	226
Fire retardant treated plywood	56	155
Fire retardant treated lumber	48	71

Smoke Toxicity

The major chemical elements found in natural wood products are carbon, hydrogen, and oxygen. When thermally decomposed, these elements primarily produce carbon monoxide, carbon dioxide, and water. Where nitrogen or halogen containing compounds, such as adhesives and laminates, are added to make composite wood products, the potential for production of hydrogen cyanide and hydrogen halide exists during the burning process. However, the toxic potency of the smoke from these composite wood products is no higher than the smoke from natural wood, as shown by smoke toxicity test data supplied to New York State on a large number of wood species and products [7,8]. A review of combustion toxicity by John Hall, NFPA, revealed that toxicants other than carbon monoxide are not a major problem in fire toxicity or overall fire safety [9,10].

Performance of Metal Fasteners and Connectors

Steel fasteners and connectors share the following common attributes:

a) they have 50% of yield strength at 1100°F[13];
b) they initially reflect radiant heat under fire conditions; and,
c) much of their structural capacity comes from the portions of connectors embedded in wood and somewhat insulated from the fire.

Fire Endurance

Questions often arise related to fire endurance characteristics of metal truss plates, protected fire assemblies, and heavy timber construction. It is commonly alleged that metal plates in trusses fail by curling away from wood due to heat in a fire. In fact, the curling occurs due to tension forces pulling on the gusset plates. This mode of failure can be seen in tension tests on unheated, uncharred wood and in connections that have been burned (Figure 1).

Figure 1: Metal Connector Plates After Fire Test

Metal splice plates curled away from wood due to tension forces induced in bottom chord of truss when the butt-ends of the lumber separated as the floor sagged during a fire test.

Figure 2 ASTM E119 Test Furnace

Full-scale floor-ceiling test furnace for performing fire tests in accordance with ASTM E119.

Figure 3 ASTM E119 Hydraulic Cylinders

Hydraulic cylinders apply load to a floor-ceiling assembly in an ASTM E119 test. Many furnaces use tanks of water to apply the design load to an assembly

Figure 4 Gypsum Wallboard After Fire Test

Red-hot gypsum wallboard ceiling during ASTM E119 fire test of a wood-based floor-ceiling assembly.

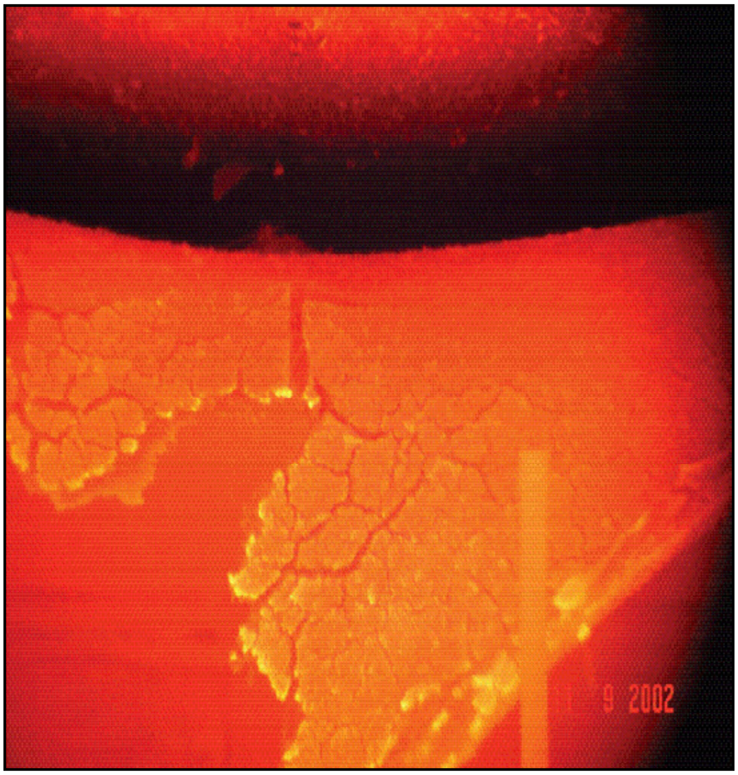


Figure 5 System Failure at End of Fire Test

System failure at the end of an ASTM E119 test of a floor-ceiling assembly.

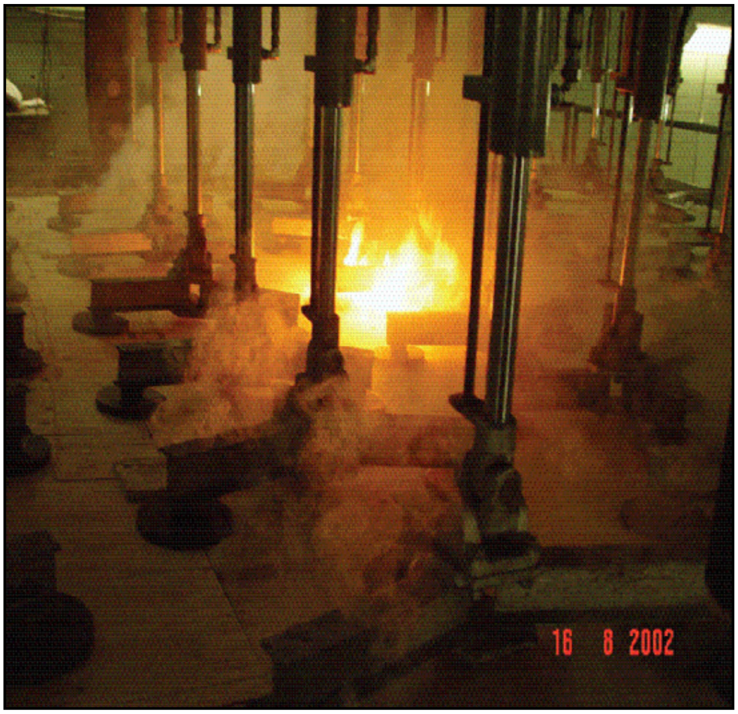
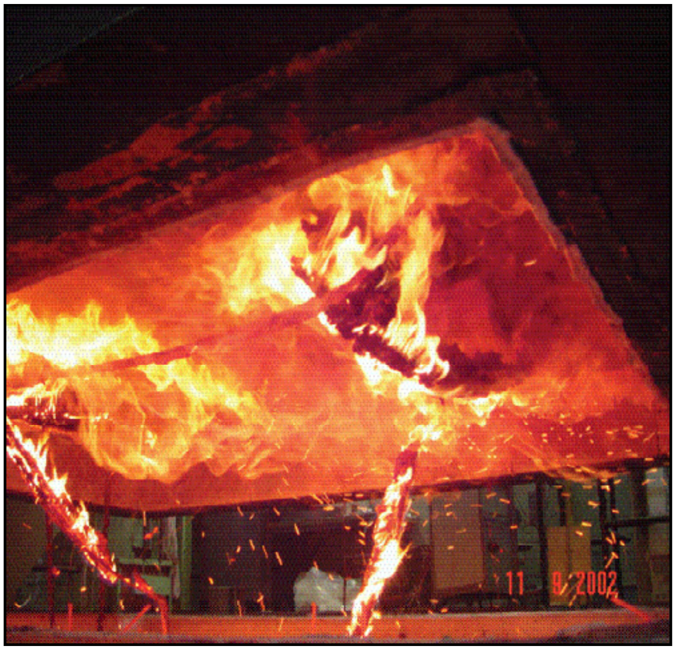


Figure 6: Floor-Ceiling Assembly Removal After Fire Test



Floor-ceiling assembly being removed from furnace at completion of ASTM E119 fire tests.

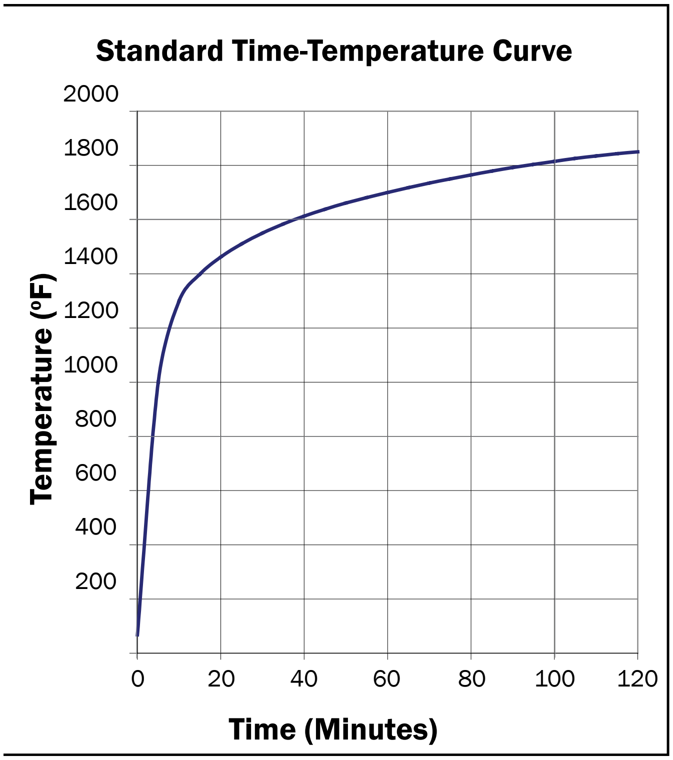
Fire endurance is typically determined in accordance with ASTM E119, *Standard Test Methods for Fire Tests of Building Construction Materials*, according to a standardized time-temperature curve. The test protocol requires the furnace temperature to reach 1000ºF in the first five minutes and increase to 1700ºF at one-hour. For structural assemblies, this test has traditionally been conducted on protected assemblies, and forms the basis of fire endurance ratings. Figures 2 and 3 show a typical floor assembly fire endurance furnace and its loading system. Figures 4 through 6 show a wood floor specimen subject to fire endurance testing. Figure 7 shows the time-temperature curve for a standard fire endurance test.

Protected assemblies are common in buildings that are required to have a fire endurance rating, such as a one or two-hour rating. Most one- and two-family residential structures do not require rated assemblies; however, there are instances when rated construction is required, such as between dwelling units, dwellings in close proximity to the property line, and between attached dwellings.

Calculation Methods

The char rate of wood is very predictable. A method has been developed that allows heavy timber trusses to be designed to achieve a calculated fire rating. The techniques requires web and chord members to be oversized to allow for charring, while the underlying fiber supports the design load. Fasteners are either concealed within the timbers or protected with gypsum wallboard. More information on this technique is available in the *National Design Specification® for Wood Construction (NDS®) [14]*.

Figure 7 ASTM E119 Standard



Example of an ASTM E119 standardized time-temperature curve, showing fire endurance in a test of building construction materials.

Fire Movement within Concealed Spaces

Fire can originate or extend into concealed spaces through holes in the protective membrane from recessed lights, electrical boxes, ventilation openings, and other penetrations. Protective membranes include gypsum wallboard, paneling, and dropped ceilings. Fire growth within the concealed space will vary, based on the volume of the space, air supply and presence of firestopping. Unlike balloon-frame construction, commonly used in the past, platform construction provides inherent barriers to the spread of fire. A comparison of balloon-frame and platform-frame construction methods can be found in *Solid Sawn Lumber*, a separate guide in this series of resource guides for the fire service.

With truss construction, building codes limit the area of concealed space. Since trusses do not provide an inherent barrier, like solid lumber or I-joist webs, building codes require installation of draftstopping to limit the concealed area within floor or roof assemblies.

Firestopping and Draftstopping

Building codes typically require firestopping in stud spaces at ceiling and floor levels to prevent the vertical spread of fire in concealed spaces. Horizontal fire-stopping is provided by requiring solid blocking of floor joists over points of support and in some cases, at partitions. Firestopping in platform construction is inherent with the way walls are framed. Continuity between the vertical stud space and horizontal truss space must be avoided. Trusses that bear directly on the top plate require no additional firestopping. If the truss is top chord bearing or a soffit is constructed, firestopping must be http://www.awc.org/codes/dcaindex.html provided in the wall cavity.

The need for draftstopping in large concealed spaces has been recognized for many years. In residential construction, draftstopping is required at 1,000 square foot intervals when there is usable space above and below the assembly. This requirement is based on the rationale that the integrity of a floor is more critical than that of a roof. Therefore, allowable open areas should be smaller within floor spaces than in attics.

SUMMARY

In summary, firefighters must understand the dangers of any structural component exposed to direct fire, regardless of component material, especially when there are large amounts of stored items such as furniture or other items within the area. It is important to consider that all building components must be designed, installed and maintained properly in order to perform properly. In many cases, homeowners are asking for much larger spans without intermediary support of the structural components.

In the residential setting, most codes do not require protection on the basement side of a structural floor. Over the years, there have been collapses involving basement fires that have led to firefighter entrapment. They have involved many different types of construction. On all incidents, it is necessary to examine the conditions present and determine if the risk of saving lives outweighs the danger in putting out the fire with an interior attack. It is recommended that tools such as a thermal imaging camera be used to examine for hidden fires or those affecting a focused area of the structural components. It is necessary for all firefighters to review buildings during construction and become familiar with the different products installed in buildings today.

