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Fire and bending properties of blockboard with fire retardant treated veneers

Abstract This study evaluated fire and bending properties of blockboards with various fire retardant treated veneers. Blockboards were manufactured using untreated fir strips and sandwiched between treated ekaba veneers at final assembly. The veneers were treated with either boric acid (BA), disodium octoborate tetrahydrate (DOT), alumina trihydrate (ATH), or a BA/DOT mixture. Modulus of rupture and modulus of elasticity tests were performed according to European Standard EN 310. Blockboards were also tested for fire resistance as indicated by a cone calorimeter. Treatments had little negative effect on flexural strength; flexural stiffness was significantly lower for the highest treatment levels. Treatments resulted in a significant reduction in predicted flame spread rate.

Abbrand- und Biegeeigenschaften von Tischlerplatten mit Feuerschutzmittel behandelten Deckfurnieren

Zusammenfassung Untersucht wurden die Abbrand- und Biegeeigenschaften von Tischlerplatten, deren Deckfurniere mit unterschiedlichen Feuerschutzmitteln behandelt worden waren. Die Mittelschicht der Tischlerplatten bestand aus unbehandelten Tannenholzleisten. Die Decklagen bestanden aus imprägnierten Ekaba Furnieren. Die Furniere waren entweder mit Borsäure (BA), Disodium-Oktoborat-Tetrahydrat (DOT), Aluminium-Trihydrat (ATH) oder einer Mischung aus BA und DOT imprägniert worden. Festigkeits- und Steifigkeitsversuche wurden gemäß der europäischen Norm EN 310 durchgeführt. Das Brandverhalten der Tischlerplatten wurde mittels eines Kegel-Kalorimeters abgeschätzt. Die Behandlung der Furniere hatte einen geringen Einfluss auf die Biegefestigkeit, wohingegen die Steifigkeit bei den stärksten Behandlungsstufen signifikant verringert war. Die Imprägnierungen reduzierten die erwartete Flammenausbreitungsgeschwindigkeit signifikant.

1 Introduction

Plywood has long been an integral part of light-frame wood construction and furniture, but other composite materials, such as blockboard, are increasingly being substituted for solid wood and plywood (Morrell 2002). Because of the way it is made, blockboard is considered a distinct type of plywood (Zanuttini and Cremonini 2002). Blockboard consists of a central layer (core) made up of solid wood strips that may contain defects undesirable for the face of the finished panels. The facing on blockboard is stiffened and bound together by glued, hot-pressed rotary-cut veneers. Adjacent veneers are oriented perpendicular to the grain.

The physical-mechanical properties of blockboard are sparsely documented, and blockboard performance standards exist in the public literature. Studies have investigated the mechanical properties of blockboard made from different species (Goker 1978, Vassiliou 1996, Zanuttini and Cremonini 2002). The properties of blackboard are more akin to those of solid wood than those of a balanced laminated plywood. Blockboard has higher flexural stiffness and strength, albeit in one direction, than plywood of a similar thickness. The combination of wood components of very different thickness (strips and veneers) makes it difficult to model bending properties.

The main advantage of blockboard over plywood is that the heart of the board is produced from thick sections of wood. Hence, the manufacture of blockboard does not require the ma-

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nipulation and fabrication of a large number of veneers, which reduces cost and manufacturing time. Typical applications are furniture, backs of cabinets, and center panels of framed doors. Blockboard is also used for partitioning, exhibition panels, tables, entertainment centers, speaker boxes, and panel moulding. It is used extensively for concrete formwork in Europe.

