New Fire-Protective Intumescent Coatings for Wood

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ABSTRACT: Polyurethane coatings are highly flammable, and because of their widespread applications on different substrates (wood, steel, and building materials), there is a need to increase their fire-safety properties. Intumescent additives sharply suppress the flammability properties of polyurethane coatings. Two problems accompany intumescent additives: their high loading percentage and incompatibility with polyurethane coatings. In this research, we succeeded in increasing the compatibility by mixing intumescent additives with a butyl acrylate polymer and in lowering the flame-retardant additive loading (up to 20%) by incorporating newly modified montmorillonite. The flammability properties of the new intumescent coatings were characterized with a cone calorimeter. © 2008 Wiley Periodicals, Inc. J Appl Polym Sci 110: 83–90, 2008

Key words: coatings; flame retardance; intumescence; polyurethanes

INTRODUCTION

Polyurethane (PU) polymers have been developed into many types and classes of products with widely varying properties that result from the ingredients of the formulations. Foams, either flexible or rigid, are the most common commercial products. Moreover, PUs are also extensively used as resins for lacquers, varnishes, and coatings and as composites in synthetic leather, adhesives, and spandex fibers, and they can be cast, injection-molded, or extruded as elastomers.[1–5] PU-based coatings have recently assumed an important place in the coating industry. In some applications, they dominate the market because of their high level of quality.[6] First, they combine outstanding resistance to solvents and chemicals with good weather stability. Second, the films show excellent mechanical properties and provide the ideal balance of hardness and flexibility, even at low temperatures. Like a majority of synthetics, PU-based coatings are combustible, and this consequently limits their use in buildings or in transport applications. A practical approach to enhancing their fire safety is the incorporation of flame-retardant additives into the PU polymeric matrix.[7,8] The use of intumescent additives allows both the fire-related properties and mechanical behavior of the materials to be optimized. During the heating process, an intumescent flame-retardant agent generates a cellular charred layer on the surface of the material, which protects the underlying material from the action of the heat flux or flame and acts as a physical barrier that limits the diffusion of combustible volatile products toward the flame and limits oxygen toward the polymer. The proposed mechanisms are based on the charred layer acting as a physical barrier, which slows down heat and mass transfer between the gas and condensed phases.[9,10] Recently, Wang et al.[11] synthesized and characterized an intumescent flame-retardant agent and applied it to PU coatings. The aim of this work was to produce new flame-retardant systems and incorporate them into PU coatings to study the fire properties of the resulting coatings and to investigate their ability to form intumescent protective layers on wood surfaces.

EXPERIMENTAL

Materials

Montmorillonite (MMT) K10 powder and divinyl benzene were supplied by Fluka (Gallen, Switzerland). Ferric chloride, butyl acrylate, and benzoyl peroxide (25% water) were supplied by Merck (Darmstadt, Germany). Melamine polyphosphate (MP) was supplied by the Institute of Inorganic Chemistry (Gliwice, Poland) under the trade name Pomel. Monopentaerythritol was supplied by Polifarb (Poland). Dimethylformamide (DMF) was supplied by Chempur (Poland). A PU coating under the trade name Hantzlack (Vianova Resins solvent base) was supplied by A. G. Solutia (Austria).

Preparation of the butyl acrylate polymer

Butyl acrylate monomer (50 mL), 1.5 g of benzoyl peroxide, and 100 mL of DMF were mixed together

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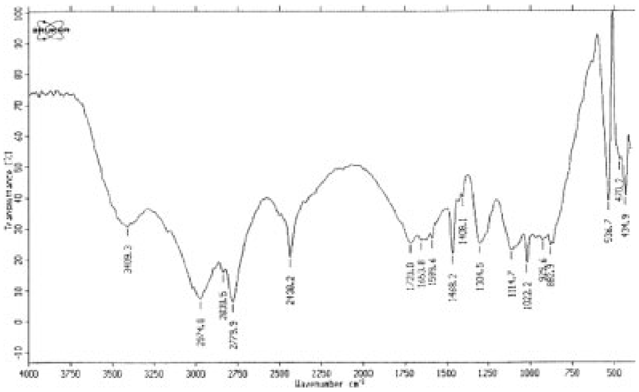


Figure 1 Infrared spectrum of maleate phosphate.

in a round-bottom flask. The mixture was refluxed for 4 h at 105°C. The butyl acrylate polymer was obtained after the evaporation of the DMF solvent.

