Fire Performance Characteristics of Acetylated Wood

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ABSTRACT

It is required that the materials selected for use must evaluated in flammability tests to estimate it role in the development and survivability of fires. Objective of this investigation was to estimate influence of wood acetylation on the wood action on fire. Conditioned according EN 13238:2002 acetylated and un-treated ash wood parquet boards were tested for reaction to fire on the flooring radiant panel equipment and on the cone calorimeter according EN ISO 9239-1:2002 and ISO 5660-1:2002. It was determined that wood acetylation diminishes its performance on reaction to fire in comparison with non-treated wood. It was assumed that acetylation decreased critical heat flux at extinguishment by acetic acid split-off in pyrolysis conditions. Acetylation decreases smoke production when burning in comparison with natural wood. More intense radiant heat flux in the cone calorimeter decrease smoke production difference between acetylated and untreated wood.

INTRODUCTION

Durability of wood can be improved considerably by acetylation that makes wood more hydrophobic and decreases wood's dimensions changes in changing humidity as well as protects it against biological damage. (Kumar 1994, Hill 2006). In the process of selecting new or alternative materials for applications in the built environment it is necessary to consider the fire performance of the material. Any changes in wood chemistry would change wood reaction to fire. Anyone could suppose that acetyl groups could bee eliminated from acetylated wood as acetic acid in conditions of pyrolysis. Acetic acid is flammable volatile substance that would increase flammability of acetylated wood. However the acetylation increases wood density that will decrease its flammability (White 2002, Njankouo *et al*. 2005). Objective of this investigation was to estimate influence of wood chemical modification with acetic anhydride on the wood reaction to fire using the flooring radiant panel and the cone calorimeter hardwares.

EXPERIMENTAL

Oven-dried till constant mass ash wood (*Fraxinus excelsior*, L.) parquet boards (200 mm x 40 mm x 15 mm) were impregnated in vacuum with acetic anhydride and acetylated for 6 hours at 390 – 393 K then dried at 376±1 K for 50 days to evacuate residual acetic acid. Reference parquet boards were stored at 376±1 K for the same period of thermal impact as for acetylated ones.

The specimens for reaction to fire (1050 mm long and 230 mm wide for the flooring radiant panel) and (100 mm x 100 mm for the cone calorimeter) tests were mounted from acetylated and reference boards conditioned at 296 K and relative humidity 50 percents according EN 13238:2002. The heat flux of the radiant panel was set according EN ISO 9239-1:2002 (Figure 1). Heat flux of cone heater was 50 kW m^{-2}. Cone calorimeter tests were realized only till flame extinguishment in contradistinction to ISO 5660-1:2002 to reduce the influence of smoldering combustion on test results. Calculations were performed using the Flooring Radiant Panel and the Cone Calorimeter software.

RESULTS AND DISCUSSION

Wood will burn when exposed to heat and air. The chemical composition changes caused by substitution of hydrogen atoms of hydroxyl groups in wood with acetyl groups during acetylation would change physical properties of wood and as consequence its fire performance. The acetyloxy group in acetylated wood is the better leaving group than the hydroxyl group in an un-modified wood. Increased amounts of flammable acetic acid would reduce acetylated wood flammability during pyrolysis in fires. Acetylated and un-modified specimens were tested in the flooring radiant panel and in the cone calorimeter hardware. The placement of the radiant panel is such that the radiant heat being imposed on the surface has a gradient in intensity down the length of the horizontal specimen (Figure 1).

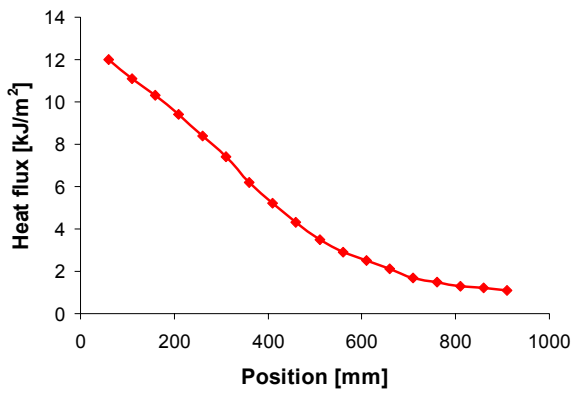

Figure 1: Radiant panel heat flux profile

Flames spread from the piloted ignition source at the end of high heat flux to the other end until they reach a location where the heat flux is not sufficient for further propagation. The impact of wood acetylation was evaluated as ratio of difference between values of indicators of acetylated and reference wood according (Eqn. 1) with the sign of the calculated impact determination in accordance with the indicator effect on fire performance.