For most applications, wood products do not require supplemental fire retardant chemicals. Where a higher level of fire safety is desirable or necessary, fire retardant treated wood products provide a viable alternative to traditional noncombustible materials (White and Sweet 1992). It is well known that chemical treatment can significantly improve the fire performance of wood-based composites and, by so doing, widens their utilization options. Boron compounds are considered good flame retardants that exert less impact on mechanical properties compared with some other flame retardant chemicals (Akbulut et al. 2004, Tran and LeVan 1990). The largest volume inorganic flame retardant used worldwide is alumina trihydrate (ATH), also known as hydrated alumina or simply hydrate, and chemically designated as aluminum trihydroxide, $Al(OH)_3$. On heating to 200 °C, ATH decomposes into 66% alumina and 34% water. This irreversible process, in part, makes ATH an effective halogen-free flame retardant and smoke suppressant filler in plastics (e.g., cables, rubber products, and carpet backing). Aluminum hydroxide is also used as an adsorbent, emulsifier, ion exchanger, mordant, antacid, and filtering medium; in the manufacture of paper, ceramics, printing inks, and detergents; for waterproofing fabrics; and in dentrifrices and antiperspirants.

To the knowledge of the authors, there is no information about the effect of fire retardant chemicals on the bending properties of blockboard. In the study reported here, blockboards manufactured with veneers treated with boric acid (BA), disodium octoborate tetrahydrate (DOT), a mixture of these fire retardant chemicals (BA/DOT), and ATH were subjected to laboratory fire and bending tests. Relative fire performance was evaluated using an oxygen consumption calorimeter commonly known as the cone calorimeter. In the test, a 100-mm-square specimen is exposed to a constant external heating flux. Ignitability is determined by observing the time needed to achieve sustained ignition. The potential contribution of the burning material to the growth of a fire is obtained by measuring the heat release rate (HRR) due to combustion. For the duration of the cone calorimeter test, HRR of the burning specimen is determined using the oxygen consumption methodology. This methodology is derived from the observation that the net heat of combustion is directly related to the amount of oxygen required for combustion. The oxygen concentration and the exhaust gas flow are measured in the test. In addition, the mass loss of the burning specimen is recorded. From these two measurements, the effective heat of combustion (heat release per unit mass loss) is calculated. The obscuration of a laser beam in the exhaust duct is also recorded as a measure of the visible smoke development from the burning specimen.

The HRR is a critical factor in the spread of flames over a surface and the overall growth of a compartment fire. It is an option for evaluating the degree of combustibility of different materials. Fire retardant treatments for wood products are designed to reduce their flammability. In the United States, the regulatory test for flammability of building products is the 7.32-m tunnel test (ASTM E 84) (ASTM International 2001). The cone calorimeter has been used to provide estimates of the flame spread index obtained in the tunnel test (Dietenberger and White 2001, White and Dietenberger 2004).

2 Materials and methods

2.1 Materials

A total of 12 blockboards, 500 by 500 by 18 m^3, were manufactured from rotary-peeled veneers of ekaba (*Tetraberlinia bifoliolata* Harms.) heartwood, which is used extensively in the plywood industry in Europe, and a core layer of fir (*Abies bornmülleriana* M.) strips at the Laboratory of Wood Mechanics and Technology, Istanbul University, Turkey. Clean 2.3-mm-thick ekaba rotary veneers and 16- by 22- by 500-mm^3 fir core strips were supplied by Pelit Arslan Plywood Corporation, Istanbul, Turkey.

Three chemicals were used in four different treatments (Table 1): (1) boric acid (BA), H_3BO_3 (U.S. Borax Inc., Valencia, California); (2) disodium octaborate tetrahydrate (DOT), $Na_2B_8O_{13} \cdot 4H_2O$ (U.S. Borax Inc.); (3) alumina trihydrate (ATH), $Al(OH_3)$ (Horasan Chemical Corp., Ankara, Turkey); and (4) a mixture of BA and DOT (BA/DOT 1:1).