Preparation of modified MMT

MMT was subjected to ion exchange with ferric chloride according to the reported method.[12] The exchanged MMT was modified with a butyl acrylate polymer, which was prepared in hot DMF with stirring for 4 h according to the method of Hassan et al.[13] The precipitate was filtered and dried.

Preparation of the new flame-retardant system (T1)

Pentaerythritol (5 g), 30 g of polyammonium phosphate, 10 g of melamine, and 5 g of MMT clay were added to 50 mL of a PU coating in a 250-mL beaker. With a high-speed mechanical stirrer, the mixture was stirred well until it became solid. The resultant solid was crushed well until it became a powder.

Preparation and characterization of maleate phosphate

Diethyl maleate (1 mol) was refluxed with 2 mol of orthophosphoric acid for 4 h at 120°C. The resultant product was left to cool and then used as a phosphate source for intumescent additives to PU coatings. The structure of maleate phosphate is shown in the following drawing and was proven by infrared and mass spectra, as shown in Figures 1 and 2:

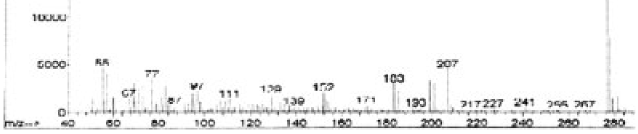
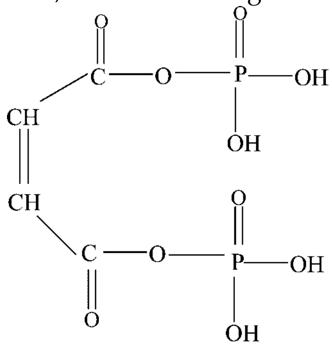


Figure 2 Mass spectrum of maleate phosphate.



Maleate phosphate was investigated with Fourier transform infrared and mass spectrometry. The Fourier transform infrared spectrum of maleate phosphate showed the following peaks:

- 2974 and 2839 cm^{-1} for symmetrical and asymmetrical absorption of the C—H group.
- 1653.8 cm^{-1} for the C=C absorption.
- 3409.3 cm^{-1} for the O—H stretching absorption.
- 1304.5 cm^{-1} for the O=P absorption.
- 1022.2 cm^{-1} for the P—O—C stretching.

The mass fragmentation pattern showed that the base peak was m/e = 277, that is, the molecular weight of maleate phosphate minus one. Also, m/e = 97 was related to the phosphate group.

Both the infrared and mass spectra gave clear evidence for the formation of maleate phosphate.

Preparation of different types of coatings

Wood block samples (10 × 10 cm^2) were coated with two layers (the weight of each layer was 20 g) of 10 coatings according to the compositions listed in

TABLE I
Chemical Compositions of Different PU Coatings

Coating	Chemical composition
WC0	Pure PU
WC1	5% T1 and 95% PU
WC2	10% T1 and 90% PU
WC3	15% T1 and 85% PU
WC4	20% T1 and 80% PU
WC5	20% modified MMT and 80% PU
WC6	One layer of 20% (butyl acrylate polymer (25%)/pentaerythritol (10%)/melamine phosphate (65%)) and 80% PU
WC7	Two layers of 20% (butyl acrylate polymer (25%)/pentaerythritol (10%)/melamine phosphate (65%)) and 80% PU
WC8	5% modified MMT, 15% (butyl acrylate polymer (25%)/pentaerythritol (10%)/melamine phosphate (65%)), and 80% PU
WC9	17% maleate phosphate, 5% urea, and 78% PU
WC10	15% maleate phosphate, 5% pentaerythritol, 5% modified MMT, and 75% PU

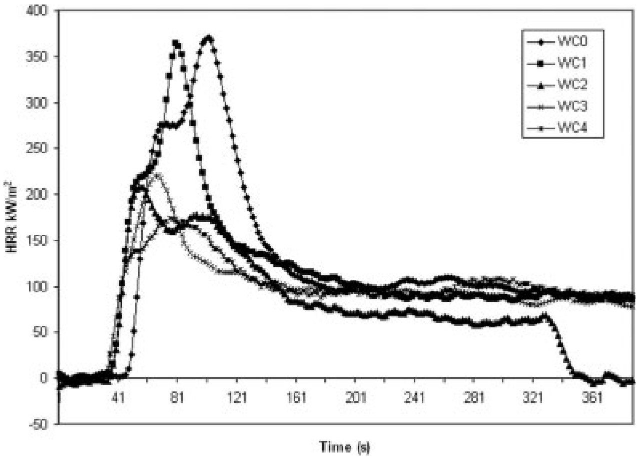


Figure 3 HRR versus time for wood coated with WC0–WC4.

