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SOME TECHNOLOGICAL PROPERTIES OF PLYWOOD AFTER FIRE RETARDANT TREATMENT IN DIFFERENT CONCENTRATIONS

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Abstract:
The treatment with fire retardant chemicals is the most effective process to protect wood and wood based products from fire. Therefore, use of fire retardant chemicals has been increased. However, the fire retardant chemicals have an effect on other physical, mechanical and some technological properties of the materials treated with them. In this study the effect of various fire retardant chemicals in different concentrations on the technological properties of plywood were examined. Poplar (Populus deltoides) and scots pine (Pinus sylvestris L.) were used as wood species; zinc borate, monoammonium phosphate (MAP) and ammonium sulfate were used as fire retardant chemicals and UF resin was used as adhesive. The veneer sheets were treated by immersion and three different concentrations, such as 5%, 7% and 10% aqueous solutions were selected. Mechanical properties of plywood panels, such as the shear strength, bending strength and the modulus of elasticity were determined according to EN 314-1, EN 310, respectively. The surface roughness of the veneer sheets was determined according to DIN 4768 standard. As a result of this study, it was found that all the mechanical strength values of panels produced by using the veneers treated with fire retardant chemicals were lower than those of control panels. With the increasing of the solution concentration their values decreased while the surface roughness values increased.

Key words: *concentration; fire retardant; plywood; surface roughness; technological properties.*

INTRODUCTION

Wood and wood based panels have been used for long as materials in the construction industry because they have a great durability, high strength and versatility (Stevens *et al.* 2006). Plywood, as a wood based product, is one of the most important material used for construction and furniture (Fateh *et al.* 2013a). Plywood has some advantages when compared to solid wood and other wood panels.Plywood presents better physical properties than other wood panels. Bending strength and screw holding capacity of plywood are very high. The product is resistant to deformation disorders such as distortion or twisting. Since plywood has a homogeneous structure, its shrinkage and swelling are much more lower than those of solid wood (Colakoglu 2004). There are some unfavorable characteristics of the plywood which are similar to wood and other wood-based composite panels.

Plywood can be easily combusted and that is one of its undesired characteristics (Ozkaya *et al*. 2007). The flammability and combustibility properties of such solid material can be reduced by applying several treatments (Fateh *et al*. 2013b). The treatment with fire retardant chemicals is the most effective process to protect wood and wood based products from fire. The use of the fire retardant chemicals has been increased and therefore the standard requirements of flame retardants have been raised accordingly. The fire retardant chemicals are harmless to human, animals and plants, there is also a less release of smoke and less toxis gases when burned and these are important parameters for consumers to select one of such products. It was also shown the fire retardant chemicals influence the physical, mechanical and some technological properties of the materials treated with them. Inorganic based fire retardant chemicals are extensively used in forest industry because they have both good thermal stability, less release of smoke, corrosive toxic gases and less strength loss (He *et al*. 2014, Yao *et al*. 2012).

Surface roughness of veneers plays an important role in plywood manufacture. Cross grain, annual ring width, rays, knots, reaction wood, ratio of early wood and late wood, pre-treatment and peeling conditions, such as the knife angle, are some of the raw material and production parameters influencing the roughness of veneer. To control the veneer surface in plywood production is essential to maintain the plywood quality (Ayrilmis *et al.* 2006).

OBJECTIVE

In this study the effect of various fire retardant chemicals in different concentrations on the technological properties of plywood were examined. For this purpose the mechanical properties and surface roughness of the veneers were determined.

MATERIALS AND METHODS

Materials

In this experimental study, 2mm - thick rotary cut veneers with the dimensions of 500mm by 500mm were obtained from poplar (*Populus deltoides*) and Scots pine (*Pinus sylvestris* L.) logs. While the poplar veneers were manufactured from freshly cut logs, Scots pine logs were steamed for 12h before veneer production. The horizontal opening between knife and nosebar was 85% of the veneer thickness, and the vertical opening was of about 0.5mm in the rotary cutting process. The veneers were then dried to 6–8% moisture content with a veneer dryer. After drying, veneer sheets were treated with some fire retardant chemicals. For this aim, 5, 7 and 10% aqueous solutions of zinc borate, monoammonium phosphate (MAP) and ammonium sulfate were used. The veneers were subjected to re-drying process at 110°C after their immersion in fire retardant solutions for 20min. The retention level for each chemical treatment was calculated by using the following equation (Eq.1). The results are presented in Table 1.

Table 1

Retention levels of fire retardant chemicals

Wood Species	**Fire Retardant Chemicals**	**Aqueous Solutions (%)**	**Retention Levels (kg/m^3)**
Poplar	Zinc Borate	5	17.118
		7	20.854
		10	30.243
	MAP	5	11.233
		7	14.219
		10	19.514
	Ammonium Sulfate	5	9.705
		7	11.594
		10	14.660
Scots pine	Zinc Borate	5	13.800
		7	19.915
		10	26.420
	MAP	5	12.689
		7	18.033
		10	23.402
	Ammonium Sulfate	5	11.578
		7	17.553
		10	24.993

$$R = \frac{G \times C}{V} \times 10 \quad (kg/m^3) \qquad (1)$$

where:

R - Retention level (kg/m^3);
G - treatment solution absorbed by the sample (g);
C - preservative or preservative solution in 100 g treatment solution (%);
V - volume of sample in cm^3.