2.1.1 Blockboard manufacturing

The core was produced from fir strips at 10% moisture content. The strips were edge-glued side to side with a polyvinyl acetate (PVA) resin and pressed at 0.1 to 0.2 $N \cdot mm^{-2}$ at 40 °C for 20 s at Pelit Arslan Plywood Corporation. The assembled core was then touch-sanded with an abrasive planer to achieve a thickness

Table 1 Typical composition of boric acid (BA), disodium octaborate tetrahydrate (DOT), and alumina trihydrate (ATH)

Tabelle 1 Typische Zusammensetzung von Borsäure (BA), Disodium-Oktaborat-Tetrahydrat (DOT) und Aluminium Trihydrat (ATH)

Treatment	Component	Amount (%)
BA	Boric oxide (B_2O_3)	56.3
	Water (H_2O_2)[a]	67.1
	Equiv. boric acid	100
DOT	Sodium oxide (Na_2O)	14.7
	Boric oxide (B_2O_3)	67.1
	Water (H_2O_2)	18.2
	Equiv. DOT	98
ATH	Al_2O_3	65
	SiO_2	0.015
	Fe_2O_3	0.02
	Equiv. ATH	99.5
	Free moisture	8

[a] By difference.

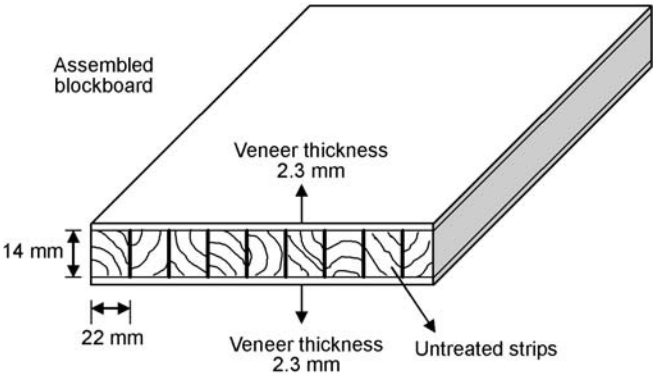

Fig. 1 Schematic view of blockboard
Abb. 1 Aufbau einer Tischlerplatte

of 14 mm. A schematic of an assembled blockboard is shown in Fig. 1.

The ekaba veneers were conditioned to 7% moisture content in a climate chamber and then dip-treated in 2.5%, 5.0%, and 7.5% aqueous solutions of BA, DOT, and BA/DOT (1:1, w:w) and 2.5% and 5.0% aqueous solutions of ATH for 3 h at 60 °C. The veneers were then subjected to a second drying process, reconditioned to 7% moisture content, and re-weighed. Net uptake of chemicals was calculated from the difference between the initial and final weights of the veneers. Fir strips for the core layer were not treated.

A commercial liquid phenol-formaldehyde (PF) was used as adhesive to bond the face and back veneers to the 14-mm core. Before gluing, the veneers were conditioned until they reached approximately 7% moisture content. The PF adhesive (solids content 47% ± 1%) was uniformly brushed onto one side of the face veneers at approximately 180 $g \cdot m^{-2}$. The core layer was then sandwiched with the grain perpendicular to the veneer face and pressed at 65 bar and 130 °C for 12 min in a hot press. The completed blockboard density was 0.50 to 0.56 $g \cdot cm^{-3}$.

2.2 Methods

2.2.1 Determination of air-dry density and flexural properties

Tests of panel flexural properties (modulus of rupture (MOR) and modulus of elasticity (MOE)) were conducted on five specimens cut from each experimental panel according to EN 326-1 (European Committee for Standardization 1994). Prior to mechanical testing, the specimens were conditioned for at least 3 weeks at 20 °C ± 2 °C and 65% ± 2% relative humidity.

Static bending properties (MOR and MOE) were determined for 50- by 410- by 18-mm^3 specimens cut from each experimental panel in accordance with EN 310 (European Committee for Standardization 1993). Five specimens from each panel were tested; three specimens were cut with their long dimension parallel to the outer layer and two specimens with their long dimension perpendicular to the outer layer. Load-deflection data were recorded at the 10% and 40% values of failure load ($P_{\max}$) to calculate specimen MOE. The Losenhausen test machine (Fig. 2) had a static loading capacity of 1000 kg (accurate to 0.1 kg). The crosshead speed was adjusted so that failure would occur within an average of 60 s ± 10 s.