END NOTES

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AMERICAN WOOD COUNCIL

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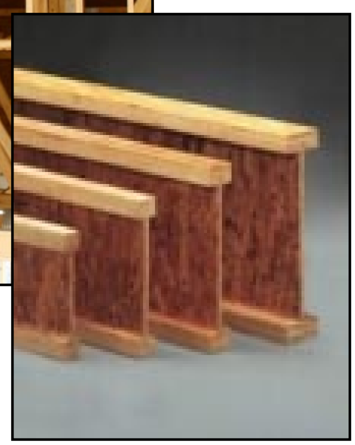
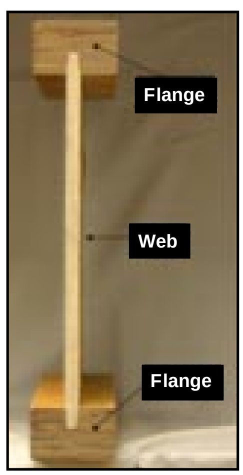
WOOD I-JOIST AWARENESS GUIDE





American Wood Council

American Wood Council

WOOD I-JOIST AWARENESS GUIDE

The American Wood Council (AWC) is the voice of North American traditional and engineered wood products, representing over 75% of the industry. From a renewable resource that absorbs and sequesters carbon, the wood products industry makes products that are essential to everyday life and employs over one-third of a million men and women in well-paying jobs. AWC's engineers, technologists, scientists, and building code experts develop state-of-the-art engineering data, technology, and standards on structural wood products for use by design professionals, building officials, and wood products manufacturers to assure the safe and efficient design and use of wood structural components. For more wood awareness information, see www.woodaware.info.

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The purpose of this informational guide is to provide awareness to the fire service on the types of wood I-joists and how they are used in the construction of residential buildings. This publication is one in a series of eight Awareness Guides developed under a cooperative agreement between the Department of Homeland Security's United States Fire Administration and the American Wood Council.

Wood I-Joists

PURPOSE OF THIS GUIDE

The purpose of this Awareness Guide is to provide the fire service with information on the types and properties of wood I-joists, how they are manufactured and how they are used in residential construction (Figure 1). It is important that the fire service understand the unique characteristics of wood I-joists and recognize their unique installation requirements.

Figure 1 I-Joists

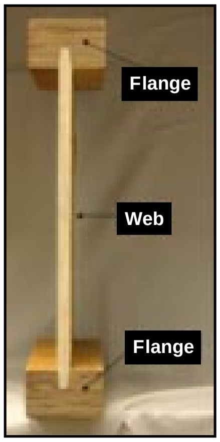
I-joists are available in an assortment of depths, flange widths, and lengths. Their primary use is in residential floor assemblies.

I-JOISTS: LONG AND STABLE

What is a Wood I-Joist?

Shaped like the letter "I," I-joists are composed of two horizontal components called flanges and a vertical component called a web (Figure 2). Wood I-joists are used as a framing material primarily in floors, but may also be used as roof rafters where long length and high load capacity are required. They are used as an alternative to sawn lumber.

Figure 2 I-Joist Components



The I-joist is manufactured by combining engineered wood products into the shape of an "I." The manufacturing process requires close tolerance between the individual components.

I-joist performance and environmental benefits have increased their use in construction. Builders choose wood I-joists because they offer uniform dimension, light weight, and long span capability. Holes may be cut in the web, allowing ducts and utilities to be run through the joist. These holes must strictly follow manufacturers' recommendations and all applicable building code requirements.

Owing to engineering mechanics, the "I" shape allows the most efficient use of wood necessary to carry the design loads. This is achieved by placing more material with the required strength and stiffness in the flanges. Flanges are manufactured from end-joined, solid sawn lumber or structural composite lumber (SCL), while webs typically consist of oriented strand board (OSB) (see Figure 3 on next page). The web is of sufficient thickness to transfer loads to the flanges. (See the *Wood Structural Panel* and *Structural Composite Lumber Awareness Guides* at www.woodaware.info for more information.)

Figure 3 Types of I-Joists

I-joists are manufactured with a variety of web and flange products. The photo on the left shows a typical I-joist manufactured for modern housing: the web is oriented strand board (OSB). The flanges are structural composite lumber, such as laminated veneer lumber (LVL) or laminated structural lumber (LSL). The photo on the right shows I-joists with a plywood web and sawn-lumber flanges. This combination of materials was common in the 1980s and was replaced by OSB in the 1990s.

How I-joists are Manufactured

All web and flange materials are graded to ensure they will perform per applicable product standards. The flanges range from $1^{5}/_{16}$" to $1^{1}/_{2}$" thick and from $1^{1}/_{2}$" to $3^{1}/_{2}$" wide. Web material in typical residential I-joists is either $^{3}/_{8}$" or $^{7}/_{16}$" thick.

The manufacturing process begins by cutting the web into the proper rectangular shape. The web edges are shaped to match the groove cut into the flange. Webs are then glued, inserted into the flanges, and pressed together in a continuous process as illustrated in Figure 4. The assembled I-joist is cut to length and typically cured in special curing ovens to develop full adhesive strength. (More information on adhesives is found in the *Adhesive Awareness Guide* at www.woodaware.info.)

Quality control procedures ensure the web-to-flange joint is properly shaped and tight at all times. Sampling and testing of I-joists immediately after manufacturing further ensures the process remains within product specifications.

Figure 4 I-Joist Manufacturing Process

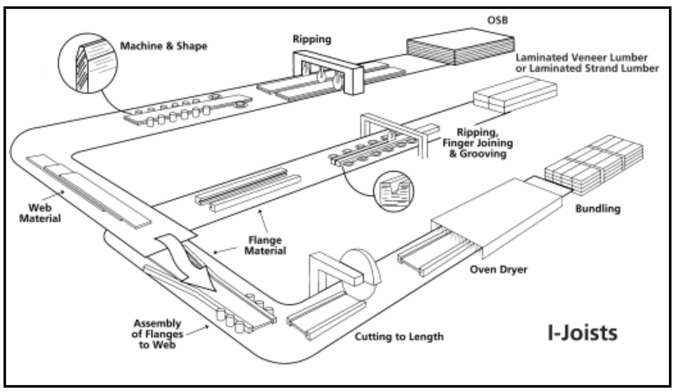


Illustration of the manufacturing process for I-joists. Web (OSB) and flange stock (lumber or LVL) is precision machined for assembly on separate lines. The materials are aligned with each other and fed through rollers that press the web tight into the flange groove. The fabricated I-joist is cut to length prior to drying. Lastly, the product is bundled for shipment.

I-Joist Use in Modern Residential Construction

For residential spans, I-joist depths from $9^1/_2$ to 16 inches typically are used. Because I-joists are manufactured in long lengths, a single continuous joist is often used to span the width of the house. Builders find efficiencies in using a single piece during construction. Like lumber joists, the I-joist must be end-supported by beams or bearings walls, and intermediate supports, depending on the total span (Figure 5).

Figure 5 I-Joists in Basement Floor Assembly

I-joists used in a typical basement floor assembly. In this figure, the I-joist spans from the exterior walls, over a steel beam to an interior bearing wall.

Most Important Performance Characteristics—Strength and Serviceability

Strength

I-joists must meet certain physical (dimensions) and mechanical property (strength) tests at the time of manufacture. For example, tests for bending, shear strength, tensile strength, fastener withdrawal strength, and increase in thickness and weight after soaking in water are performed.

Serviceability

I-joists are designed for serviceability considerations, such as deflection, vibration, creep, dimensional changes, and strength retention under normal conditions.

I-Joist Design

Span tables and other load charts are reviewed by the applicable evaluation services (e.g., International Code Council Evaluation Service) and state or local building code authorities. Once accepted, this design information can be used by designers, suppliers, builders, and building officials to select appropriate products and verify their adequacy.

Items which must be considered in the design of structures using I-joists include:

- *Strength and Stiffness*
  Members selected must have enough capacity to carry design loads without failing or deflecting beyond specified limits.
- *Connections*
  Members in the structure must be properly connected to ensure proper transfer of loads resulting from gravity, wind, and earthquakes forces to the foundation.
- *Modifications*
  Holes for mechanicals may be cut in I-joist webs as permitted by published hole charts (see manufacturers literature) or structural analysis. Holes that are too large or any damage to the flanges must be repaired or evaluated by the manufacturer.
- *Vibration*
  In addition to structural capacity, consideration is also given in design to how the floor system *feels* to the occupant. While criteria such as the evenness of the floor, vibration, and bounce are not required within building codes, they are often important design considerations.

The design of a residential structure may be required by state, regional or local building code requirements to be performed by a registered design professional. Other factors, such as building size and framing complexity may necessitate the use of a design professional. In some cases, single-family homes are designed and constructed using code-specified requirements for conventional construction, along with I-joist design information provided in the evaluation reports described earlier.

Is It an I-Joist or a Truss?

I-joist and truss terminology is often interchanged, such that the two products are thought of as being the same. Manufacturers, engineers, and builders, however, separate these two products based on their design and installation requirements, which are uniquely different. The following similarities and differences help to compare the features of I-joists and trusses:

Similarities

1. Share common component names. For example, both have top and bottom chords (flanges).
2. Make efficient use of wood fiber through design.

Differences

1. I-joists have fixed design properties, while trusses are commonly designed for each specific project.
2. I-joists are glued together with adhesives continuously along their length.

3. Truss web and chord members are typically attached together with metal connectors at specific locations.
4. Individual truss web members can be long and slender and require bracing against buckling.
5. Forces in the webs are distributed and transferred using differing structural mechanics.
6. I-joists can be manufactured anywhere in North America and transported through distribution channels to the job site. Trusses are generally not transported great distances, with manufacturing occurring within a regional area.

General Construction Practices

Examples of I-Joist Installation

I-joists are typically installed in a manner similar to sawn floor joists (Figures 6 and 7). They can also be used as roof rafters (see Figure 8 on next page). Although I-joist placement and installation appears similar to that of sawn lumber, careful attention should be paid to connection details and framing configuration.

Figure 6 I-Joist Floor Assembly

An I-joist floor assembly viewed from the floor below. When the ceiling is attached and finished, it won't be obvious that I-joists frame into a beam. I-joists must be held vertically in place wherever they are supported by a beam. This rigid alignment is frequently achieved by using blocking or joist hangers. By holding the member vertically, the full strength of the I-joist can be developed. Special attention should be directed at all connectors during the installation process.

Figure 7 I-Joist Floor Assembly Components

I-joist assemblies have many floor framing components similar to traditional solid sawn assemblies. The ends of an I-joist are capped with a rim joist, to hold the joist vertical and transfer loads from the wall, above. The rim joist is attached to a sill plate that is bolted or strapped to the top of the foundation.

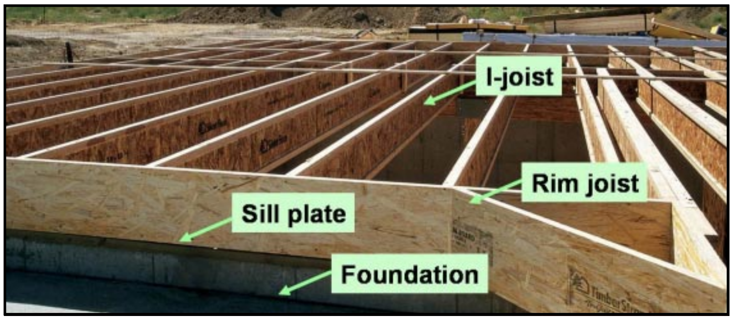


Figure 8 I-Joists Used as Roof Rafters

I-joists are used as roof rafters where high, open ceilings are desired, such as this 2 1/2-story room. The I-joists are supported at the ridge by an LVL ridge beam. Since there are no ceiling joists to resist outward thrust, the I-joists must be supported at both ends. The load on the ridge beam is carried by columns to the foundation.

Site Visits

Although residential construction is built from the ground up, framing is best inspected from the roof down. The most important structural characteristic common to all buildings and all types of construction is referred to as "load path continuity." The load path is the prescribed route that gravity loads—such as live, snow, and water ponding; and lateral loads—from wind and earthquakes—follow to the footings. For simple single-family dwellings, the roof, ceiling, and floor loads are collected by rafters or joists, which rest on exterior walls and interior beams or bearing walls. Figures 9 and 10 (see next page) illustrate typical layouts for floor and roof framing, respectively.

Proper installation and job site use are important considerations. I-joists are intended for dry-use applications. It is acceptable for structural framing to be exposed to rain during the construction process. However, prolonged exposure to rain or other moisture can cause damage to the I-joist. Whenever possible, products should be kept dry and protected from long-term exposure to the elements. Proper installation includes correct spacing of sheathing joints, care in fastening of the joists and sheathing, and providing adequate and level supports. All of these considerations are essential for proper system performance.

When visiting a building as part of a pre-planning or training exercise, the fire service should look for the following information:

1. The layout drawings, typically available at the job site. This document will include information about individual I-joist elements, including required spacing, and the specification and location of connections.
2. Whether the I-joists have proper bearing on walls, girders, or joist hangers. The layout drawings will show where the member must be supported. Web stiffeners should be attached where specified. Depending on the type of hanger, it may be necessary to have a nail in every hole, which meets the manufacturers requirements. Typically, screws are not permitted to be used as a replacement for nails.
3. Whether the I-joists are properly connected to the framing, using straps or other types of connectors.
4. Whether field modifications to accommodate wiring, plumbing or HVAC follow manufacturer's recommendations.

