

Abstract

Flame retardants for wood alter the combustion properties of wood to reduce surface flame spread. Flame retardant chemicals cause acid catalyzed dehydration reactions in wood to facilitate the formation of char and reduce the effective heat of combustion, resulting in lower heat release and flame spread. Boron compounds can also form glassy films that may inhibit mass transfer of combustible vapors.

This paper discusses the role of boron in providing flame retardancy to wood. Different loading levels of borax-boric acid, ranging from 0 to 20 percent add-on by weight, were applied to Southern Pine. Two types of fire tests were used to evaluate flame retardancy. Clearwood and plywood specimens were tested in the fire tube test and in a heat release rate calorimeter, respectively. It was estimated from fire tests results that loading levels of more than 7.5 percent add-on (3 lb/ft³/ (48 kg/m³)) of borax-boric acid are required to meet the ASTM E 84 class I for flame retardant classification.

Introduction

The earliest work at the USDA Forest Service Forest Products Laboratory (FPL) on the mechanisms of flame (or fire) retardancy on wood substrates was done by Browne (1958). Several mechanisms by which chemicals impart fire retardancy were proposed and discussed. A more recent review of the subject was given by LeVan (1984). Basically, fire retardants promote char formation and reduce effective heat of combustion, thereby reducing heat release and flame spread.

The fire retardancy of boron compounds has been noted for quite some time. Mixtures of borax and boric acid have been used as a preservative in wood. It was found that these compounds have some efficacy in retarding flame spread on wood surface. In addition to the usual char-forming catalytic effect, they have a rather low melting point and form glassy films when exposed to high temperatures in fires. The formation of the film barrier inhibits the flow of combustible volatiles to the fire-exposed surface. Borax tends to reduce flame spread but can promote smoldering or glowing. On the other hand, boric acid suppresses smoldering but has little effect on flame spread. Therefore, these compounds are normally used together.

Because of their beneficial effects, boron compounds are often considered a good flame retardant. These beneficial effects include preservative effectiveness, neutral pH, and less impact on mechanical properties compared to some other flame retardant chemicals. However, the question remains about the level of chemical necessary to impart the degree of fire retardancy necessary for applications that require class I flame spread classification (ASTM E 84: ASTM 1988a). The main objective of our study is to evaluate the influence of borax-boric acid loading levels on fire performance of a selected wood substrate using standard fire tests.

Experimental

Materials and Treatments

southern Pine was used as the wood substrate throughout the study. Clear-wood sticks and plywood were treated to obtain different loading levels of borax-boric acid. The chemicals used were a commercial product routinely used for preservative treating of wood. Prior to treatment, the wood samples were cut to the size needed for the fire tests. The sticks were 40 inc. (1m) long and 3/4 by 3/8 in. (19 by 10 mm) in cross section. The plywood samples were 5/8 in. (17 mm) thick and 6 by 6 in. (150 by 150 mm) in surface area.

The heat release rate samples were selected from a single sheet of 4 by 8 ft. (1.22 by 2.44 m) Southern Pine plywood. The specimens were matched for similar density of 31 lb/ft³ (496 kg/m³). They were then pressure impregnated with aqueous solutions of borax-boric acid. The concentrations of the solutions used in the treatment for different target add-on retentions (percentage by weight) and loading levels (lb/ft³) (kg/m³) are shown in Table 1. Untreated (control) samples of the same stock were used as reference.

A vacuum was drawn in the loaded treating cylinder for 60 min. After the treating solution was introduced, 150 lb/in² (1,033 kPa) pressure was maintained for 120 min. The treated samples were dried and conditioned at 23 deg C and 50 percent RH to reach an equilibrium of about 9 percent prior to fire testing. Calculations of weight gains showed that actual retention of chemicals was in good agreement with the target levels shown in Table 1.

TABLE 1. Treating solution concentrations and target retentions

Solution concentration (percent)	Target add-on (percent)	Loading level (lb/ft ³) ^a
17.0	20.0	7.4
12.7	15.0	5.5
8.5	10.0	3.7
6.4	7.5	2.8
4.2	5.0	1.8
2.1	2.5	0.9
0.9	1.0	0.4

^a1 lb/ft³ = 16 kg/m³.

Fire Tests

There are a myriad of fire tests to evaluate fire performance of materials. Historically, old generation fire test methods were arbitrarily designed to try to mimic real life. It was soon realized that the results from such tests were only applicable in narrow ranges of products and application because of the complexity of fire problems. A survey of fire tests available for surface flammability of building materials was described by Eickner (1977). Some of these tests are still being used today for quality control and regulation purposes.