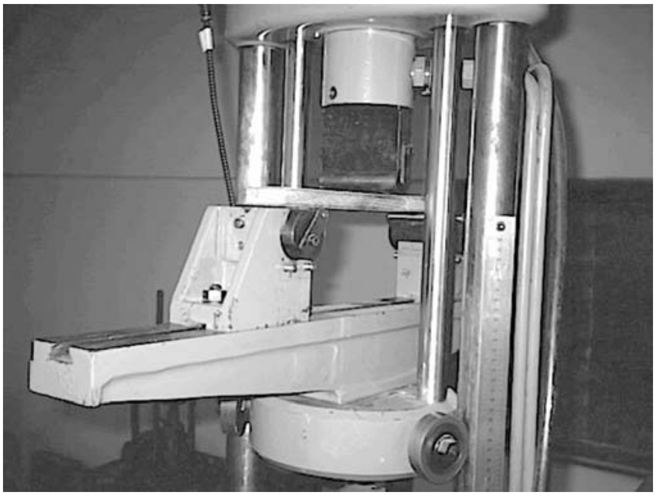

Fig. 2 MOR and MOE test set-up (Losenhausen test machine)
Abb. 2 Festigkeits- und Steifigkeitsprüfung (Losenhausen Prüfmaschine)

Moisture content was measured after static bending tests. Measurements of density and dimensions were made according to EN 325 (European Committee for Standardization 1993). Specimens for measuring density (50- by 50- by 18-mm^3) were taken from an undamaged portion of the flexural specimens from each panel. Density was measured according to EN 323 (European Committee for Standardization 1993). For density and bending properties, all multiple comparisons were first subjected to an analysis of variance (ANOVA), and significant ($\alpha \leq 0.05$) differences between mean values of control and treated blockboard specimens were determined using Duncan's multiple range test.

2.2.2 Fire performance

The cone calorimeter method for determining heat release rate (HRR) is described in ASTM E 1354-02 (ASTM International 2002) and ISO 5660-1 (ISO 2002). In this study, the external heat flux was 50 kW/m^2 and the retainer frame (without wire grid) was placed over the test specimen. The electric spark igniter was placed above the test specimen until sustained ignition occurred. Two replicates of each material type were tested. Specimens were tested in the horizontal orientation; the conical radiant electric heater was located above the specimen.

3 Results and discussion

3.1 Retention of fire retardant

Table 2 displays average retention of BA, DOT, BA/DOT, and ATH in top and bottom veneers of blockboards. Blockboards with veneers treated with 7.5% aqueous solutions of alumina

Table 2 Retardant retention in blockboards
Tabelle 2 Einbringmenge Feuerschutzmittel in Tischlerplatten

Blockboard number	Treatment	Treatment concentration (%)	Treatment retention[a] (kg m^{-3})	(% face veneer wt.)
1	Control	No chemical		
2	DOT	2.5	30	4.4
3		5.0	50	7.3
4		7.5	60	8.7
5	BA	2.5	75	10.9
6		5.0	93	13.5
7		7.5	104	15.1
8	BA/DOT	2.5	11	1.6
9		5.0	33	4.8
10		7.5	60	8.7
11	ATH	2.5	60	8.7
12		5.0	80	11.6

[a] Retention in top and bottom veneers of each blockboard.

trihydrate were not included because their retention contents (kg · m^{-3}) were the same as that of blockboards with veneers treated with 5% aqueous solutions of alumina trihydrate in this study. We note that loading levels of more than 48 kg · m^{-3} (approximately 10% to 20% by weight, depending on wood species/density) of borax or boric acid are said to be required to meet the ASTM E 84 class I flame retardant classification (ASTM 1988, Tran and LeVan 1990). However, typical commercial flame retardant retentions range from 15% to 25% borate (combination of boric acid and/or borax) by weight (Fogel and Lloyd 2002).

3.2 Density and bending properties

Results of physical and mechanical tests are shown in Table 3. Air-dry density values ranged between 0.53 and 0.56 g · m^{-3}. Density influences both the physical and mechanical properties of wood and wood-based materials. In this study, the same processing conditions were chosen to achieve equal board densities. However, blockboards treated with aqueous solutions of BA (5% and 7.5%), DOT (7.5%), and ATH (2.5% and 5.0%) showed a significant difference ($p = 0.001$) in density values as compared to control specimens. Blockboards treated with BA (2.5% and 5%) had the highest density values. This increase in density was directly attributed to the level of BA loading, which was almost twice that of the other treatments (Table 2).