Table I. The quantitative amount of each coating was 0.2 g/cm^2. Butyl acrylate polymer was used as a compatibilizer.

Characterization

The flammability properties of the coated wood samples were characterized with a cone calorimeter. Experiments were performed according to ISO-5660 at a heat flux of 35 kW/m^2 with Cone 2 equipment manufactured by Atlas (Atlas, IL).

RESULTS AND DISCUSSION

Flammability properties

The flammability properties and fire parameters of the coated wood samples were studied with a cone calorimeter. The prepared coatings were divided into three groups according to their compositions. The different flammability properties were determined with computer-aided analysis. These properties are the heat release rate [HRR (kW/m^2)], peak heat release rate [PHRR (kW/m^2)], average heat release rate [AHRR (kW/m^2)], total heat release [THR (MJ/m^2)], average mass loss rate [MLR (g/m^2 s)], average effective heat of combustion [AEHOC (MJ/kg)], average specific extinction area [ASEA (m^2/kg)], average CO yield (kg/kg), average CO$_2$ yield (kg/kg), and total weight loss (g).

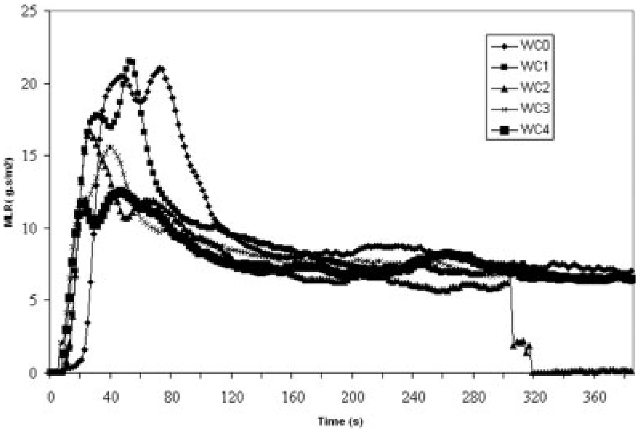


Figure 4 MLR versus time for wood coated with WC0–WC4.

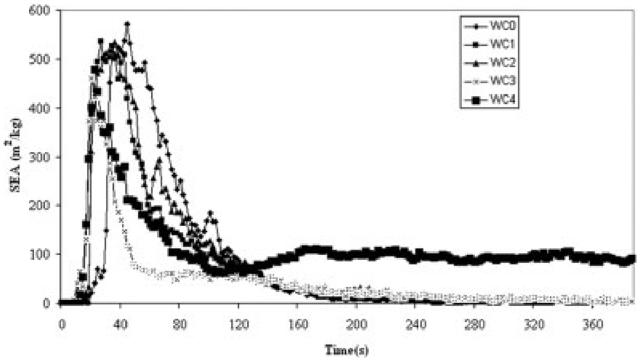


Figure 5 SEA versus time for wood coated with WC0–WC4.

First group of wood coatings

This group was based on PU coatings filled with 5, 10, 15, or 20% of the new flame-retardant system (T1).

The relation of HRR and time for the differently coated wood samples, including a wood sample coated with pure PU, is shown in Figure 3. The MLR and specific extinction area (SEA) versus time are shown in Figures 4 and 5. THR, AEHOC, AHRR, and ASEA for wood samples with different coatings (WC0–WC4) are presented in a bar chart in Figure 6, and the data are tabulated in Table II.

The maximum HRR of the wood sample coated with pure PU (WC0) was 370.95 kW/m^2. The incorporation of 5% of the T1 flame-retardant system into

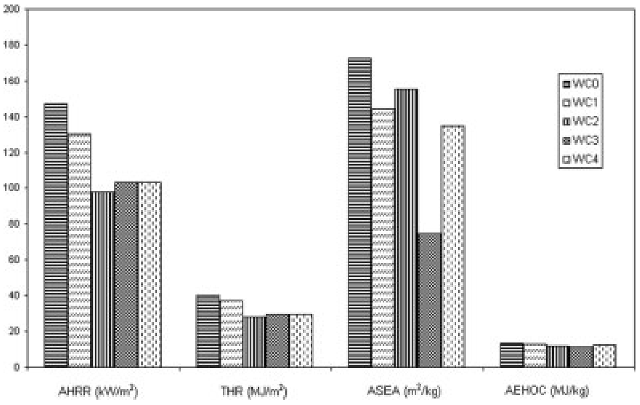


Figure 6 Combustion characteristics of wood protected by coatings WC0–WC4.