For interior finishes, the North American codes refer to the Steiner tunnel or 25-ft. (7.6-m) tunnel furnace method (ASTM E 84-88). Ac-

The role of boron in flame-retardant treatments

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cording to this method, which uses red oak as the reference material, materials are ranked in three classes depending on their flame spread index (FSI). Materials having an FSI of 0.25 are class I, 0.26-75 class II, and 76-200 class III. Fire retardant materials must meet class I. Most untreated wood materials fall into class III.

At FPL, we use two small-scale tests for quality control and product development work. (1) The fire tube test method (ASTM E 69, ASTM 1988b1 and (2) an Ohio State University (OSU) heat release rate apparatus (ASTM F 906; ASTM 1985C). Some main features of the two tests are summarized below.

In the fire tube test, the sample stick is inserted inside a 38 in.- (1-m-) long, 3-in.- (76-mm-) diameter galvanized iron tube. A Bunsen burner adjusted for a flame height of 11 in. (280 mm) is used to ignite the bottom end of the stick. Weight loss of the stick is monitored via a balance mechanism. The burner is removed after 4 min. The final percentage of weight loss is used as the main criterion for comparison.

The OSU apparatus at FPL has been modified for improved accuracy. The modification was described by Tran (1990). The OSU apparatus is designed to measure the heat release rate per unit area of burning specimen when exposed to a fixed radiant heat flux. Since heat release rate is the main driving force for flame spread in the ASTM E 84 tunnel test, estimate of FSI can be made based on heat release rate data.

Test Results

The Southern Pine clearwood sticks were tested in the fire tube test in five replicates for each loading level. The plywood samples were tested in the OSU apparatus in duplicates at a fixed radiant heat flux of 35 kW/m².

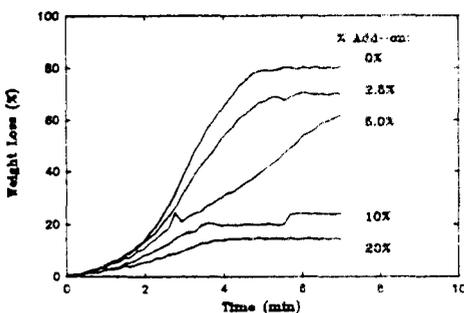


Figure 1.—Typical weight loss curves from fire tube tests of Southern Pine treated with borax-boric acid

Fire Tube Data

Typical weight loss curves from the fire tube tests are shown in Figure 1. Upon removal of the Bunsen burner at 4 min., some samples continued to burn and lose weight (0 to 5 percent add-on levels). Other samples at higher retention levels of borax-boric acid stopped burning and reached their final weight loss levels. The final weight loss data is plotted

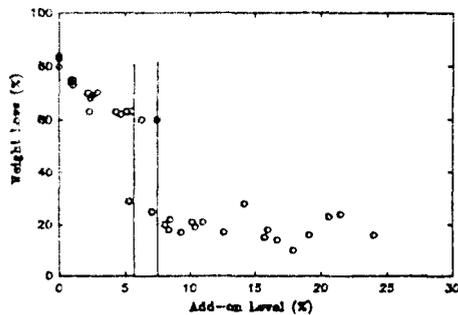


Figure 2.—Weight loss of fire tube samples as a function of loading level

against the percent add-on levels in Figure 2. The plot has two distinct regions. The first region includes untreated controls and loading levels below which any flame retardancy is achieved. Untreated samples had a weight loss of about 80 percent. Weight loss decreased gradually to about 60 percent for samples having add-on levels up to 5 percent. The second region shows characteristic behavior for those loading levels that provided flame retardancy. Above the 7.5-percent add-on level, weight loss of the samples was about 20 percent, with some scatter of the data. The region between 5 and 7.5 percent add-on levels represents a sharp reduction in the weight loss data. The fire tube data indicate a linear relationship between loading level and flame retardancy does not occur but a minimum loading level is apparently necessary to achieve any degree of flame retardancy.

OSU Apparatus Data

Typical heat release rate data are shown in Figure 3 for Southern Pine plywood treated with borax-boric acid at different add-on levels. Ignition of the samples coincides with the sharp rise in measured heat release rate. Ignition times increased with increasing levels of chemicals. As expected, heat release rate decreased with increasing loading levels.