In general, treatments did not not exert a negative effect on MOR. The MOR and MOE values parallel-to-axis were 20% to 30% higher than the perpendicular-to-axis values. Our results with these small specimens showed that the MOR (parallel-to-axis) values of blockboards met the flexural strength performance requirements of the PS-2-02 (NIST 2002) voluntary standard. This standard presently requires the use of full panel specimens. It is not limited to plywood but applies to all wood-based structural panels in general, regardless of composition. Blockboards with DOT, BA, and BA/DOT treated veneers generally showed similar MOR results at all loading levels. However, MOR of blockboards treated with ATH (2.5% aqueous solution) was better than that of the untreated control and the other treated specimens (Figs. 3 and 4). At all concentrations, blockboards with BA, DOT, BA/DOT, and ATH treated veneers showed statistically no differences in MOR when compared to control specimens. Increasing the retention of DOT and ATH generally caused a minor reduction in MOR.

The MOE values demonstrated similar trends and results to those for MOR (Figs. 5 and 6). The MOE of blockboards treated with the 2.5% aqueous solution of fire retardant was better than that of blockboards treated with the higher solutions. The MOE of the single DOT and ATH treated blockboards generally decreased with increasing chemical content. Generally, parallel-to-axis MOE values of blockboards treated with the 2.5% aqueous

Table 3 Air-dry density and bending properties of blockboards [a]
Tabelle 3 Normal-Dichte und Biegeeigenschaften der Tischlerplatten

Treatment	Treatment concentration (%)	Air-dry density (g · cm^{-3})	MOR (N · mm^{-2}) Parallel	MOR (N · mm^{-2}) Perp	MOE (N · mm^{-2}) Parallel	MOE (N · mm^{-2}) Perp
Control	–	0.53 (0.007)	47.77 (1.27)	37.49 (0.67)	3928.77 (292.02)	2766.36 (135.66)
BA	2.5	0.54 (0.009)	47.40 (0.64)	36.66 (0.74)	3607.42 (91.71)	2632.99 (99.18)
	5	0.56^{***} (0.009)	46.79 (1.26)	36.87 (0.51)	3428.42^{**} (238.77)	2470.92 (67.18)
	7.5	0.56^{***} (0.014)	46.99 (1.06)	36.37 (0.53)	3547.85 (196.17)	2706.71 (14.94)
DOT	2.5	0.54 (0.006)	47.02 (1.47)	36.46 (0.33)	3633.91 (317.36)	2522.78 (150.34)
	5	0.54 (0.007)	46.63 (0.62)	36.32 (0.44)	3548.59 (182.05)	2480.02 (138.54)
	7.5	0.55^{***} (0.004)	46.58 (1.28)	35.70 (0.86)	3311.79^{**} (291.68)	2342.46 (83.76)
BA/DOT	2.5	0.53 (0.005)	46.57 (0.24)	36.92 (0.84)	3480.32^{**} (443.86)	2779.19 (173.62)
	5	0.53 (0.012)	47.02 (0.86)	36.54 (0.85)	3506.34 (110.37)	2541.20 (253.40)
	7.5	0.54 (0.008)	45.69 (0.83)	35.54 (0.96)	3226.10^{**} (218.20)	2303.90 (136.48)
ATH	2.5	0.55^{***} (0.027)	48.16 (0.99)	37.52 (0.17)	3850.42 (255.62)	2705.01 (217.82)
	5	0.55^{***} (0.005)	47.12 (1.23)	37.12 (0.54)	3114.60^{**} (208.75)	2537.35 (161.30)

[a] Numbers in parenthesis are standard deviations. Asterisks denote significant difference compared with with untreated controls.
*** $p = 0.001$, ** $p = 0.01$. MOR is modulus of rupture, MOE is modulus of elasticity; parrallel and perp indicate parallel and perpendicular to major axis of panel. $n = 3$ for MOR (perp), $n = 2$ for MOE (perp), and $n = 5$ for density.