Plywood Manufacture

Three-ply-plywood panels having 6mm thickness were manufactured by using urea formaldehyde resin. The formulations of adhesive mixture used for plywood manufacturing are given in Table 2. Veneer sheets were conditioned to approximately 5–7% moisture content in a climatization chamber before gluing. The glue mixture was applied at a rate of 160g/m^2 to the single surface of veneer by using a four-roller glue spreader. Hot press pressure was 8kg/cm^2 for poplar and scots pine while the hot pressing time and temperature were of about 6min and 110ºC, respectively. Two replicate panels were manufactured for each test groups.

Table 2

The formulations of UF glue mixture used for the manufacturing of plywood

Glue Type	Ingredients of Glue Mixture	Parts by weight
UF	UF resin (with 55% solid content)	100
	Wheat flour	30
	Hardener - NH_4Cl (with 15% concentration)	10

Methods

The shear strength of plywood panels was determined according to EN 314-1 (2014) with a universal testing machine. Samples prepared for shear strength were tested after being soaked in water at 20ºC for 24 h. Twenty-five specimens were used for the evaluation of shear strength tests.

The bending strength and modulus of elasticity of plywood panels were determined according to EN 310 (1993) with a universal testing machine. Sixteen specimens were used for the evaluation.

A fine stylus-type profilometer, Mitutoyo Surftest SJ-301 Surface Roughness Tester was used for the surface roughness test (Fig.1). This device consists of a main unit and a pickup. The pickup has a skid-type diamond stylus with a radius of 5µm and a tip angle of 90º. A cut off length of 2.5mm was used and one roughness measurement was performed perpedicular to the grain over the tracing length of 12.5mm on each veneer sheet. Twenty replicates of veneer samples for each group were used for surface roughness measurement. The veneer samples cut at the dimensions of 50×50×2mm were used for each test group to evaluate their surface roughness. The Rz roughness parameter (mean of the 10-point height of irregularities) was used to evaluate surface roughness of the samples according to DIN 4768.

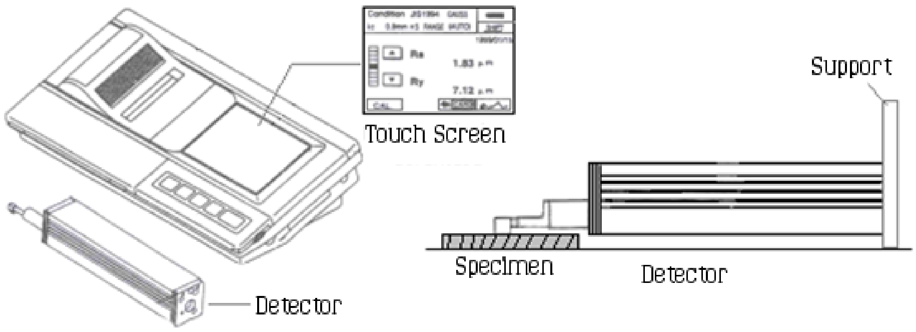

Fig. 1.
Mitutoyo Surfest SJ-301 surface roughness meter.

RESULTS AND DISCUSSION

The effect of zinc borate, MAP and ammonium sulfate on the technological properties of plywood produced from poplar and scots pine veneers is shown in Table 3 and Fig. 2.

Table 3

The mean values of technological properties of plywood treated fire retardant chemicals

Wood Species	Fire Retardant Chemicals	Aqueous Solutions (%)	Shear Strength (N/mm^2)		Bending Strength (N/mm^2)		Modulus of Elasticity (N/mm^2)		Surface Roughness (µm)	
			X	SD	X	SD	X	SD	X	SD
Poplar	Control	-	1.561	0.16	74.87	7.22	5220	367	78.1	9.8
	Zinc Borate	5	1.421	0.15	70.87	3.42	4891	306	84.3	4.4
		7	1.370	0.25	64.04	3.90	4516	270	93.9	9.6
		10	1.235	0.30	60.71	6.08	4368	307	111.3	9.1
	MAP	5	1.270	0.15	71.84	5.42	4969	380	80.2	9.7
		7	1.231	0.12	71.31	3.08	4948	226	88.8	9.4
		10	1.168	0.13	67.98	7.71	4703	384	104.2	13.4