TABLE II
Fire Parameters of Wood Coated with WC0–WC4

Coating	PHRR (kW/m^2)	AHRR (kW/m^2)	AHRR after 60 s (kW/m^2)	AHRR after 180 s (kW/m^2)	THR (MJ/m^2)	AEHOC (MJ/kg)	Average MLR (g/m^2 s)	Total weight loss (g)
WC0	370.95	147.23	145.59	170.54	40.07	13.35	11.33	29.97
WC1	363.71	130.49	123.61	153.80	37.06	13.18	10.24	28.13
WC2	207.66	97.84	100.82	116.00	27.83	11.95	8.31	23.20
WC3	219.69	103.13	92.11	109.43	29.76	11.75	8.92	25.23
WC4	174.31	103.08	77.99	107.44	29.68	12.44	8.32	23.87

the PU coating caused a small decrease in the maximum heat released from the wood sample (363.71 kW/m^2). Increasing the loading percentage of T1 in the PU coating to 10% (WC2) reduced the maximum heat release by 44% (207.66 kW/m^2) in comparison with the wood sample with WC0. The wood sample coated with one layer of WC3 (15% T1) showed a maximum HRR of 219.69 kW/m^2, which meant about a 40% decrease in PHRR. A remarkable decrease in the maximum heat release was noticed for the wood sample coated with WC4 (20% T1). The value of the maximum heat release in the case of wood coated with WC4 was 174.31 kW/m^2, which was lower than the maximum heat released from the wood sample coated with WC0 by 53%.

The average heat release of the wood sample coated with pure PU was 147.23 kW/m^2. The wood sample coated with PU loaded with 5% of the T1 flame-retardant system showed lower AHRR (130.49 kW/m^2). The maximum decrease in AHRR (97.84 kW/m^2) was obtained through the coating of the wood samples with PU loaded with 10% T1. There was no big difference between the average heat released from the wood samples coated by WC3 and WC4 (the values were ca. 103 kW/m^2).

The average heat release after ignition times of 1 and 3 min gives us a picture about the situation of the early beginning of the fire process. With the loading percentage of T1 increasing in the PU coating, the average heat released from the wooden sample after 1 and 3 min decreased. The wooden sample coated with WC1 showed average heat release values after 1 and 3 min of 123.61 and 153.80 kW/m^2, respectively, whereas the wood sample coated with WC2 showed values of 100.82 and 116.00 kW/m^2. The wooden samples coated with WC3 and WC4 showed nearly the same average heat release after 3 min, and the values were 109.43 and 107.44 kW/m^2, respectively.

THR is an important fire-safety indicator. Some classification systems of materials are based on the values of THR. The lower the THR value is, the safer the material is. The total heat that evolved from the wood sample coated with pure PU was 40.07 MJ/m^2. The total heat that evolved from the wood sample coated with WC1 was reduced by 7.51% (37.06 MJ/m^2) in comparison with that with the coating WC0. The wood samples coated with WC3 and WC4 had basically the same THR, 29.76 and 29.68, respectively. On the other hand, THR decreased by 31.66% when the wood was coated with the WC2 coating.

The other combustion parameters, the average MLR, AEHOC, and total weight loss, for the wood samples coated by WC1–WC4 were lowered by different percentages in comparison with the sample coated with WC0.

Smoke and toxicity

The ASEA, CO, and CO_2 yield values for wood coated with WC0–WC4 are tabulated in Table III. SEA versus time for the differently coated wood samples is shown in Figure 5.

The new flame-retardant system showed a significant effect in reducing the amount of smoke production from PU coatings. This is clearly shown in a comparison of the SEA values of the wood sample coated with pure PU and that coated with PU loaded with different percentages of the new flame-retardant system T1. ASEA produced from the wood sample coated with WC0 was 172.45 m^2/kg. The lowest decrease in smoke production was achieved with the coating WC3. ASEA of the wood coated with WC3 (15% T1) was 74.46 m^2/kg. This means that SEA was reduced by 56.82% in comparison with that of the wood sample coated with WC0 (100% PU). The smoke produced from the wood samples coated with the coatings WC1, WC2, and WC4 was decreased by values within the range of 10–21% in comparison with the smoke of the wood coated with WC0.