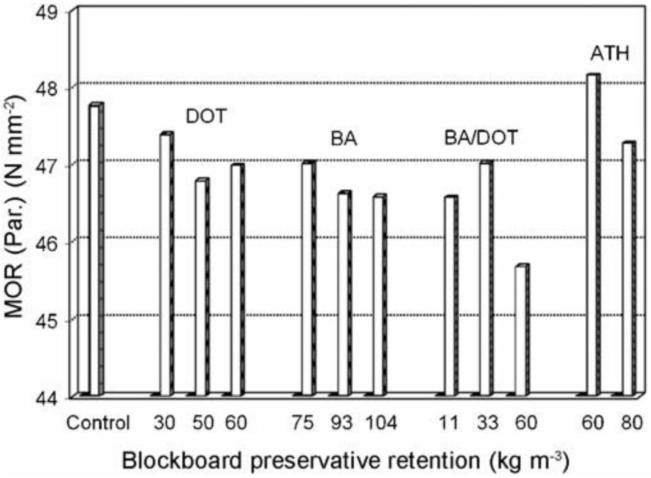

Fig. 3 Parallel-to-plane MOR as function of retardant retention in blockboards
Abb. 3 Biegefestigkeit in Plattenebene in Abhängigkeit der Einbringmenge des Feuerschutzmittels

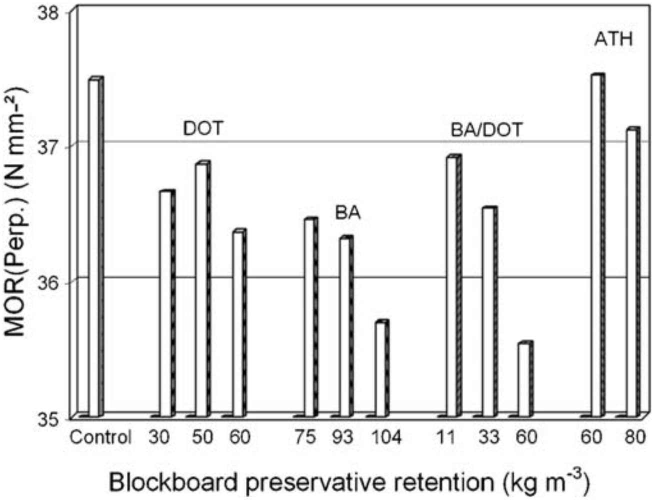

Fig. 4 Perpendicular-to-plane MOR as function of retardant retention in blockboards
Abb. 4 Biegefestigkeit rechtwinklig zur Plattenebene in Abhängigkeit der Einbringmenge des Feuerschutzmittels

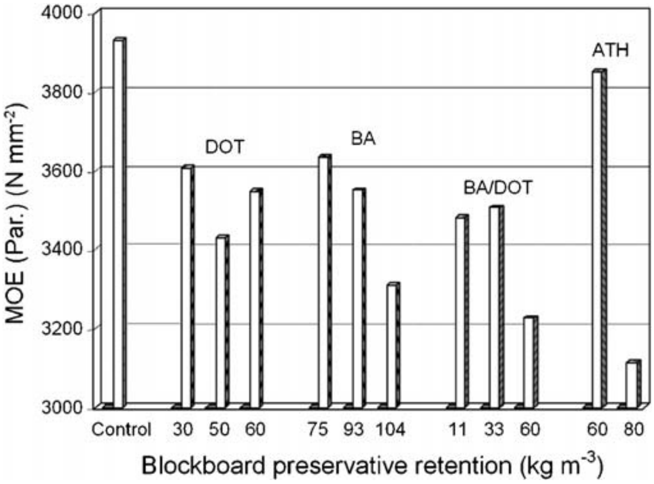

Fig. 5 Parallel-to-plane MOE as function of retardant retention in blockboards
Abb. 5 E-Modul in Plattenebene in Abhängigkeit der Einbringmenge des Feuerschutzmittels