Figure 9 I-Joist Floor System Framing Detail Layout

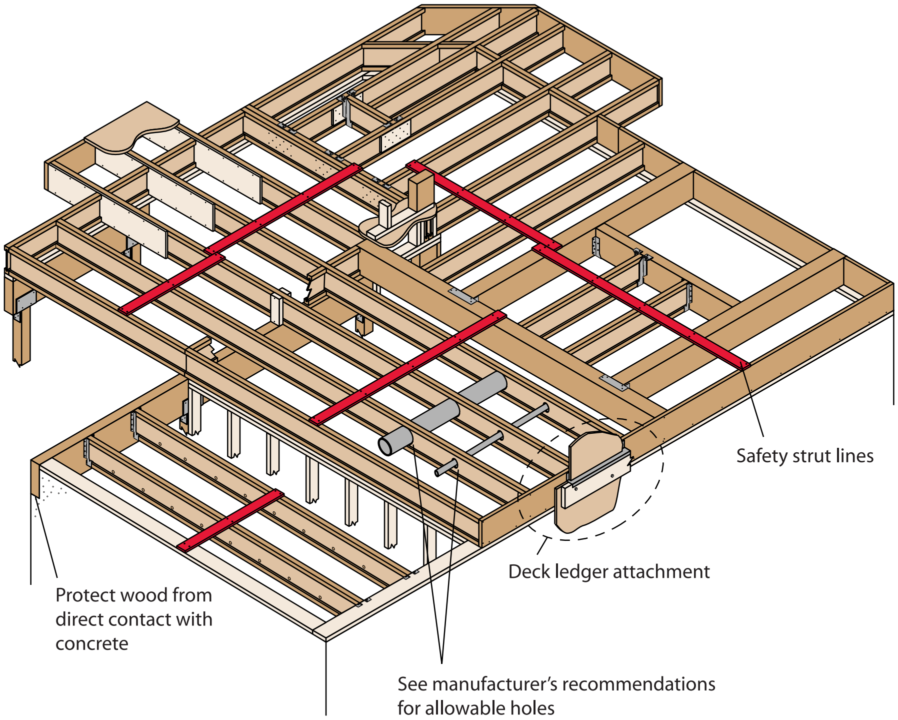
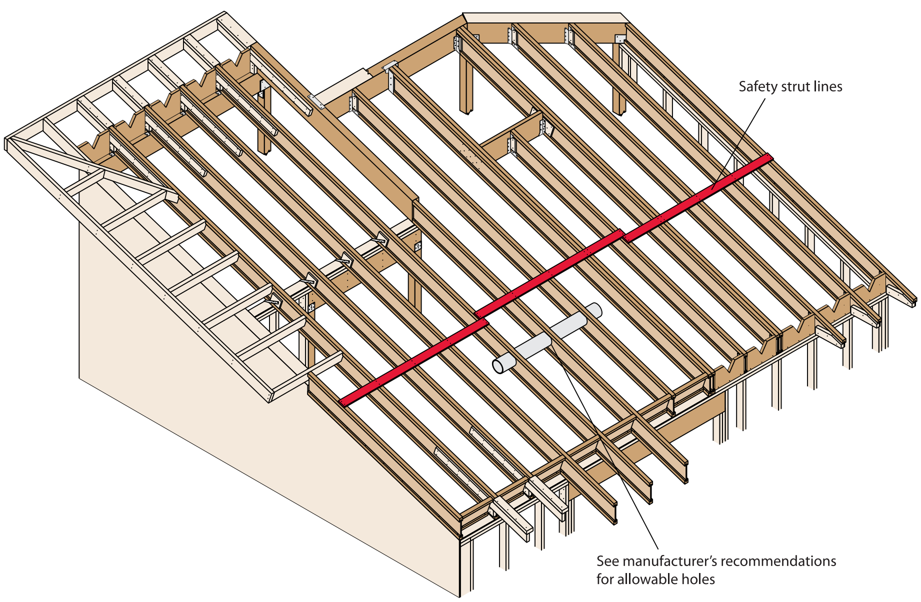


Figure 10 I-Joist Roof System Framing Detail Layout



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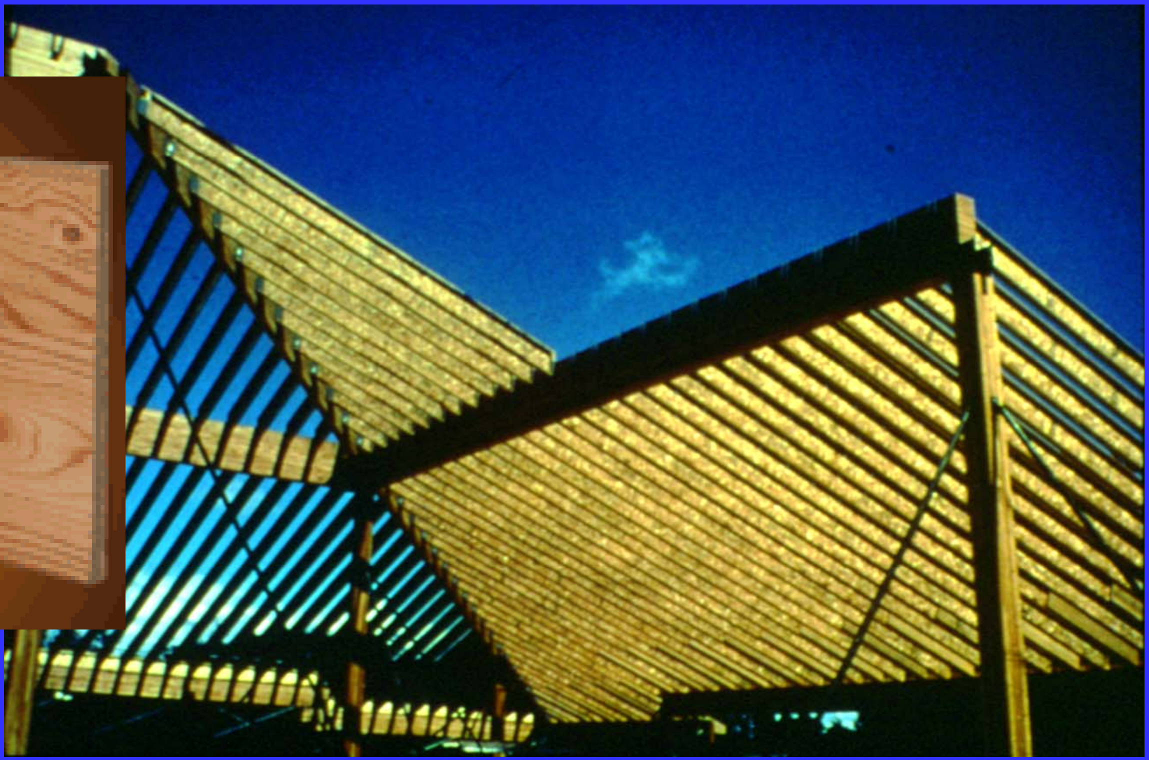
Wood I-Joists and Firefighter Safety



American Wood Council
Engineered and Traditional Wood Products

Presentation Outline

Concern has been raised about the hazard from wood I-joist floor collapses during fires

This presentation:

- provides general information about wood I-joists and their use
- provides information on the relationship between wood I-joists and firefighter casualties
- details firefighter educational material developed by the wood industry

Wood I-Joist Popularity

- Efficient use of resources (trees)
- Desired attributes for architectural design
- Desired attributes for structural performance

Resource Efficiency

Wood I-joists qualify as a resource-efficient framing material in many green building standards

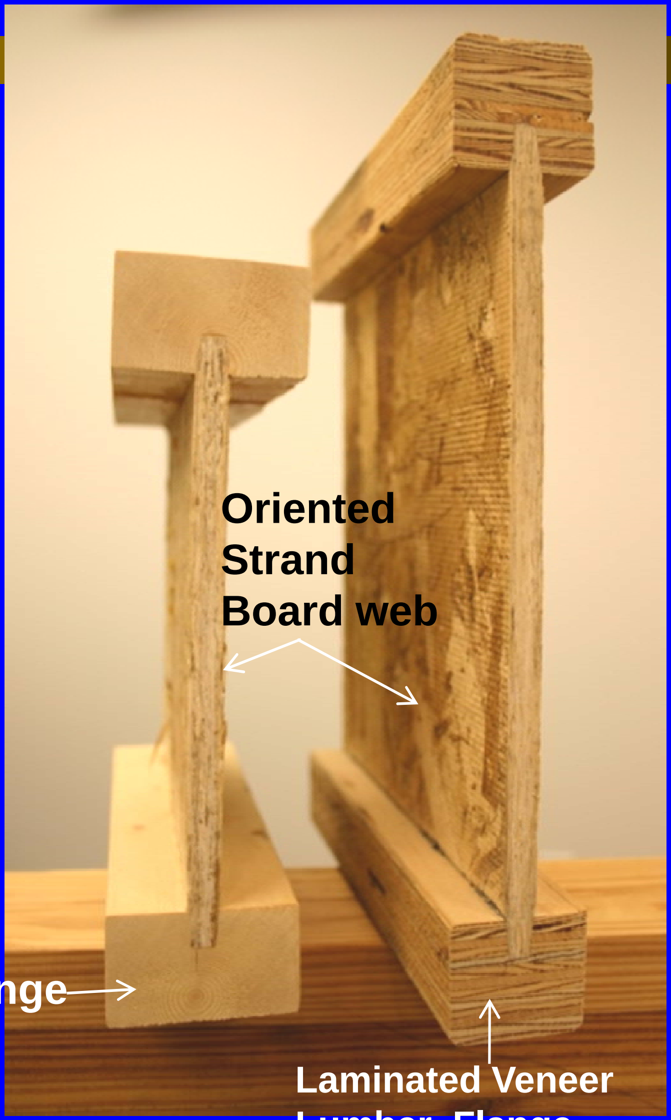
Architectural Design

Design flexibility with greater open spaces

– **Manufactured to required length**

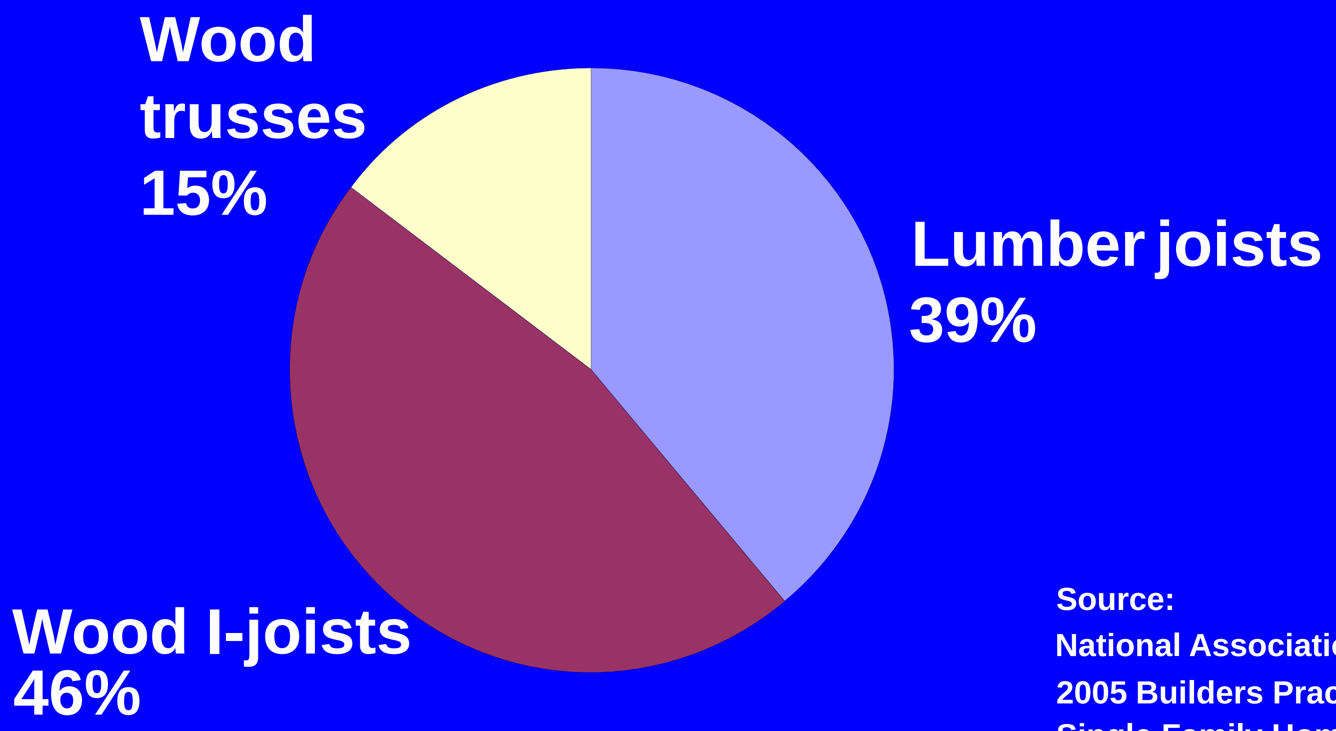
Structural Performance

Strength and stiffness of wood I-joists are established through engineering and testing



How Popular are Wood I-Joists?

Floor assembly by type (2005 statistics)



Source:
National Association of Home Builders
2005 Builders Practices Survey
Single Family Homes - Floors

How Fire Safe are Homes with Wood I-Joists?