TABLE III
Smoke and Toxicity Parameters for Wood Coated with WC0–WC4

Coating	ASEA (m^2/kg)	Average CO yield (kg/kg)	Average CO_2 yield (kg/kg)
WC0	172.45	0.0143	1.365
WC1	144.31	0.010	1.322
WC2	155.32	0.011	1.276
WC3	74.46	0.002	1.335
WC4	134.72	0.004	1.303

TABLE IV
Fire Parameters of Wood Coated with WC5–WC8

Coating	PHRR (kW/m^2)	AHRR (kW/m^2)	AHRR after 60 s (kW/m^2)	AHRR after 180 s (kW/m^2)	THR (MJ/m^2)	AEHOC (MJ/kg)	Average MLR (g/m^2 s)	Total weight loss (g)
WC5	349.87	140.68	159.26	158.38	39.95	13.97	10.18	28.59
WC6	255.03	99.19	99.19	112.94	28.60	12.04	8.41	23.70
WC7	160.30	63.40	50.46	77.33	18.90	7.39	8.29	23.41
WC8	185.56	53.55	—	—	2.77	4.83	11.49	3.64

One of the main toxic gases to be measured in the smoke is CO. The high values of CO production play an important role in increasing the number of deaths in fire accidents. The CO values measured by the cone calorimeter are expressed as kilograms per kilogram of the burned sample. The average CO yield that evolved from the wood sample coated with pure PU was 0.014 kg/kg. A noticeable decrease in the average CO yield was achieved by the loading of the PU coating with the new flame-retardant system T1. The big decrease in the average CO yield appeared in the case of coatings WC3 and WC4 (0.002 and 0.004 kg/kg). There was no big difference between the average CO released from the wood sample coated with WC1 (0.010 kg/kg) and that coated with WC2 (0.011 kg/kg).

In general, the CO_2 released from the wood samples coated with flame-retardant PU coatings (WC1–WC4) was lower than that released from the wood samples coated with pure PU. The decrease in CO_2 release was not so big and ranged between 3 and 6.5%. The highest decrease in CO_2 was achieved with coating WC2 (1.276 kg/kg). The average CO_2 released from the wood sample coated with WC0 was 1.365 kg/kg.

Second group of wood coatings

This group of PU coatings with new flame-retardant systems was designed to reveal intumescent properties. To better mix the additives with PU and to prevent precipitation of the fire-retardant system, a butyl acrylate polymer was used as new compatibilizer.

PHRR, THR, AEHOC, and other combustion parameters are tabulated in Table IV. HRR versus time for the different wood samples coated with the coatings WC5–WC8 is shown in Figure 7.

The PHRR values of the wood samples coated with WC5–WC8 were lower than that of WC0. The reduction in PHRR was changed from a slight decrease in the case of WC5 (349.87 kW/m^2) to a sharp decrease in the case of WC7 (160.30 kW/m^2). Moreover, the decrease in PHRR (185.56 kW/m^2) shown by WC8 (PU filled with modified MMT together with MP and pentaerythritol) means that the WC8 coating succeeded in forming an intumescent protective layer over the wood sample when it burned. This intumescent protective layer prevented the wood from further combustion, and the flame burned off 55 s after the test was started. This effect was accompanied by zero AHRR after 60 and 180 s. Loading the PU with melamine phosphate and pentaerythritol only (WC7) did not lead to an intumescent protective layer over the wood sample. However, it reduced AHRR after 60 and 180 s to 50.46 and 77.33 kW/m^2, respectively. Two layers of the PU coating filled with melamine phosphate and pentaerythritol (WC7) resulted in good fire resistance in comparison with one layer coatings (WC6). The AHRR values after 60 s for wood samples coated with WC6 and WC7 were 99.18, 5046 kW/m^2,

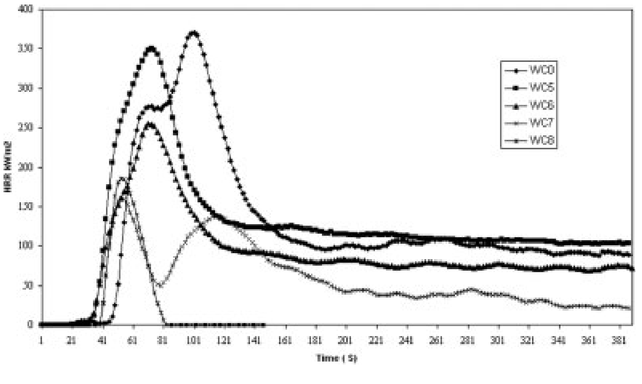


Figure 7 HRR versus time for wood coated with WC0 and WC5–WC8.