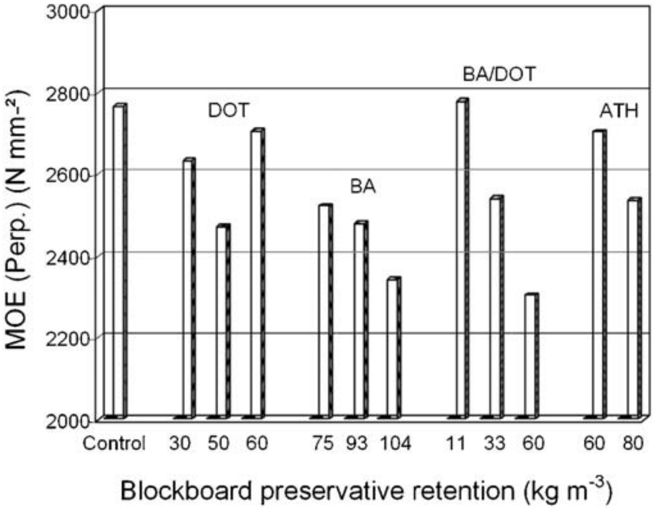

Fig. 6 Perpendicular-to-plane MOE as function of retardant retention in blockboards
Abb. 6 E-Modul rechtwinklig zur Plattenebene in Abhängigkeit der Einbringmenge des Feuerschutzmittels

solution of ATH were better than MOE values of the other treated specimens (Table 3, Fig. 5). MOE values of blockboards treated with 7.5% aqueous solutions of BA and BA/DOT were significantly lower than those of control boards.

3.3 Fire performance

The primary result from the cone calorimeter test is a heat release rate (HRR) curve over the duration of the test. The typical curve for wood is an initial increase to a peak, a drop to a steady state, and then a second peak as the final portion of the specimen is consumed. The typical curve for wood products was observed in these tests. For reporting purposes, the heat release curve is often reduced to single numbers; e.g., the peak HRR values in Table 4. Total heat release is cumulative heat release over the duration of the test (Table 4). The average effective heat of combustion was computed from the total heat release divided by the total mass loss. The average specific extinction area was computed from the smoke obscuration data, and the time for sustained ignition of the test specimen was recorded. Estimates for the ASTM E 84 flame spread were calculated from peak HRR, total heat release, and time for sustained ignition (Table 4, Fig. 7). The procedure is discussed in Dietenberger and White (2001). The equations used to estimate the flame spread index are not sensitive to variations in values greater than 75. Estimates are for the standard test duration of 10 min as specified in ASTM E 84. The results in Table 4 are averages for the two replicates.

Table 4 Average cone calorimeter results
Tabelle 4 Ergebnisse der Kegel-Kalorimetermessung – Mittelwerte

Treatment	Retention (% face veneer wt)	Peak heat release rate[a] (kW/m^2)	Average effective heat of combustion (MJ/kg)	Average specific extinction area (m^2/kg)	Time to sustained ignition (s)	Total heat release (MJ/kg)	Estimated FSI[a]
ATH	2.5	204	12.1	54.8	31.7	104.68	126
	5	180	11.8	55.4	25.5	107.18	86
	7.5	181	11.8	58.1	24.0	93.89	93
BA	2.5	162	11.9	43.3	28.2	98.04	66
	5	162	11.9	43.3	30.4	106.15	64
	7.5	164	11.9	38.9	32.3	104.89	64
BA/DOT	2.5	170	11.8	34.5	32.1	99.72	69
	5	163	12.3	82.6	31.7	99.89	65
	7.5	158	11.8	24.0	31.1	88.48	62
DOT	2.5	162	11.4	47.8	28.8	100.01	65
	5	191	11.3	48.3	31.3	95.07	56
	7.5	143	11.2	42.6	27.6	95.37	56
Control	–	204	12.3	49.7	31.7	100.62	138
Borax/BA[b]	58 kg/m^3	86	6.5	4.3	52	–	25

[a] Calculated using metodology described in Dietenberger and White (2001).