$$I = \frac{\left(P_{acet} - P_{ref}\right)}{P_{ref}} \cdot 100 \qquad (1)$$

The results of calculation of indicators as well as modification impacts in flooring radiant panel tests are presented in the Table 1 and in cone calorimeter in the Table 2.

Table 1: Results of flooring radiant panel tests

Indicator	**Reference ash wood**	**±**	**Acetylated ash wood**	**±**	**Impact [%]**
Density [kg.m^{-3}]	607	62	700	32	15%
Time to ignition [s]	147	5	139	5	6%
Time to flame out [s]	1185	533	1675	121	-41%
Extent of burning [mm]	437	82	600	48	-37%
Critical heat flux at extinguishment [kW.m^{-2}]	4,8	1,4	2,6		47%
Total integrated smoke [%.min]	10,38	4,41	6,65	4,69	36%
Potential classification	C/D(f1)		E(f1)		negative
Smoke production classification	s1		s1		neutral

Acetylation of ash wood increased flame phase duration, flame spread but decreased critical heat flux at extinguishment. Changes in all these parameters had negative effect on fire performance of modified wood that decreased its potential classification.

Table 2: Results of cone calorimeter tests

Parameter	Reference ash wood	±	Acetylated ash wood	±	Impact
Time to ignition [s]	17	2	19	2	-8%
Time to flame out [s]	476	9	613	11	-29%
Total heat release in 0-300 s [MJ m^{-2}]	55	6	52	5	6%
Fuel load [MJ kg^{-1}]	9	1,1	10	0	-7%
Total smoke release [m^2 m^{-2}]	337	58	274	25	19%
Effective heat of combustion [MJ kg-1]	11	0,8	12	0,2	-6%
Mass loss rate [g s^{-1}]	0,14	0,01	0,13	0,02	10%
Specific extinction area [m^2 kg^{-1}]	46	4	31	4	32%
Carbon monoxide yield [kg kg^{-1}]	0,0035	0,0006	0,0033	0,0011	6%
Carbon dioxide yield [kg kg-1]	1,34	0,03	1,40	0,03	-4%
Mass loss rate in non-flaming phase [g s-1]	0,126	0,006	0,010	0,226	92%
Heat release rate [kW m^{-2}]	162	25	156	19	4%
Effective heat of combustion [MJ kg^{-1}]	11	0,8	12	0,2	-6%
Total smoke release: non-flaming phase [m^2 m^{-2}]	1,2	0,9	1,4	0,4	-17%
Total smoke release: flaming phase [m^2 m^{-2}]	337	58	274	25	19%

The total smoke production was decreased by 36±7 % for acetylated specimens in comparison with un-treated wood in the radiant panel tests and by only by 19±6 % in the cone calorimeter tests due to the more intense radiant heat flux. It could be supposed that acetic acid formed in the wood pyrolysis improves volatile products burning to carbon dioxide (Richter and Howard 2000, Babrauskas 2003, Hull and Paul 2007).
We found good positive correlation between acetylated ash wood density and mass loss rate in cone calorimeter tests but the same correlation for the untreated wood was poor. It is accepted that the more dense wood has higher pyrolysis rate (White 2002, Njankouo *et al*. 2005). (Lingens *et al*. 2005) didn't found the such coherence. Statistically significant correlation wasn't found between degree mass gain by acetylation and modified wood's fire performance that could be explained by heterogenic acetyl group distribution.

CONCLUSIONS

Wood acetylation decreases the wood fire performance and the appropriate modified wood fire safety class. Wood modification with acetic anhydride decreases smoke production when burning in comparison with natural wood. Such impact is less pronounced in the conditions of more intense radiant heat flux that indicates on the degradation process and exact products of thermal degradation dependence upon the rate of heating as well as the temperatures.

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