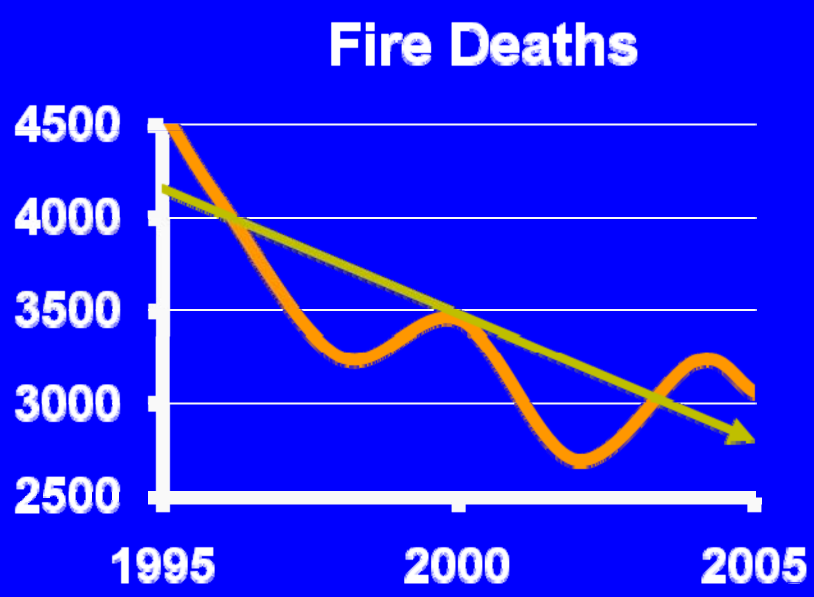
Primary Considerations

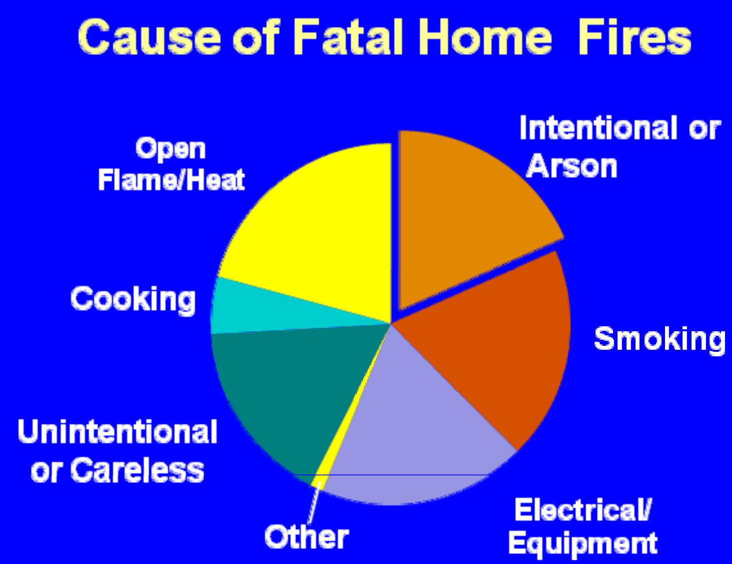
- Safety of occupants
- Safety of firefighters

Let's take a look at both

Fire Safety of Occupants:
Trends and Causes of Fatalities

20% reduction in occupant deaths in a decade

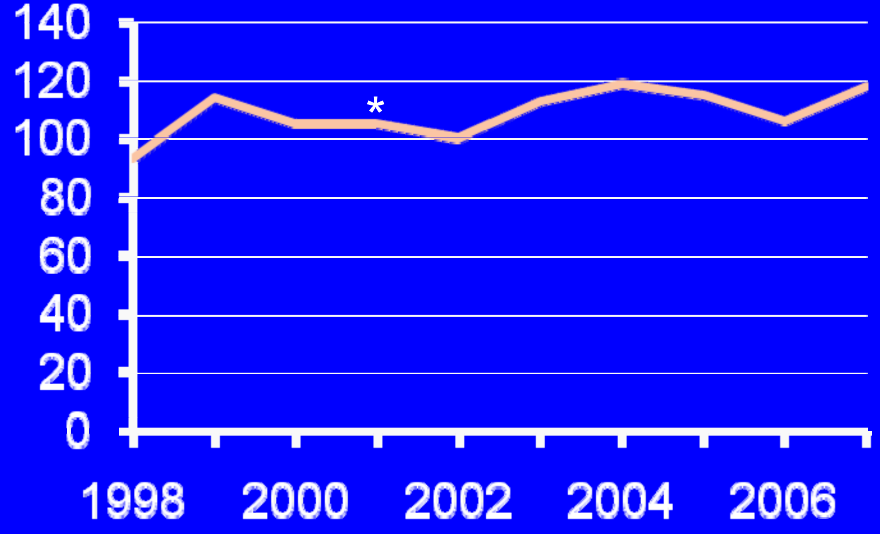




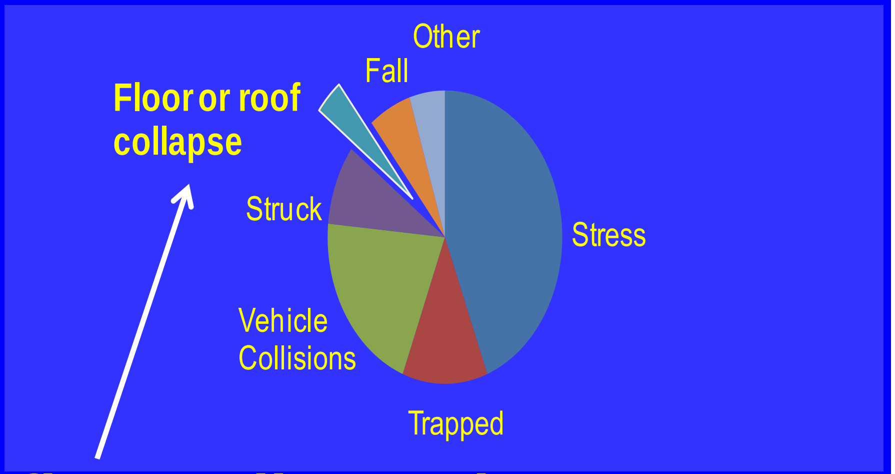
Fire in the United States 1995 to 2004, USFA Report FA-311, 2007, Figure 18
Residential Structure and Building Fires, USFA Report , October 2008, Figure 3

Fire Safety of Firefighters:
Affected by Wood I-Joists?

All firefighter fatalities (1998-2007)



Causes of all firefighter fatalities (2000)



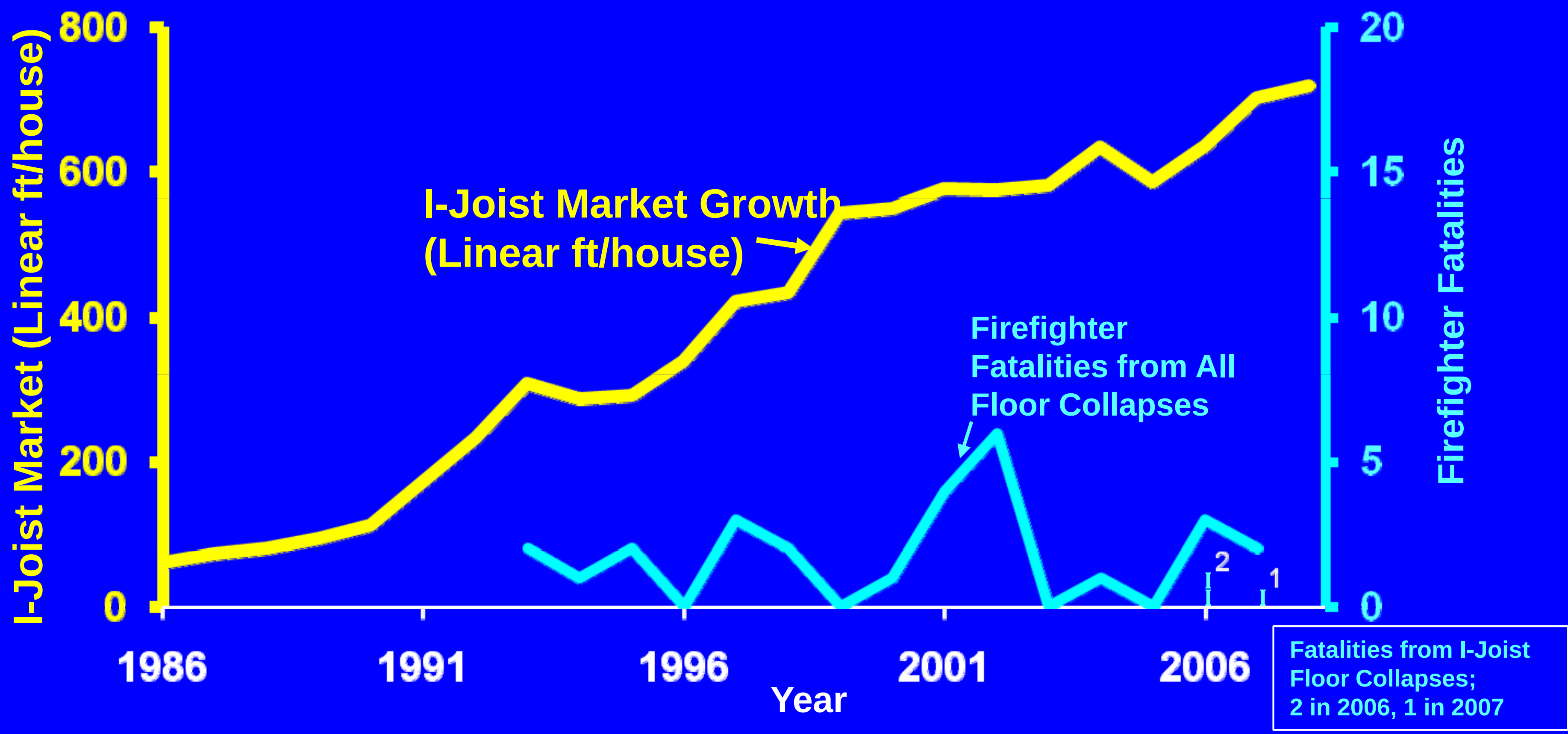
Let's take a close look at floor collapse data ....

U.S. Fire Administration Firefighter Fatalities in the U.S. in 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005,2006, 2007

* Does not include the 344 firefighters who died in the World Trade Center collapse, 2001

Fire Safety of Firefighters:

Fatalities in Single-Family Homes Compared to I-Joist Market Growth



Popularity of wood I-joists - no impact on firefighter safety

Source: APA Production Statistics, McGraw Hill Housing Statistics, FEMA Annual Fatality Reports

Firefighter Fatalities

For the decade of 1998-2007

A total of 1033* firefighters died in the line of duty (all causes included)

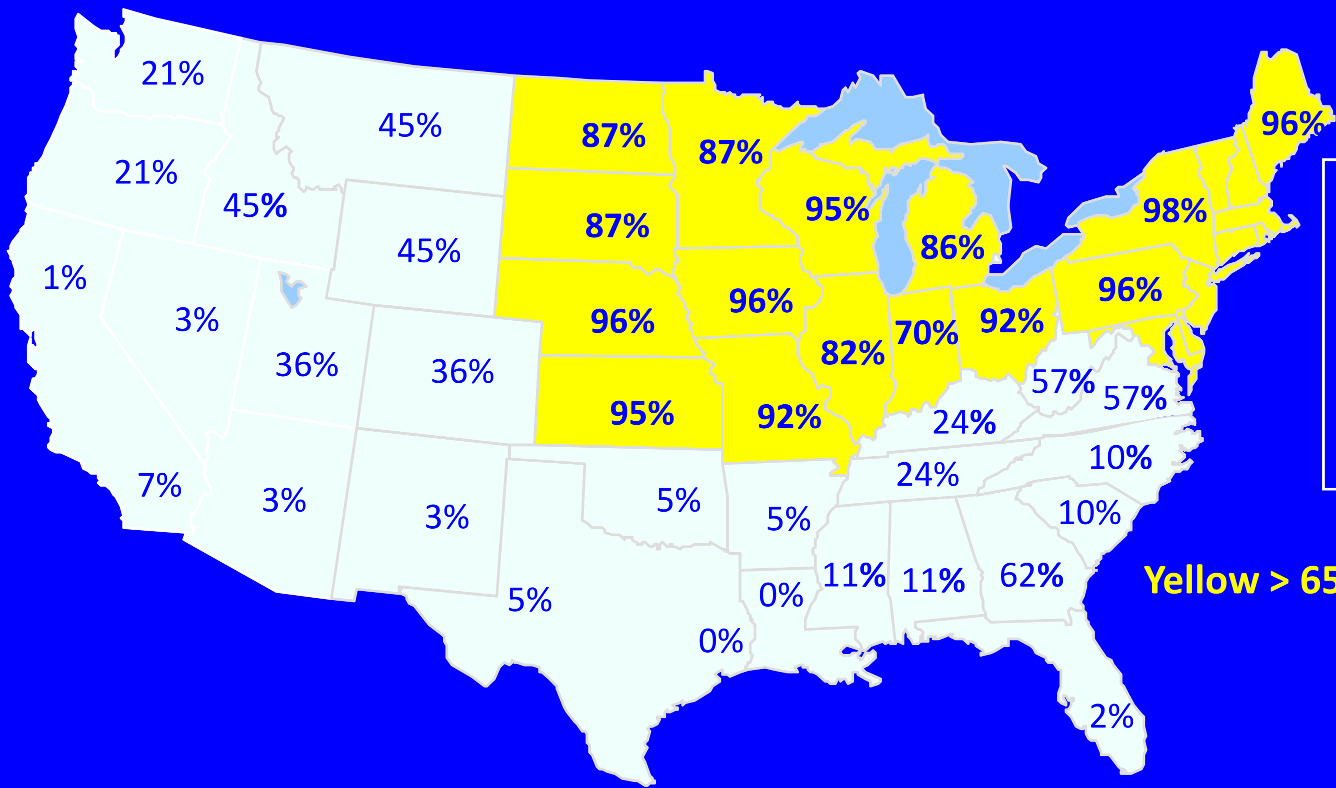
- **Of those 1033 ⟶ 61 died due to structural collapse**
- **Of those 61 ⟶ 19 died in single family floor collapses**
- **Of those 19 ⟶ 12 were over basements**
- **Of those 12 ⟶ 3 died in unprotected I-joist floor collapses over basements**

* Does not include the 344 firefighters who died in the World Trade Center collapse

Basements: Where are they?