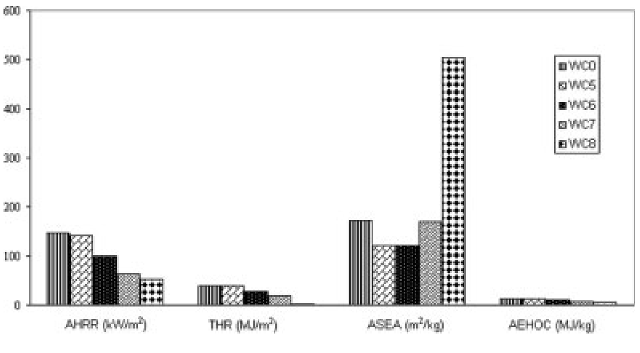


Figure 8 Combustion characteristics of wood protected by coatings WC0 and WC5–WC8.

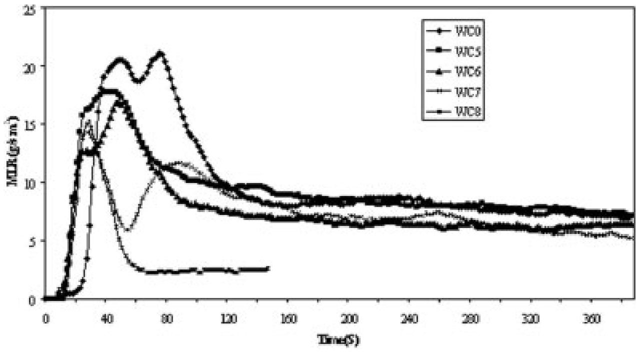


Figure 9 MLR versus time for wood coated with WC0 and WC5–WC8.

respectively. Coating a wood sample with WC5 also resulted in PHRR decreasing in comparison with PHRR of a sample coated with WC0.

A comparison of the AHRR values of the different wood samples coated with coatings WC0 and WC5–WC8 is graphically presented in a bar chart in Figure 8. A remarkable decrease in AHRR can be noticed for all wood samples coated with the second coating system in comparison with the pure PU coating, except for the coating WC5, which showed only a small decrease in AHRR (140.68 kW/m^2). The lowest AHRR value was obtained with the WC8 coating (53.55 kW/m^2). One layer of coating WC6 was not efficient in reducing AHRR like two layers of the same composition (WC7). The AHRR values of the wood samples coated with WC6 and WC7 were 99.19 and 63.40 kW/m^2, respectively.

THR of the second coating system is graphically presented in a bar chart in Figure 8. The THR data give a good indication about the efficiency of the new flame-retardant system in reducing the flammability properties of PU coatings in comparison with PU coatings without any additives. Coating WC8, which formed an intumescent protective layer on the wood after a short period of burning, showed the lowest THR value (2.77 MJ/m^2) of the coatings. The second big decrease in THR was achieved with coating WC7 (52.83%). The incorporation of the modified MMT alone into PU had nearly no effect on THR for the wood sample in comparison with THR for the sample coated with pure PU.

TABLE V
Smoke and Toxicity Parameters for Wood Coated with WC5–WC8 Coatings

Coating	ASEA (m^2/kg)	Average CO yield (kg/kg)	Average CO$_2$ yield (kg/kg)
WC5	121.13	0.005	1.404
WC6	120.27	0.006	1.254
WC7	169.42	0.013	1.314
WC8	503.87	0.072	1.402

A comparison of the AEHOC values of the second PU coating formulations is shown in Figure 8. A remarkable decrease in AEHOC was noticed for the wood sample coated with WC8 (4.83 MJ/kg). Also, coatings WC6 and WC7 caused a decrease in AEHOC of the tested wood samples, and the values were 12.04 and 7.39 MJ/kg, respectively. Coating WC5 showed no effect on the value of AEHOC in comparison with the coating WC0 (13.35 MJ/kg). The wood samples were coated only by two thin layers of PU (WC0), and when subjected to heat (during the cone test), PU burned fast, and then the wood itself started to burn. The contribution of the wood to the burning process was higher than that of PU, and this is the reason that the effective heat of combustion of the wood samples coated by WC0 was near that of the wood itself.

The MLR values versus time are shown in Figure 9. The MLR curves showed the same trend as the HRR curves. The weight-loss results showed that coating WC8 gave the wood sample high thermal stability, and the total weight loss was 3.64 g. The other coatings, WC6 and WC7, gave wood nearly the same thermal stability, and the total weight loss was 23.70 and 23.4 g, respectively. Coating WC5 caused a small increase in the thermal stability of wood samples in comparison with coating WC0.