[b] Samples of 38-mm pressure-treated southern pine lumber treated with borax/boric acid White and Dietenberger (2004).

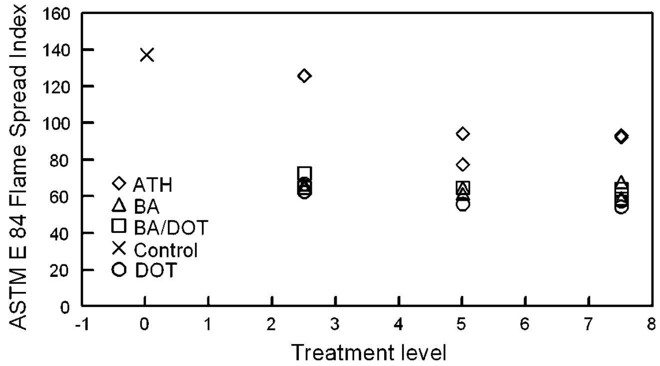

Fig. 7 Estimated ASTM E 84 flame spread index for samples
Abb. 7 Geschätzter Flammenausbreitungsindex nach ASTM E 84

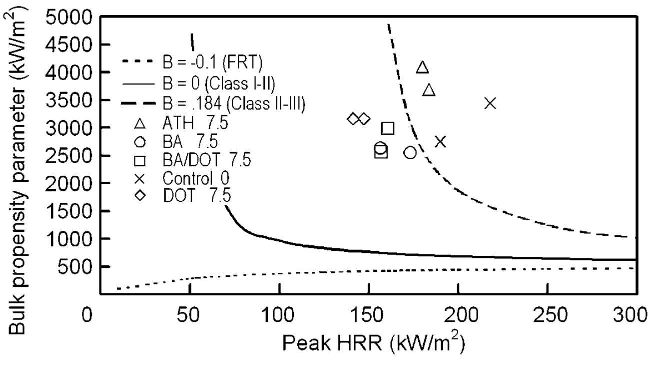

Fig. 8 Fire growth propensity of samples treated to 7.5% retention
Abb. 8 Brandverhalten von Prüfkörpern mit 7,5%-iger Feuerschutzmittelimprägnierung

Although the treated samples performed better than the untreated control samples, the improvements were considerably less than that expected for a fully fire retardant treated wood product. For comparison, results for southern pine treated with borax/boric acid (White and Dietenberger 2004) are included in Table 4. Only the face veneers of the blockboards were treated with the fire retardant chemicals. Figure 8 illustrates the fire growth propensity of the samples based on the model discussed in Dietenberger and White (2001) using the samples treated to 120 kg/m^3. In this model, the surface fire growth propensity is represented by the peak HRR. Some reductions in peak HRR occurred with treatment, as shown in Fig. 8. The bulk propensity parameter was calculated from total HHR, time for sustained ignition of sample, and sample thickness. Consistent with the results for the surface treatments, the results for the bulk propensity parameter of the treated samples were similar to the results for the two control samples (i.e., *y*-axis of Fig. 8). Results for a traditional Class I fire retardant treatment would be to the left of the solid line in Fig. 8 (Dietenberger and White 2001).

4 Conclusions

The face and back veneers of blockboards were treated at a fairly low level with various fire retardants. Mechanical property tests indicated that none of the treatments had a significant negative effect on flexural strength. Flexural stiffness was significantly lower for the highest treatment level and showed a statistically insignificant change for the lowest treatment level. Heat release rate testing indicated significant reductions in the predicted flame spread rate. However, these improvements fell short of the levels required for typical Class I fire retardant treated materials. The improvements were limited by the relatively thin veneer of the dip-treated wood exposed during the fire testing. Considering the small volume of material treated, the improvement in performance warrants further investigation of fire retardant treatment for commercial applications of blockboard. Specifically, more thorough treatment of the veneers could be achieved with pressure treatment and another level of fire performance could be achieved through treatment of the core.

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