Percent single family houses with basements

AK – 21
HI – 2

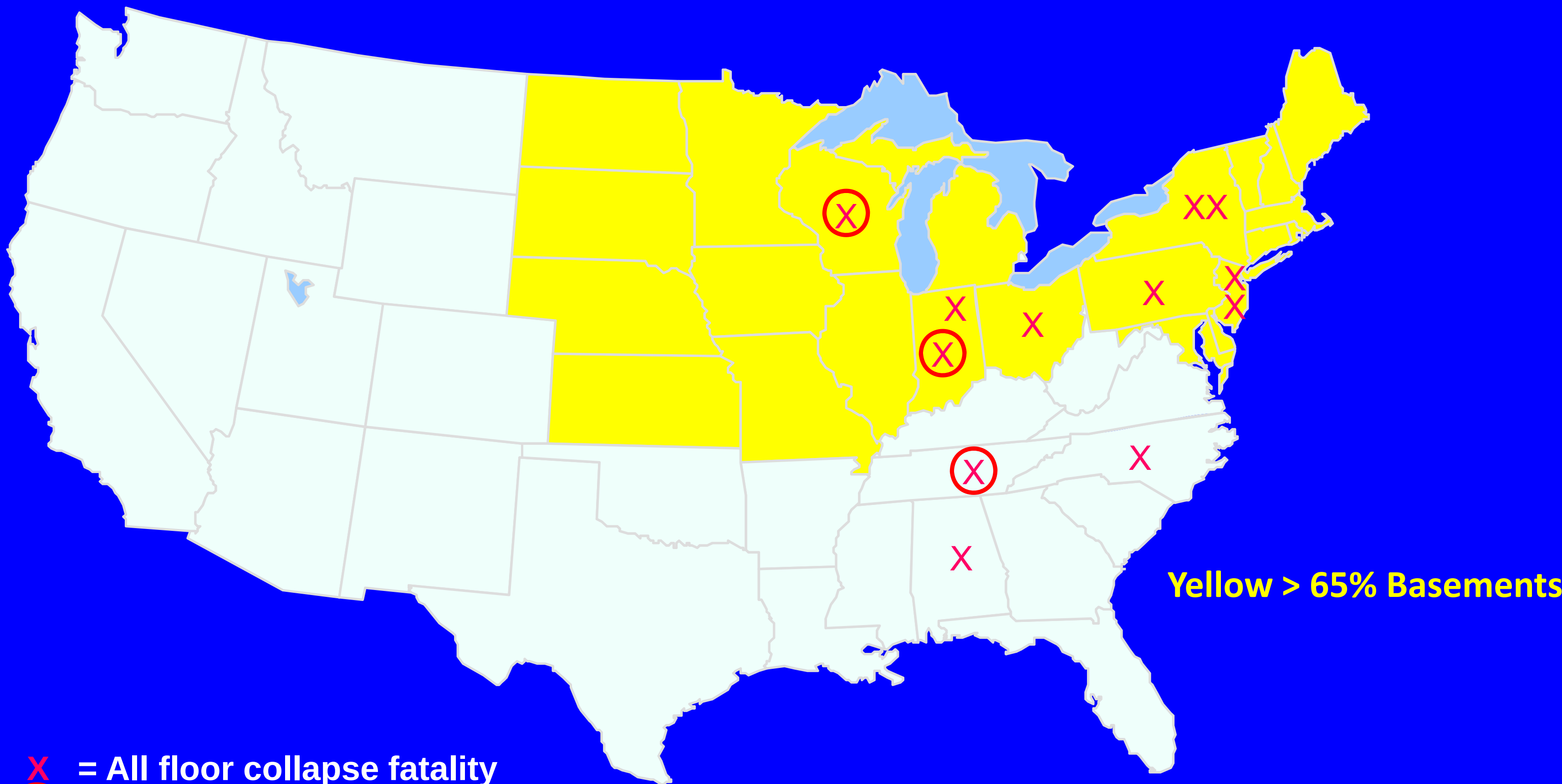


VT – 96%
NH – 96%
MA – 89%
RI – 89%
CT – 89%
NJ – 88%
DE – 77%
MD – 77%

Yellow > 65% Basements

Data Source: NAHB 2007 Builder Practices Survey

Basement Collapse with Fatality 1993-2007



X = All floor collapse fatality

(X) = I-joist collapse fatality: IN, WI, TN

Data Source: FEMA Annual Firefighter Fatality Reports

12 floor collapse events were over basements

Firefighter Education and Training

The wood industry is committed to providing education to the fire service to reduce firefighter deaths from collapse.

Firefighter Education and Training

- Product awareness guides
  - *www.woodaware.info*
- AF&PA website on fire performance of wood
  - *www.awc.org*
- Wood products display cases for firefighter training centers

Wood I-joist for hands-on training

Wood I-Joists: One of Many New Features of Modern Construction

Feature

- Larger homes
- Open floor plans
- Increased fire loads
- Floor/ceiling/attic voids
- New building materials

Fire Effect

- Faster fire propagation
- Shorter time to flashover
- Shorter escape times
- Shorter time to structural collapse

Source: UL University – Structural Stability of Engineered Lumber in Fire Conditions – Underwriters Laboratories

Summary

- Wood I-joists are popular, resource efficient, and recognized as green
- Use of wood I-joists has increased without a corresponding increase in firefighter deaths due to collapse
- Floor collapse fatalities occur primarily over basements
- Changes in building practices and modern furnishings create new challenges for the fire service

Our Commitment

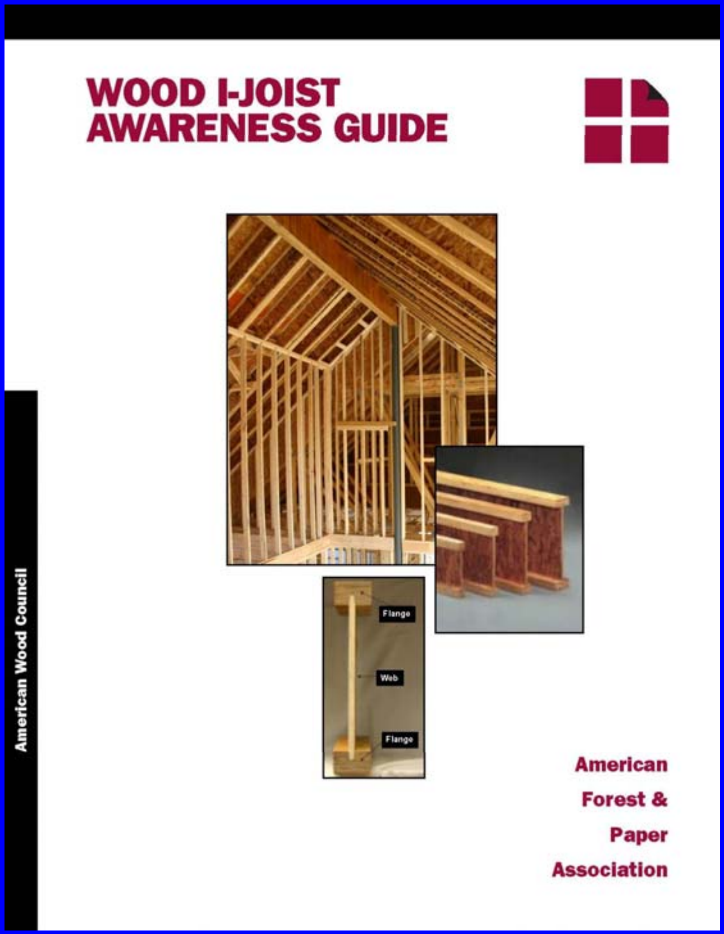
AF&PA continues to work with fire service leaders to:

- define collapse risk of unprotected floors
- define factors that contribute to collapse
- develop solutions that meet their needs

Thank You

For more information, please visit:

www.woodaware.info



SOLID SAWN LUMBER AWARENESS GUIDE

American Wood Council

American Wood Council

SOLID SAWN LUMBER AWARENESS GUIDE

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The purpose of this informational guide is to provide awareness to the fire service on the types and properties of solid sawn lumber and how they are used in the construction of residential buildings. This publication is one in a series of eight Awareness Guides developed under a cooperative agreement between the Department of Homeland Security's United States Fire Administration and the American Wood Council.

Solid Sawn Lumber

PURPOSE OF THIS GUIDE

The purpose of this Awareness Guide is to provide the fire service with information on the types and properties of solid sawn lumber and how it is used in residential construction (Figure 1).

Figure 1 Solid Sawn Lumber

Solid sawn, dimension lumber is used in many aspects of today's house construction. Lumber is used almost exclusively for wall framing. It is still common in floor construction, but less so as roof framing.

SOLID SAWN LUMBER—TRADITION MEETS TECHNOLOGY

Wood has been and continues to be one of the most widely used building materials in the world. Wood products are strong, lightweight, easy to work with, and environmentally friendly since they are obtained from a renewable resource—trees. Wood products are very cost-effective, manufactured from a natural material that requires very little manufacturing energy. This Awareness Guide describes one of these wood products—lumber.

Brief History

Lumber has been used in building construction for centuries. In the 1700s, lumber in the United States was produced from logs that were hand-hewn or hand-sawn into rectangular lumber members. In the mid-1800s, steam and water-powered sawmilling operations were constructed. These operations used powerful circular saws to cut logs into lumber. In the early 1900s, sawmilling operations began to plane rough sawn lumber into "dressed" lumber, which made it easier to handle and grade for structural applications (see Figure 1). Today, most lumber used in structural applications is dressed lumber.

Methods of Wood Construction

Western Platform

In platform-frame construction, floor joists are sheathed with sub-flooring, such as plywood or oriented strand board. Prior to volume production of plywood, most floor and roof sheathing consisted of diagonal wood boards. Although still uncommon, some new construction uses tongue and groove solid or laminated decking. This creates a "platform" upon which exterior walls and interior partitions are constructed (see Figures 2 and 3).

In platform systems, it is common practice to assemble wall framing flat on the floor and tilt the wall section into place. The sole plate of the wall is fastened through the subfloor into the framing beneath. Today this is the most popular type of construction used in home building. It provides a work surface at each floor level and is readily adapted to various methods of prefabrication. Further, worker safety is improved, since the use of ladders is reduced and the work surface is secure.

For the fire service, platform construction provides a structural frame that is fire blocked by virtue of the style of construction—the wall sole plates and top plates isolate the horizontal floor cavity from the vertical wall cavity, as required by building codes.

Figure 2 Platform Construction

Platform construction is today's most common method of construction. It combines safety for framers while the building is under construction, with inherent firestopping once the walls are sheathed.

Figure 3 Integrated Fire Blocking

Platform construction provides a structural frame that is fire blocked by virtue of the style of construction—the wall sole plates and top plates isolate the horizontal floor cavity from the vertical wall cavity, as required by building codes. The top plates of the wall prevent movement of fire into the floor cavity. Similarly, the top and sole plates of the wall above prevent fire spread from the floor joist cavity into the walls.

Balloon Framing

In older style balloon-frame construction, exterior wall studs are continuous from the foundation to the roof (see Figure 4). First floor joists and exterior wall studs both bear on the anchored sill. Second-floor joists bear on a minimum 1x4-inch ribbon strip, which has been let-in to the inside edges of exterior wall studs. In two-story buildings with brick or stone veneer exteriors, balloon framing reduces variations in settlement of framing and the masonry veneer. Where exterior walls are solid masonry, balloon framing of interior bearing partitions also reduces distortions in door and closet openings in crosswalls. The requirement for longer studs, and the difficulty in accommodating current erection practices and fire blocking (see Figure 5), has reduced the popularity of this system.

Figure 4 Balloon Framing

Early house construction was "balloon" framed. This house, undergoing major renovation, is a good example of balloon framing. Unless firestopping is added, fire within the wall can easily spread vertically, since there are no top plates. Fire originating in the floor/ceiling assembly can spread horizontally and eventually vertically through the walls.

Figure 5 Firestopping in Balloon Framing

In accordance with the recommendations of the American Forest & Paper Association and building codes, firestopping will be installed in this balloon framing at the ceiling line and floor line.

Types and Characteristics of Lumber Today

Note: All dimensions referring to lumber (e.g. 2x4) are "nominal" dimensions, not exact ones. This is because after the rough sawn lumber is planed ("dressed") and dried, the resulting actual dimensions are slightly smaller.

Dimension Lumber

—Products of rectangular cross-section that are from 2" to 4" (nominal) in thickness and 2" or more (nominal) in width. Categories and grades of dimension lumber are standardized under the *National Grading Rule for Softwood Dimension Lumber*, which provides standard use categories, grade names, and grade descriptions. These products are sorted and graded as either *visually-graded dimension lumber* or *mechanically-graded dimension lumber*.

■ **Visually-Graded Dimension Lumber**

—Dimension lumber that has been graded and sorted by visual inspection. It is primarily intended for conventional and engineered applications (see Figure 6). Visual grading is the oldest stress-grading method. Stress grading determines strength and structural capacity. Skilled graders examine the lumber for defects, and grade it in comparison to clear wood with a straight grain. Tree growth characteristics, that affect lumber properties and can be seen and judged by eye, are used to sort the lumber into stress grades. Typical visual sorting criteria include density, decay, heartwood and sapwood, slope of grain, knots, shake, checks and splits, wane, and pitch pockets.

Visually-graded dimension lumber is further separated into four categories:

- Structural Light Framing (2" to 4" thick, 2" to 4" wide)
- Light Framing (2" to 4" thick, 2" to 4" wide)
- Studs (2" to 4" thick, 2" or wider)
- Structural Joists & Planks (2" to 4" thick, 5" or wider).

Figure 6 Wall & Roof Framing

Dimension lumber is used for wall and roof framing. When lumber is used for roof framing, it is referred to as rafters. This complex rafter framing will be extremely difficult to detect once the sheathing and drywall are installed.

■ **Mechanically-Graded Dimension Lumber**

—Dimension lumber that has been evaluated and sorted by mechanical stress-rating equipment that involves nondestructive testing of individual pieces. It is primarily intended for engineered applications. Mechanically-graded dimension lumber is itself divided into two categories:

- *Machine evaluated lumber (MEL)*
  —Dimension lumber that has been evaluated by calibrated mechanical grading equipment, which measures certain properties and sorts the lumber into various strength classifications. MEL lumber is also required to meet certain visual grading requirements. Machine evaluated lumber is typically 2" or less thick and 2" or more wide.
- *Machine stress rated (MSR) lumber*
  —Dimension lumber that has been evaluated by mechanical stress-rating equipment to measure and sort the lumber according to its stiffness (which

correlates with strength). It is intended for any engineered application where strength and stiffness are important, such as trusses, floor or ceiling joists, or rafters. MSR lumber is also required to meet certain visual grading requirements. Machine stress rated lumber is typically 2" or less thick and 2" or more wide.