Smoke production and toxicity

The ASEA values of the second coating group are graphically presented in a bar chart in Figure 8, and the data are tabulated in Table III. Coatings WC5 and WC6 caused a reduction in the smoke production by about 28% with respect to coating WC0. Coating WC7 led to a small decrease in ASEA (169.42 m^2/kg) produced from the wood sample in comparison with coating WC0 (172.45 m^2/kg). The ASEA value of the wood sample coated with WC8

TABLE VI
Fire Parameters of Wood Coated with WC9 and WC10

Coating	PHRR (kW/m^2)	AHRR (kW/m^2)	AHRR after 60 s (kW/m^2)	AHRR after 180 s (kW/m^2)	THR (MJ/m^2)	AEHOC (MJ/kg)	Average MLR (g/m^2 s)	Total weight loss (g)
WC9	179.31	57.59	73.05	71.37	16.74	10.61	5.54	15.72
WC10	267.95	129.62	—	—	7.13	7.72	9.54	3.54

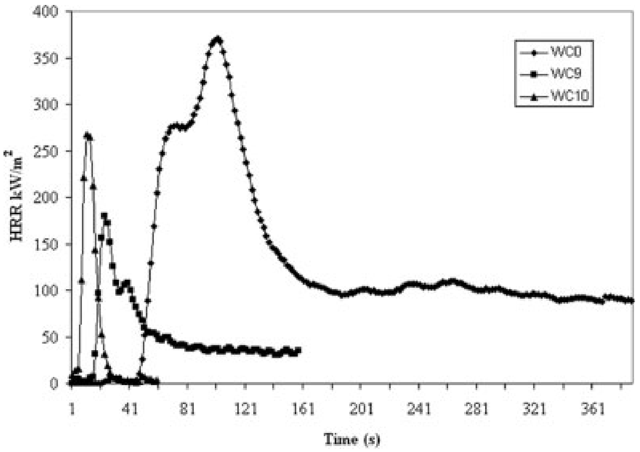


Figure 10 HRR versus time for wood coated with WC0, WC9, and WC10.

was higher than that of the wood sample coated with WC0.

The average CO and CO_2 yield that evolved during the combustion process are tabulated in Table V. A remarkable decrease in the average CO yield can be noticed for the wood samples coated with WC5 (0.005 kg/kg) and WC6 (0.006 kg/kg). Coating WC7 decreased the average CO yield up to 0.013 kg/kg. Coating WC8 increased the CO yield to 0.072 kg/kg.

Coatings WC5 and WC8 caused a small increase in the CO_2 yield of 2.8% in comparison with the average CO_2 yield from the wood sample coated with WC0, whereas coatings WC6 and WC7 decreased the average CO_2 yield by 8.13 and 3.73%, respectively.

Third group of PU coatings

The third group of PU coatings was prepared through the mixing of the newly prepared maleate phosphate as the main component with the PU coatings. Two different coatings were prepared, WC9 and WC10. The different combustion parameters of the third group of PU coatings are tabulated in Table VI. HRR versus time is graphically presented in Figure 10. The incorporation of maleate phosphate together with urea into PU (WC9) resulted in a big reduction in PHRR (46.80%). Not only was the peak heat release reduced, but AHRR after 60 s (73.05 kW/m^2) and after 180 s (71.37 kW/m^2) was also reduced. It clearly appears that HRR until 180 s was too low, and this provided good protection for wood. The second coating (WC10) formed an intumescent layer over the sample and protected it from further combustion, and the flame was totally burned off before 1 min after the start of the test. This can be clearly seen from the values of AHRR after 60 and 180 s, which were equal to zero. The maximum HRR value of the wood sample coated by WC10 was 267.95 kW/m^2.

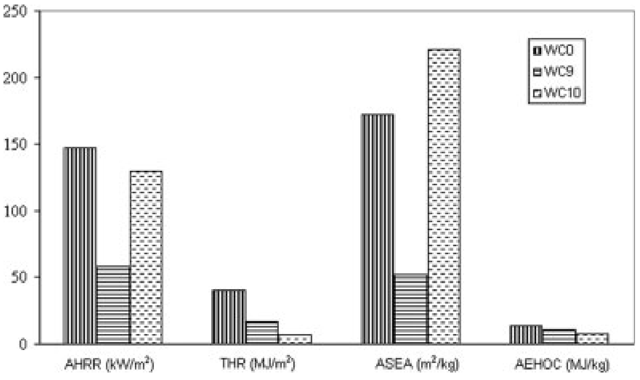


Figure 11 Combustion characteristics of wood protected by coatings WC0, WC9, and WC10.