To estimate the FSI (ASTM E 84) of the treated plywood, a correlation between FSI of a range of wood materials and their heat release

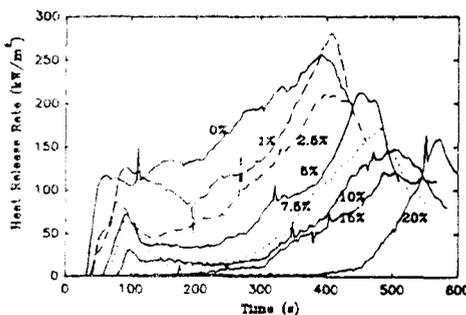


Figure 3.—Heat release rate of Southern Pine plywood at different loading levels at 35 kW/m² heat flux

rate (HRR) obtained in the OSU apparatus was made. The materials used for the correlation were described by Tran (1990) in another

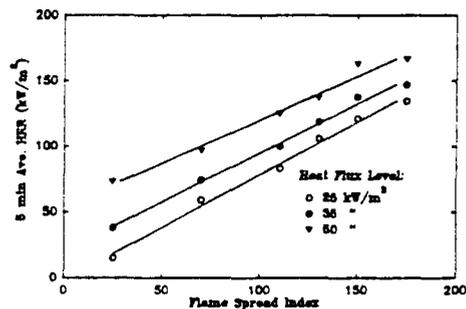


Figure 4.—Correlation between heat release rate (HRR) and ASTM E 84 flame spread index.

study. The 5 min. average HRR taken from ignition was found to be the most suitable parameter for the correlation. As shown in Figure 4, linear relationships between FSI and 5-min. HRR at different levels of radiant heat flux were established. The relationship for 35 kW/m² is used to evaluate the treatments in this study.

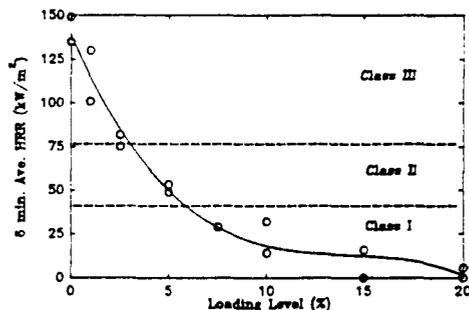


Figure 5.—Heat release rate (HRR) of Southern Pine plywood treated with different levels of borax-boric acid.

The 5 min. average HRR of the plywood samples are plotted against loading levels in Figure 5. As determined from the established correlation (Fig. 4), materials having a 5-min. average HRR of less than 40 kW/m² would be acceptable as class I. Those between 40 and 75 kW/m² would be class II. Above 75 kW/m², the materials would be class III. It is estimated from Figure 5 that loading levels of more than 7.5 percent add-on are needed to meet class I classification.

From the HRR tests, we gleaned additional information about the effect of fire retardant treatment. The tests were terminated after flaming ceased and the residues were mainly char. The total heat release throughout the whole test divided by total mass loss represents the effective heat of combustion. Figure 6 illustrates the effective heat of combustion and the percentage of char residue as functions of loading level. For untreated Southern Pine

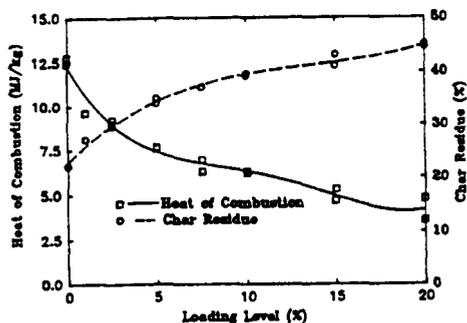


Figure 6.—Effective heat of combustion and char residue of plywood treated with borax-boric acid.

plywood, effective heat of combustion was about 12.5 MJ/kg during the flaming period. The effective heat of combustion decreased with increasing loading level. For untreated plywood, char residue was about 22 percent. The char residue increased with loading level and was 45 percent at 20 percent add-on of borax-boric acid.

Summary

The fire test data from the two test methods are consistent with each other. As shown, the fire tube test and the OSU apparatus are very

helpful as small-scale tests to evaluate effectiveness of fire retardant treatments of wood. A few conclusions can be drawn from the experimental data:

- 1) Fire retardancy is a function of the loading level of chemicals.
- 2) We estimated that loading levels of at least 7.5 percent add-on level (3 lb/ft³) (48 kg/m³) of borax-boric acid are needed for southern Pine to meet the ASTM E 84 class I requirement.
- 3) The loading levels often used for preservative treatment (about 0.2 lb/ft³) (3.2 kg/m³) do not impart any flame retardancy effectiveness to wood. There is a minimum loading level of approximately 5 percent borax-boric acid necessary to achieve a class 2 requirement (FSI) and 7.5 percent loading level to achieve a class 1.

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