Beams and Stringers
—Products of rectangular cross section that are 5" or more in thickness with the width more than 2" greater than the thickness. These members, such as 6x10s, 6x12s, 8x12s, 8x16s, and 10x14s, are intended primarily to resist bending loads applied to the narrow face.

Figure 7 Post Frame Construction

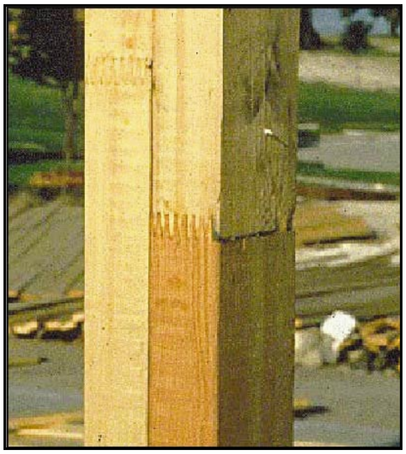
Post frame construction is used widely in the construction of agricultural buildings. Tall columns are embedded in the ground and are braced from buckling by horizontal purlins. Roof trusses are supported along the length of the wall by headers attached to the tops of the columns.

Posts and Timbers
—Products of square or rectangular cross section that are 5" (nominal) or more in thickness, but with width not more than 2" greater than the thickness. These columns, such as 6x6s, 6x8s, 8x10s, and 12x12s, are intended primarily to resist axial loads (see Figure 7).

Decking
—Lumber from 2" to 4" thick, intended for use as floor, roof, or wall sheathing. Decking is primarily applied in the flat-wise direction with the wide face of the decking in contact with supporting members. The narrow face of decking may be flat, tongue-and-grooved, or spline-and-grooved for interconnection of the decking members.

Finger-Jointed Lumber
—Dimensional lumber made of short pieces cut from traditional lumber stock. The ends of each small piece are machined in a finger profile and glued together. Because structural finger-jointed lumber products are graded using the same rules that are applied to solid-sawn dimension lumber, they bear the same grademarks as may be found on solid-sawn lumber (see Figure 8). There are a number of adhesives used in the fabrication of finger-jointed lumber. For more information, see the *Adhesives Awareness Guide*.

Figure 8 Finger-jointed Lumber



Finger-jointed lumber is made up of short pieces with the ends machined in a finger profile and glued together. The adhesive used varies based on the application.

FIRE INCIDENTS

The National Institute of Occupational Safety and Health (NIOSH) maintains a database of firefighter fatalities. Each fire is reported separately with details on the fire and circumstances leading to the fatality. Additionally, the reports provide a summary of fire ground management and command activities upon which improvement could be made. This information is extremely valuable to the fire service as a learning aid.

You are encouraged to access the reports at the NIOSH website and make them part of your training curriculum. For more information, visit:
http://www.cdc.gov/niosh/fire/

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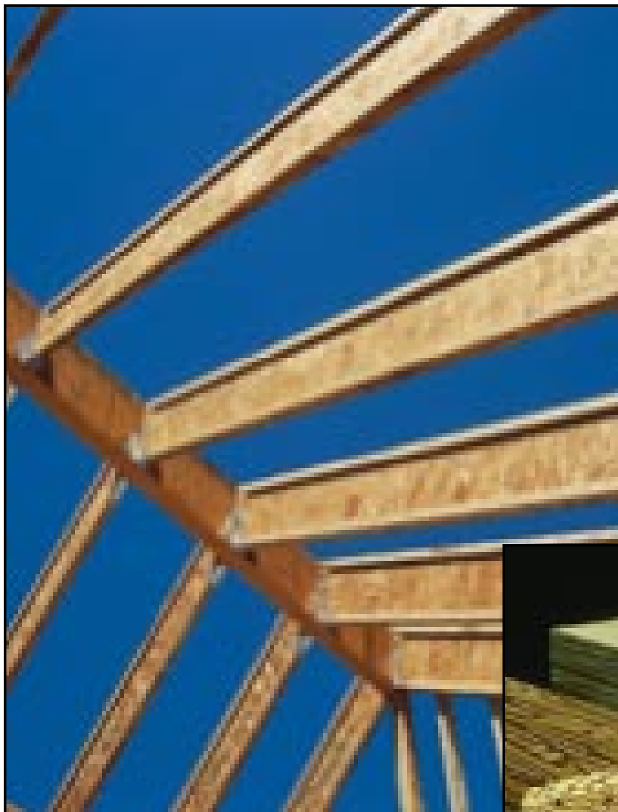
STRUCTURAL COMPOSITE LUMBER & GLUED LAMINATED TIMBER AWARENESS GUIDE



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The purpose of this informational guide is to provide awareness to the fire service on the types of Structural Composite Lumber and Glued Laminated Timber and how they are used in the construction of residential buildings. This publication is one in a series of eight Awareness Guides developed under a cooperative agreement between the Department of Homeland Security's United States Fire Administration and the American Wood Council.

Structural Composite Lumber & Glued Laminated Timber

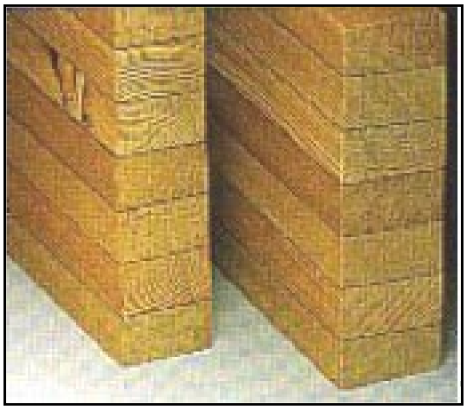
PURPOSE OF THIS GUIDE

The purpose of this Awareness Guide is to provide the fire service with information on the types and properties of Structural Composite Lumber (SCL) and Glued Laminated Timber (glulam), how the products are manufactured, and how they are used in residential construction (Figures 1 and 2).

Figure 1 Parallel Strand Lumber & Laminated Veneer Lumber

Parallel Strand Lumber (PSL) and Laminated Veneer Lumber (LVL) are two types of Structural Composite Lumber (SCL).

Figure 2 Glued Laminated Timber (Glulam)



WHAT ARE SCL AND GLULAM?

Structural composite lumber (SCL) and glulam timbers are recognized as rectangular shaped products that have strength, stiffness, and consistency resulting from wood fiber orientation and strict manufacturing process control. Advancements in technology have given SCL manufacturers the ability to take apart a smaller log, sort the pieces, apply adhesive, and reassemble them back together into an engineered product. SCL products have grown in popularity because of the ability to manufacture long lengths and large cross-sectional dimensions with consistency.

Glulam is produced in laminating plants by gluing together layers of sawn lumber to form large cross-section timbers that retain the traditional look of wood along with engineered strength.

TYPES OF STRUCTURAL COMPOSITE LUMBER

Proprietary brand names are frequently used in the marketplace to identify SCL, such as Microlam®, Ganglam®, and Parallam®. However, the products can be identified by generic names, based on the size and shape of the wood pieces that are glued together:

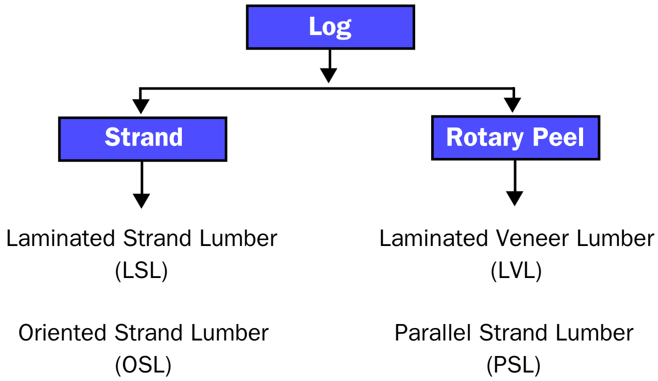
- Laminated Veneer Lumber (LVL)
- Laminated Strand Lumber (LSL)
- Oriented Strand Lumber (OSL)
- Parallel Strand Lumber (PSL)

Manufacture of Structural Composite Lumber

Structural composite lumber products are produced through two primary log-processing methods—stranding and rotary peeling—as depicted in Figure 3.

Photos and graphics courtesy of APA – The Engineered Wood Association. For more information, visit www.apawood.org

Figure 3 SCL Log Processing Methods

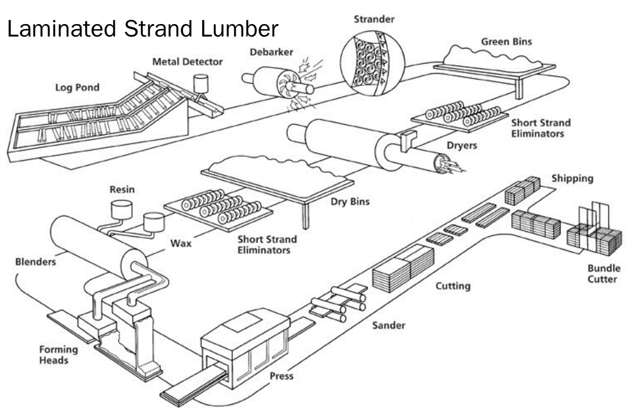


The manufacturing process for all SCL typically includes sorting and aligning the strands or veneer, applying adhesive, and pressing the material together under heat and pressure (Figures 4, 5, and 6). By redistributing natural defects, sorting for stiffness or density, and through quality control procedures, the resulting product is uniform.

Stranding slices the entire log into 3-inch to 12-inch strands, similar to grating a block of cheese. The strands are dried in a large rotary drum, where an adhesive is applied. The strands are then dropped into a forming bin and pressed together to form the individual products. These products can be thin and flat sheets, like plywood, or long and wide, like sawn lumber.

There are two types of SCL strand products—LSL and OSL—which are used primarily as lumber substitutes and as flanges in I-Joists. LSL uses longer length strands than OSL.

Figure 4 Laminated Strand Lumber Manufacturing Process



Rotary peeling uses a knife placed parallel to the outside edge of a spinning log on a lathe. The wood is peeled off the log starting on the outside and working towards the center, similar to removing paper towels from a roll. The wood slices are then cut into individual sheets called veneer, dried, glued, and pressed together to form the product.

There are two types of SCL made from rotary-peeled veneer—LVL and PSL—which are used primarily as lumber or heavy timber substitutes, and as flanges in I-joists. LVL uses full-size veneer sheets, which can range from one-tenth to one-sixth of an inch thick. PSL uses veneer which is too narrow for LVL or plywood.

Figure 5 Parallel Strand Lumber Manufacturing Process

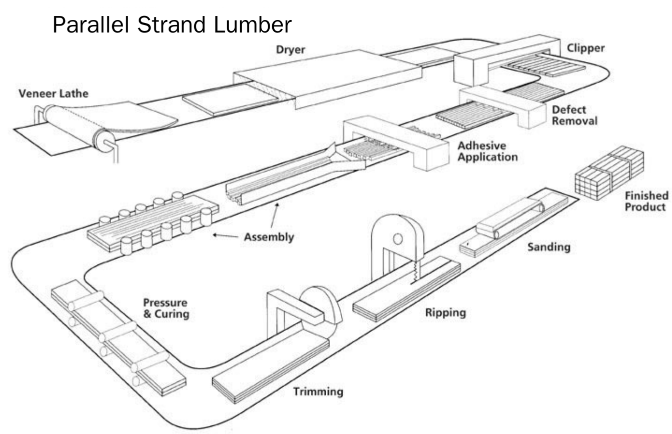
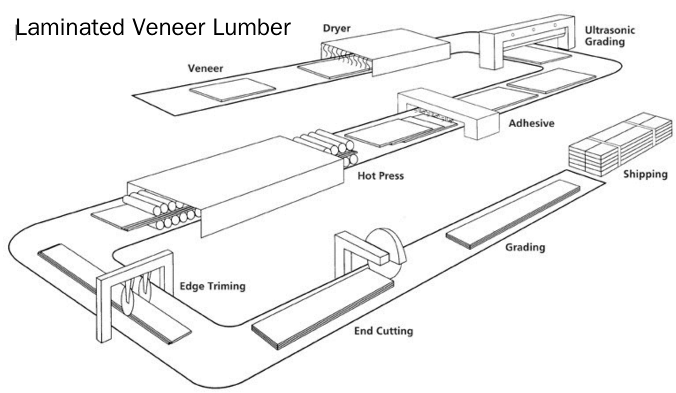


Figure 6 Laminated Veneer Lumber Manufacturing Process



Structural composite lumber is available in a range of sizes and grades. The material typically undergoes final processing in a continuous or fixed press to form what is called a "billet" (for example: 4' wide x 60' long), which is then resawn into final product dimensions. SCL ranges in depths from $3^1/2$" to 18" and thicknesses up to 7".

Manufacture of Glued Laminated Lumber (Glulam)

Glulam is fabricated using individual pieces of nominally 1- to 2-inch thick, kiln-dried lumber, laminated together under controlled conditions of temperature and pressure, to form large timber sections (Figure7). It is typically manufactured using Douglas fir, Hem-Fir, Southern pine, Spruce-Pine-Fir, Alaskan Yellow cedar, and Ponderosa pine lumber.

Glulam can be fabricated in almost any straight or arched configuration for long spans. Glulam is manufactured with laminate layers (called lams), glued together. The required strength and position of each lamination is predetermined through engineering analysis. The tension and compression (outside) lams are made of higher-grade lumber and carry much of the bending load. However, the core lams are equally important as they resist the horizontal shear stresses. Individual lams are formed by cutting kiln-dried lumber into pre-determined thicknesses. For glulam, the lams are then joined together using thermosetting adhesives. These adhesives undergo irreversible chemical change when first heated under pressure. (The Adhesive Awareness Guide in this series contains specific information on engineered wood product (EWP) adhesive performance.)