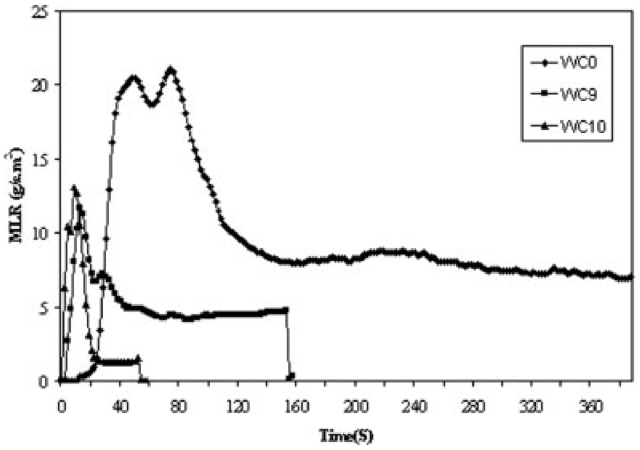


Figure 12 MLR versus time for wood coated with WC0, WC9, and WC10.

AHRR is graphically presented in a bar chart in Figure 11. There was an obvious decrease in the AHRR values of the wood samples coated by WC9 and WC10. AHRR decreased to 57.59 kW/m^2 in the case of the wood sample coated by WC9 and to 129.62 kW/m^2 in the case of the wood sample coated by WC10.

THR from the wood samples coated by WC9 and WC10 in comparison with WC0 is shown in Figure 11. The new coating WC9 showed a better effect in reducing THR from wood. Coating WC9 reduced THR to 16.74 (85.22%), whereas coating WC10 was

TABLE VII
Smoke and Toxicity Parameters for Wood Coated with WC9 and WC10

Coating	ASEA (m^2/kg)	Average CO yield (kg/kg)	Average CO_2 yield (kg/kg)
WC9	51.82	0.006	0.037
WC10	220.89	0.018	1.527

much more efficient in reducing THR to 7.13 MJ/m^2 (82.20%).

MLR, low for coatings WC9 and WC10 in comparison with WC0, is graphically presented in Figure 12. The wood sample coated by WC9 had an average MLR value of 5.54 g/s m^2, which was lower by more than 50% than that of WC0 (11.33 g/s m^2). The average MLR value for the wood sample coated by WC10 was 9.54 g/s m^2.

The wood samples coated with the new coatings WC9 and WC10 had high thermal stability, and this can be seen from the total mass loss values of these samples. The wood sample coated with WC10 had the lowest total weight loss (3.45 g) in comparison with the wood samples coated with the other coating formulations. The total weight lost from the wood sample coated by WC9 was 15.72 g.

AEHOC for the third group of PU coatings is graphically presented in Figure 11. The values of AEHOC for WC9 and WC10 were 10.61 and 7.72, respectively.

The ASEA, CO, and CO_2 yield values are tabulated in Table VII. The ASEA yield is graphically presented in Figure 11. Coating WC9 had the lowest ASEA value among the different coatings of the three groups; it was 51.82 m^2/kg. Coating WC10 increased ASEA to 220.89 m^2/kg.

The average CO and CO_2 yields that evolved from the third coating group are tabulated in Table VII. Coating WC9 showed a significant effect in reducing the CO and CO_2 yields from wood burning, and this meant a reduction in the toxicity. The average CO and CO_2 yields that evolved during the burning of wood samples coated with WC9 were 0.006 and 0.037 kg/kg, respectively. Coating WC10 caused a small increase in the CO and CO_2 yields in comparison with coating WC0.

CONCLUSIONS

- Mixing some commercial flame retardants with PU resulted in a new flame-retardant system for PU coatings. This new system had a good effect in reducing the flammability properties of PU coatings with only 20% loadings.
- The butyl acrylate polymer played an important role as a new compatibilizer for the homogeneous mixing of melamine phosphate and pentaerythritol with PU coatings. Also, the newly modified MMT mixed completely with PU without any phase separation. This new flame-retardant system, added to the PU coatings, gave the coatings high intumescent properties with a low loading percentage (20%). This intumescent property of the PU coatings may be considered a great achievement of the new flame-retardant system.
- The newly prepared flame-retardant system, maleate phosphate and modified MMT, formed together with PU coatings new intumescing coatings for wood.

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