Figure 7 Glue-Laminated Timbers Used in Roof Truss

Glulam timbers are desirable for their strength characteristics and appearance. Glulam is available in a variety of widths, depths, and lengths.

Performance Requirements: Strength and Durability

Strength–Engineered wood products, such as SCL, must meet certain physical (dimension) and mechanical property (strength) tests.

Glulam quality control programs ensure that the product meets required performance criteria.

Durability–It is important that an engineered wood product such as SCL retain its strength and structural integrity after it has been in service, and, in some cases, exposed to exterior conditions under normal conditions of use.

How SCL or Glulam is Used

During construction is the best time to see how an SCL or glulam framing system is configured and carries loads. These large cross-section dimension members can be used almost anywhere, and typically are installed as floor or roof beams, headers over doors and windows, rimboard around the edge of a foundation, or as studs in wall framing (Figures 8 and 9).

Site Visits

Although residential construction is built from the ground up, framing is best inspected from the roof down. The most important structural characteristic common to all buildings and all types of construction is referred to as "load path continuity." Load path is the prescribed route that gravity loads—such as live, snow, and water ponding—and lateral loads—from wind and earthquakes—follow to the footings. For simple single-family dwellings, the roof, ceiling and floor loads are collected through rafters or joists, which rest on exterior walls, and interior beams or bearing walls.

Figure 8 SCL Used as Ridge Beam in Roof

The layout drawings will show the minimum grade and species required of each SCL or glulam member, the on-center spacing, points of bearing, and connector information. It is also important to assure that large cross-section dimension members are properly attached to adjacent framing members and tied together with straps, hangers or other types of approved connectors.

FOR MORE INFORMATION

Barnes, Derek, 2000. "An Integrated Model of the Effect of Processing Parameters on the Strength Properties of Oriented Strand Wood Products," *Forest Products Journal* 50 (11/12): 33-42.

http://www.forestprod.org

Figure 9 SCL Used as Header and Blocking

SCL is used here as a header above a window and as blocking between I-joists. Note the V-notches for roof ventilation.

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WOOD STRUCTURAL PANEL AWARENESS GUIDE

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The purpose of this informational guide is to provide awareness to the fire service on the types of wood structural panels and how they are used in the construction of residential buildings. This publication is one in a series of eight Awareness Guides developed under a cooperative agreement between the Department of Homeland Security's United States Fire Administration, and the American Wood Council.

Wood Structural Panels

PURPOSE OF THIS GUIDE

The purpose of this Awareness Guide is to provide the fire service with information on the types and properties of wood structural panels and how they are used in residential construction (Figure 1).

Figure 1 Plywood & OSB Panels

WOOD STRUCTURAL USE PANELS —Sheathing for Roofs, Floors, and Walls

Plywood and oriented strand board (OSB) are two types of wood structural panels commonly used in residential construction. Less frequently seen is particleboard and it is seldom used in structural applications, but is often used as underlayment over floor sheathing, in cabinets, and in furniture. All are available as 4' x 8' panels but are sometimes available in larger sizes.

Wood structural panels are available in three bond classifications – *Exterior, Exposure 1*, and *Interior*.

This classification provides a measure of moisture resistance of the glue bond but does not relate to fungal decay resistance of the panel. Wood panels with an *Exterior* bond classification are suitable for repeated wetting and redrying or long-term exposure to weather or other conditions of similar severity (Figure 2).

Figure 2 Wood-Framed Apartments under Construction

Wood panels with an *Exposure 1* bond classification are suitable for uses not permanently exposed to weather. *Exposure 1* panels are intended to resist the effects of moisture on structural performance due to construction delays, or other conditions of similar severity. Exposure 1 panels may also be used when exposure to the outdoors is on the under-side only, such as at roof overhangs.

Wood panels with *Interior* bond classification are intended for interior applications only.

Plywood

Plywood is a wood structural panel made with plies (sheets) of wood veneer that are glued together under heat and pressure. Plywood is stronger and stiffer when the grain of the face veneers are oriented perpendicular to supports, which is the typical orientation for most floor and roof applications. On floors and roofs, it should seldom be oriented with the long axis parallel to supports. Plywood can be rated as Exterior or Exposure 1.

Photos and graphics courtesy of
APA – The Engineered Wood Association.
For more information, visit www.apawood.org

Figure 3 Plywood Production Line

Plywood panels are assembled in the factory by laying-up thin sheets of wood veneer. The veneers are sorted and dried prior to being coated with adhesive (Figure 3).

Oriented Strand Board (OSB)

In response to greater demand for housing and commercial buildings, a decreasing supply of older trees, and increasing environmental restrictions on logging, waferboard was developed in the United States in the mid-fifties, followed by OSB in the late 1970s. OSB is a second-generation mat-formed product resulting from process improvements made to the earlier waferboard products.

OSB is made with layers of thin, rectangular strands or flakes of wood that are produced by feeding freshly cut hardwood or softwood logs through a cutting machine called a strander. Strands are then dried and blended with adhesives. Strands in the face layers are generally formed at right angles to those in the core layers, thus providing directional strength and stiffness properties. The trees needed to make OSB are usually smaller, less merchantable, and faster growing than the ones used for plywood. OSB is *not* made from recycled wood or wood waste from other manufacturing operations.

The wood strands are blended with adhesives, then glued under heat and pressure to the desired panel thickness (Figure 4).

Figure 4 OSB Production Line

Particleboard

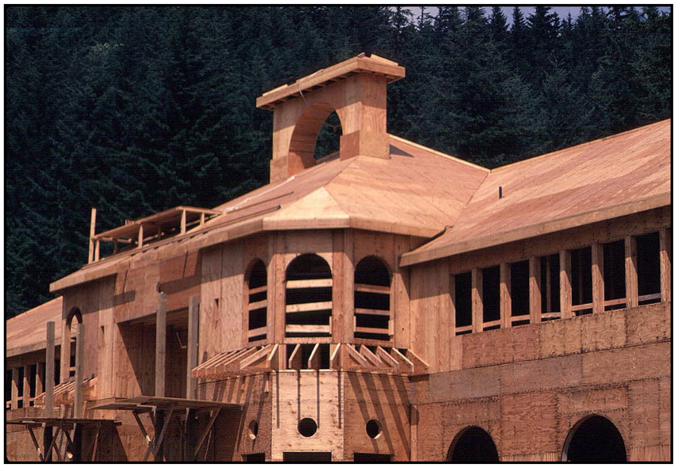
Particleboard is composed of very small particles of wood glued together under heat and pressure. It is not classified in the building codes as a wood structural panel and is therefore not generally used in normal construction for structural purposes such as floor, roof, or wall sheathing. It is, however, sometimes used in floors in manufactured housing. Its glue bond is classified as "Interior," which means that it is not to be used in high-humidity locations.

Grades of Wood Structural Panels

Wood structural panels are available in many thicknesses, ranging from $^1/_2$" – $1^1/_2$". These panels are primarily used in residential construction as roof sheathing, wall sheathing, subflooring, as single layer floors under carpet and pad, in structural insulated panels, I-joist webstock, and rim boards.

"Sheathing" is an unsanded panel intended for use as a structural covering and nail-base material for roofs, subfloors, and walls (Figure 5).

Figure 5 Sheathing

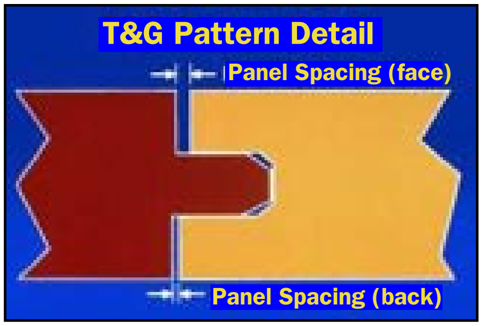


Sheathing that will be covered with shingles, brick veneer, etc.

"Underlayment" is used as the top layer in a two-layer floor-panel system. It is usually plywood and it may be sanded on the top face.

"Single-floor" is used as a combination subfloor and underlayment in single-layer floor applications. It is often used under carpet and pads. It is commonly available with tongue-and-groove edges (T&G) along the 8-foot sides (Figures 6 and 7).

Figure 6 Tongue and Groove (T&G) Profile



The T&G edges ensure that adjacent panel surfaces move up and down together when walked on to ensure even wear of finish flooring such as vinyl or carpet.

Figure 7 Single-Layer Floor Panel Installation

"Siding" panels are generally available as plywood, but some siding-grade panels and lap siding are available in OSB (Figures 8a and 8b). Lap siding is manufactured by cutting wood structural panels covered with a moisture resistant surface finish and edge treatment.

Figure 8a Siding Installation

Figure 8b Siding Installation

Structural Insulated Panels (SIPs)

Structural insulated panels (SIPs) are composites of foam plastic [usually expanded polystyrene (EPS)] sandwiched between wood structural panels. The SIPs are used to make floors, walls, and roofs (Figure 9).

SIPs are used because they are energy efficient. They are generally made with 7/16" OSB skins over EPS. The EPS can be up to a foot thick, making SIPs ideal for cold climates.

SIPs are made in a factory with all the openings and shapes precut and the electrical and plumbing chases in place. Once the foundations are in place, the building can be enclosed within two or three days. The interior surface of SIPs is then covered with gypsum wallboard, just as with a field-built structure.

Figure 9 Wood Structural Insulated Panel (SIP) Installations

WHERE ARE PANELS USED?

Applications of Structural Panels in Construction

Floors

The most common wood structural panel installed in typical floor applications is 23/32–inch thick, installed at 24 inches on center, and used as a combination subfloor-underlayment (Figures 10a and 10b). With supports at 24 inches on-center or less, these panels provide a strong, stiff, and solid surface on which different types of finish flooring (such as carpet and pad) can be directly applied. A two-layer floor system, comprised of a layer of structural subflooring and an underlayment layer, is also used in many applications.

Figure 10a Floor Construction

Figure 10b Floor Construction

Walls

Wood structural panels keep walls standing upright by resisting forces along the walls (“racking”) that come from wind and earthquakes (Figures 11 and 12). In some cases, wall sheathing of cardboard, foam plastic, or other materials replaces the wood structural panel bracing system.

Roofs

Wood structural panels are routinely used as roof sheathing in pitched and flat roofs under various waterproofing systems. In addition to carrying gravity loads from snow, rain, finish roofing, mechanical units, and people, they also serve to resist lateral forces applied to buildings from high winds or earthquakes.

The most common panel thicknesses used in roofs are $^{7}/_{16}$" and $^{15}/_{32}$". They are generally supported by trusses spaced 24" oc. In areas with minimal or no snow loads, building codes typically permit wood structural panels as thin as $^{3}/_{8}$" thick in roofs with supports up to 24" oc.

Figure 11 Wall Construction

Figure 12 Seismic Test of Walls

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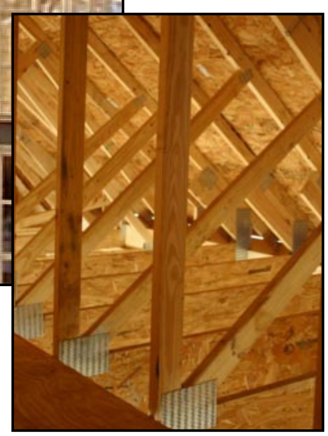
WOOD TRUSS AWARENESS GUIDE



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Wood Trusses

PURPOSE OF THIS GUIDE

The purpose of this Awareness Guide is to provide the fire service with information on the types and properties of wood trusses and how they are used in residential construction (Figure 1).

Figure 1 Roof Trusses

Trusses are the most frequently used system in residential roof construction. Truss placement requires skilled and trained crew members to properly and safely fabricate the roof system.

WHAT IS WOOD TRUSS CONSTRUCTION?

Trusses—The Power of a Triangle

Trusses in buildings are easily identified by a triangulated framework of structural elements. Triangles are what distinguish a truss from other structural products. Trusses have been used in long span structures for hundreds of years. Their inherent structural efficiency makes them a cost-effective solution for many bridges, towers, and buildings. Metal plate connected wood trusses are the predominant type of truss used in residential construction. They are typically fabricated from 2x4 or 2x6 dimension lumber. Trusses built with larger dimension wood members can occasionally be found in custom-built homes.

In a roof truss, the three sides (or perimeter elements) of the triangle are called "chords." The "webs" are wood pieces connecting the top and bottom chords. Chords and webs are the "members" or elements of the truss. The "connectors" joining chords and webs in modern trusses are usually metal-toothed plates.

Metal plate connected wood trusses were introduced in the mid-1950s. The most common application is in the roof assembly (Figure 2). Trusses used to form the roof assembly are referred to as "pitch chord," since the top chord is sloped. The bottom chord is typically horizontal, since it directly supports the ceiling. Complex roof structures can be assembled and sheathed using factory supplied trusses.

Figure 2 Pitch Chord Truss

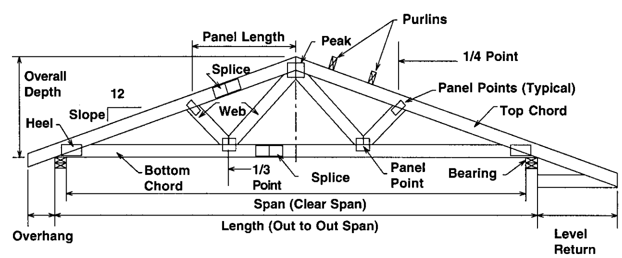
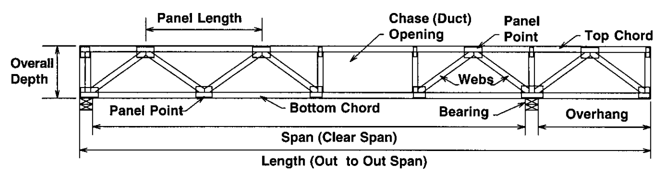


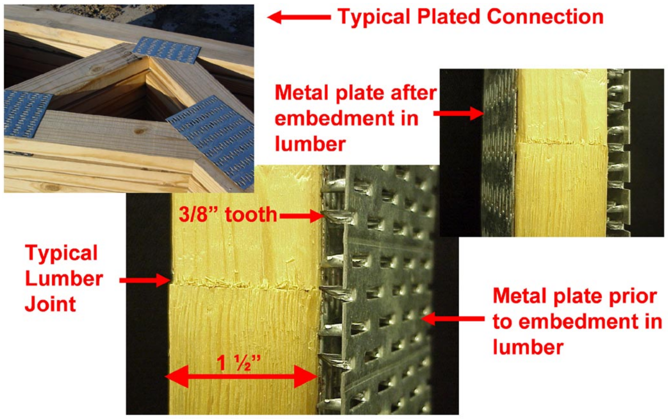
Figure 3 Parallel Chord Truss



Parallel chord trusses (Figure 3) can also be used to form roof assemblies, but they are more commonly used to form floor assemblies.

Photos and graphics courtesy of WTCA – Representing the Structural Building Components Industry. For more information, visit www.sbcindustry.com/firepro.php.

Figure 4 Metal Tooth Plate Connectors



Metal tooth plate connectors like those shown are used extensively in parallel and pitched chord trusses. The multi-tooth plates are embedded into the wood fiber using hydraulic presses.

Metal Plate Connected (MPC) Wood Trusses

Metal plate connected wood trusses (Figure 4), are often referred to as *plated* trusses and are used for a wide variety of applications. Analysis, design, and manufacturing specifications are developed in accordance with standards of the Truss Plate Institute.

More details regarding metal plate connected wood trusses can be found in the *Metal Plate Connected Wood Truss Handbook*.[1]

How a Truss Carries Load

The popularity and practicality of the truss is easy to understand—a simple triangle is naturally stable. Any force applied to a triangle will be transferred around the three sides of the triangle with limited movement or change of shape. As shown in Figures 2 and 3, web members connect the top and bottom chords.

Under gravity loads (live loads, snow loads), the top chord is in compression and the bottom chord is in tension. (“Live” loads include everything except the weight of the assembly itself.) However, high winds or earthquakes can result in the reversal of these forces in chord and web members. A truss designer checks the performance of each member under all anticipated load conditions.

Bracing

There are two types of lateral bracing used in truss construction—temporary and permanent. Temporary bracing holds the trusses vertical during construction. Permanent bracing is used where required by the engineering analysis. The type and location of required bracing is indicated in the information provided by the truss manufacturer to the field when the trusses are delivered to the job site. For metal plate connected wood trusses, the most up-to-date bracing recommendations are provided in *Building Component Safety Information*[2].

Redundancy—Load Redistribution

The historical performance of wood construction, whether exposed to hurricane force winds, earthquakes, or fire can be attributed to two factors, “structural redundancy within the truss” and “load redistribution across the floor or roof.” There is structural redundancy within each truss. In other words, when one truss member fails, the loads are carried among the remaining truss members. Additionally, the entire roof or floor assembly will redistribute loads (through sheathing and/or bracing) to adjacent trusses if one truss loses strength or stiffness.

In engineering terms, the structural redundancy within the truss is provided by continuity of the chords from one panel to the next and by the rotational stiffness of the connections. While a truss’s structural integrity is compromised when a single member is cut, this by itself will not usually cause catastrophic collapse. In fact, in most cases the truss will continue to carry most normal loads that are being applied to it. The cut member will generally cause noticeable defection that will warrant inspection. Total collapse would depend on many factors, such as load amount, span, spacing and integrity of the roof, floor or ceiling sheathing (membrane) and the degree of structural redundancy within the truss.

HOW WOOD TRUSSES ARE MANUFACTURED

The manufacturing process for trusses ranges from considerable manual assembly to entirely automated processes. Trusses are designed using software that accurately calculates the structural load conditions in accordance with building code requirements. The calculation of forces within the truss elements and connector plates is based on the laws of physics and to a great extent is independent of the material. Selecting the proper grade and species of lumber and the correct plate size is a function of the calculated forces within the truss web and chord member.

Figure 5 Truss Manufacturing Process

Trusses are manufactured on large horizontal tables called jigs. Truss members are held firmly in place while the entire assembly is moved through a hydraulic press. Roller pressure is applied to each plate to assure the teeth are properly embedded in the wood.

The web and chord elements are fabricated to exact dimensions. The pieces are arranged in their final orientation and the metal plates are applied using equipment capable of exerting high pressure to embed the metal plate teeth (Figure 5). Trusses are inspected for proper plate orientation and plate-teeth penetration depth prior to shipment to the job site.

HOW ARE TRUSSES USED?

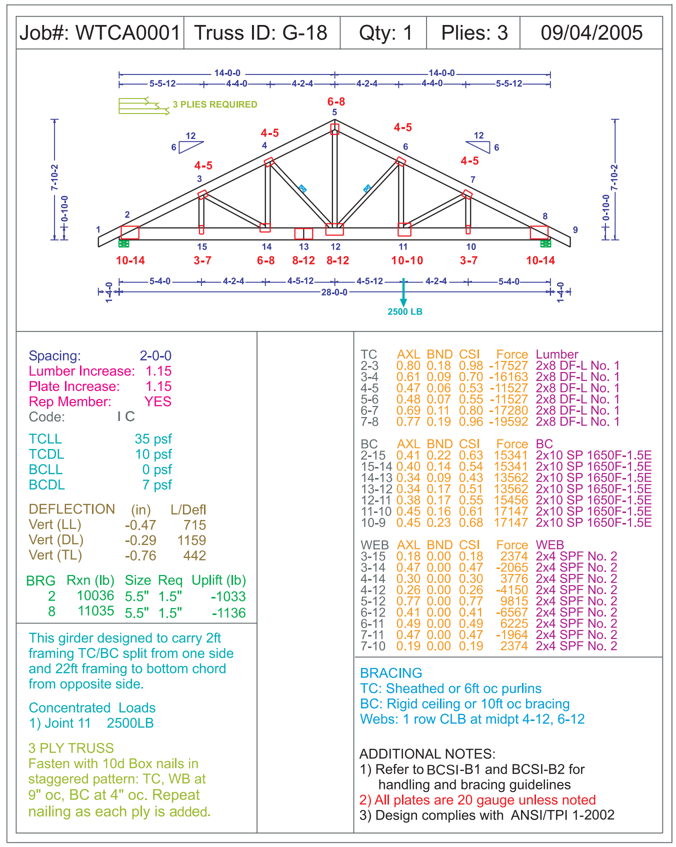
During construction is the best time to see how a truss roof system is configured and distributes loads (see Figures 8 through 11). Almost as soon as trusses are set in place, maybe even the same day, the roof sheathing is attached. This quick construction time limits the opportunity to see the framing method from outside the building.

Elements of a Truss Inspection

Comparing Structure to Approved Design Drawings

The framing inspection provides the building inspector with an opportunity to review the plans and determine whether the structure matches the approved drawings (Figure 6). At the time of this inspection, the fire service has its best opportunity to review the framing and its proper installation. The trusses and their placement will be checked against the design documents. These documents show the minimum grade and species of each piece of lumber in the truss, the on-center spacing, points of bearing, and field required permanent bracing. Temporary bracing may be required during erection of the trusses to prevent roof collapse. Permanent bracing perpendicular to the span of the truss, which connects adjacent truss web elements, will be specified on the drawings to prevent buckling of specific long and slender members.

Figure 6 Truss Design Drawings



Job#: WTCA0001	Truss ID: G-18	Qty: 1	Plies: 3	09/04/2005

3 PLIES REQUIRED

Spacing: 2-0-0
Lumber Increase: 1.15
Plate Increase: 1.15
Rep Member: YES
Code: I C

TCLL 35 psf
TCDL 10 psf
BCLL 0 psf
BCDL 7 psf

DEFLECTION	(in)	L/Defl
Vert (LL)	-0.47	715
Vert (DL)	-0.29	1159
Vert (TL)	-0.76	442

BRG	Rxn (lb)	Size	Req	Uplift (lb)
2	10036	5.5"	1.5"	-1033
8	11035	5.5"	1.5"	-1136

This girder designed to carry 2ft framing TC/BC split from one side and 22ft framing to bottom chord from opposite side.

Concentrated Loads
1) Joint 11 2500LB

3 PLY TRUSS
Fasten with 10d Box nails in staggered pattern: TC, WB at 9" oc, BC at 4" oc. Repeat nailing as each ply is added.

TC	AXL	BND	CSI	Force	Lumber
2-3	0.80	0.18	0.98	-17527	2x8 DF-L No. 1
3-4	0.61	0.09	0.70	-16163	2x8 DF-L No. 1
4-5	0.47	0.06	0.53	-11527	2x8 DF-L No. 1
5-6	0.48	0.07	0.55	-11527	2x8 DF-L No. 1
6-7	0.69	0.11	0.80	-17280	2x8 DF-L No. 1
7-8	0.77	0.19	0.96	-19592	2x8 DF-L No. 1

BC	AXL	BND	CSI	Force	BC
2-15	0.41	0.22	0.63	15341	2x10 SP 1650F-1.5E
15-14	0.40	0.14	0.54	15341	2x10 SP 1650F-1.5E
14-13	0.34	0.09	0.43	13562	2x10 SP 1650F-1.5E
13-12	0.34	0.17	0.51	13562	2x10 SP 1650F-1.5E
12-11	0.38	0.17	0.55	15456	2x10 SP 1650F-1.5E
11-10	0.45	0.16	0.61	17147	2x10 SP 1650F-1.5E
10-9	0.45	0.23	0.68	17147	2x10 SP 1650F-1.5E

WEB	AXL	BND	CSI	Force	WEB
3-15	0.18	0.00	0.18	2374	2x4 SPF No. 2
3-14	0.47	0.00	0.47	-2065	2x4 SPF No. 2
4-14	0.30	0.00	0.30	3776	2x4 SPF No. 2
4-12	0.26	0.00	0.26	-4150	2x4 SPF No. 2
5-12	0.77	0.00	0.77	9815	2x4 SPF No. 2
6-12	0.41	0.00	0.41	-6567	2x4 SPF No. 2
6-11	0.49	0.00	0.49	6225	2x4 SPF No. 2
7-11	0.47	0.00	0.47	-1964	2x4 SPF No. 2
7-10	0.19	0.00	0.19	2374	2x4 SPF No. 2

BRACING
TC: Sheathed or 6ft oc purlins
BC: Rigid ceiling or 10ft oc bracing
Webs: 1 row CLB at midpt 4-12, 6-12

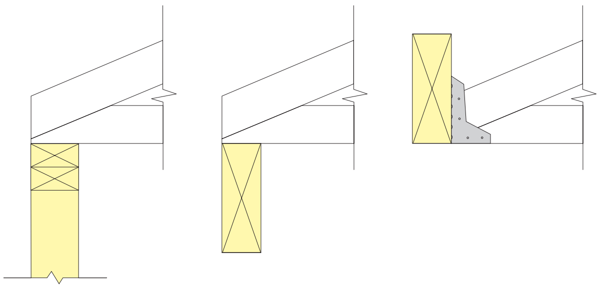
ADDITIONAL NOTES:
1) Refer to BCSI-B1 and BCSI-B2 for handling and bracing guidelines
2) All plates are 20 gauge unless noted
3) Design complies with ANSI/TPI 1-2002

Truss design drawings are the graphic depiction of individual trusses prepared by the truss designer. The information is provided for assurance that the truss design meets specifications.

Truss Support

The truss must have proper bearing on (or support from) walls or girders. For structural purposes, the truss must be supported exactly where indicated on the truss design (Figure 7–on next page).

Figure 7 Design Drawing of Truss Support



The truss design drawing illustrates which structural support is designated by the building designer to carry the truss reaction to the foundation.

Truss Connections

The truss must be properly connected to the bearing location. The building plans will specify how the truss must be connected to the structure.

Truss Repair

Truss damage, installation errors, or field modifications to accommodate roof openings for skylights, duct work, chimneys, and other purposes, must be repaired according to the specifications of the truss or building designer. There are no "standard" repair details available that cover every situation. Trusses and types of damage to them vary greatly, so each repair detail is prescribed on a case-by-case basis. Truss designers most often specify plywood or OSB gussets over damaged plates or joints, metal nail-on plates, lumber or repair frames over broken chords or webs, or truss plates applied by a portable press.

For additional information, visit:

www.sbcindustry.com/firepro.php
www.cdc.gov/niosh/fire

Figure 8 Pan Ceiling Truss

Trusses can be used to create many different ceiling configurations. In this instance, trusses are used to create a "pan" or "tray" ceiling. From the exterior, the roof appears to be constructed on trusses. From the interior, it isn't so obvious.

Figure 9 Transfer Truss

A "transfer" truss is designed to support roof loads from above and porch trusses framed into the side. The transfer truss is built into the wall assembly, so it is not obvious how the roof is supported.

Figure 10 "Bonus" Room Above Garage

The space above this multi-car garage is being used as a "bonus" room. Once gypsum wallboard is attached to the bottom chord of the trusses, it will not be obvious there is a room above. The bottom chord members are laminated strand lumber (LSL), which are engineered to carry the floor load and span from the garage door header to the interior wall.

Figure 11 View of Trusses from Inside Bonus Room

From inside the bonus room, the knee-walls, top chords, and engineered LSL bottom chords are visible.

End Notes

1. *Metal Plate Connected Wood Truss Handbook*, 3rd Ed., WTCA, Madison, WI, 2002. www.sbcindustry.com/firepro.php
2. *Building Component Safety Information*, BCSI, WTCA, Madison, WI, 2003. www.sbcindustry.com/bcsi.php

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