	Ammonium Sulfate	5	1.256	0.26	66.15	4.24	4610	247	85.8	8.9
		7	1.186	0.24	61.67	7.02	4596	398	88.2	9.3
		10	1.170	0.13	60.18	6.49	4584	299	89.2	8.5
Scots pine	Control	-	1.115	0.11	70.04	5.74	5258	239	62.9	9.6
	Zinc Borate	5	1.070	0.20	64.86	15.22	4840	426	72.8	9.8
		7	1.032	0.17	63.68	4.68	4820	410	79.8	7.0
		10	0.962	0.17	58.23	6.31	4267	394	83.9	7.1
	MAP	5	0.833	0.07	64.96	10.75	4654	605	72.8	4.6
		7	0.798	0.09	64.30	5.44	4757	262	73.3	5
		10	0.793	0.09	56.76	5.65	3956	405	74.4	9.1
	Ammonium Sulfate	5	0.876	0.16	61.63	5.55	4856	439	72.2	9.5
		7	0.759	0.19	62.48	2.32	4857	577	80.0	7.7
		10	0.734	0.10	59.47	7.06	4716	383	82.7	7.5

where: X represent the mean values and SD is the standard deviation

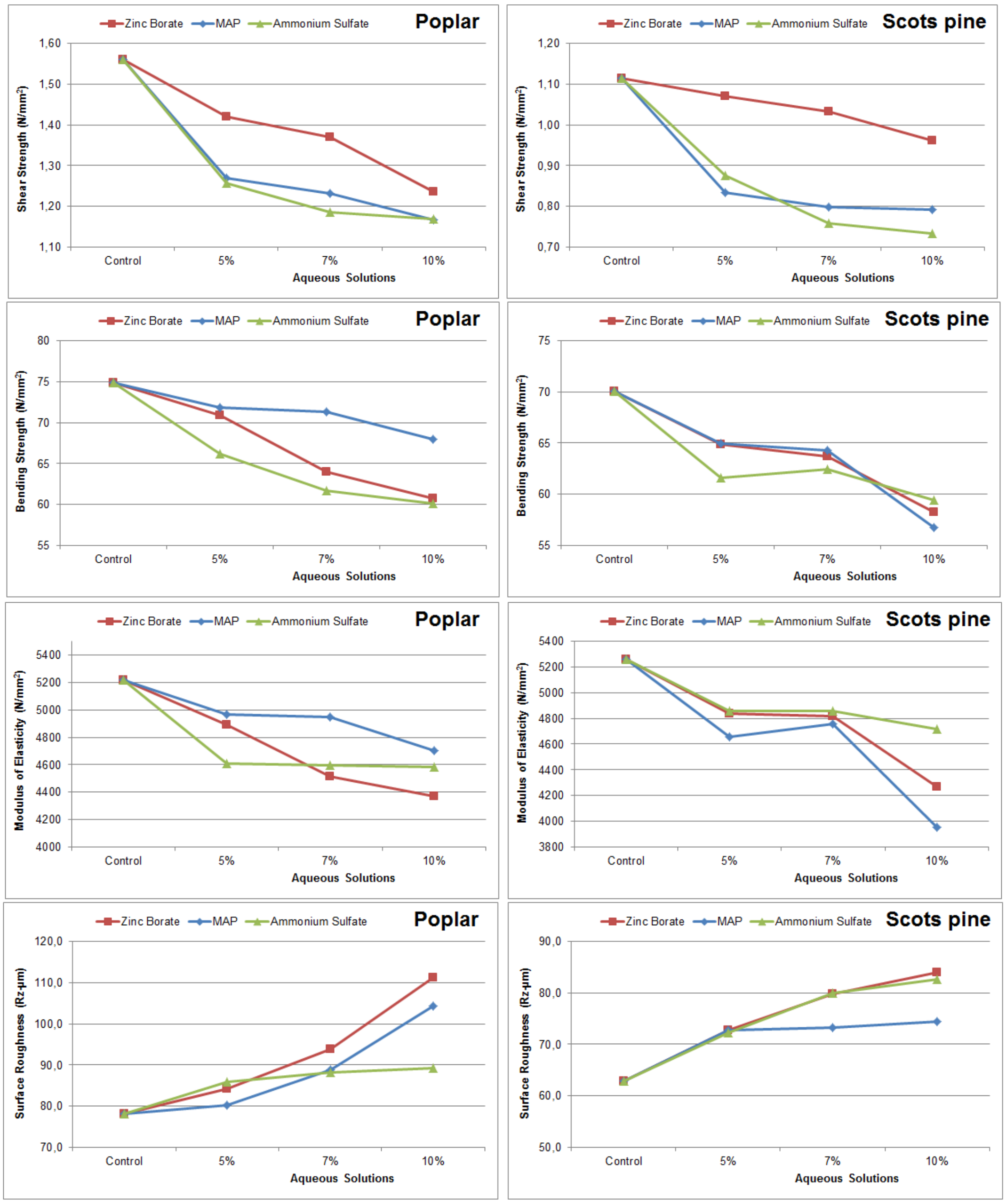

Fig. 2.
Effect of fire retardant chemicals in different concentrations on technological properties of plywood.

The results listed in Table 3 show that the shear strength values recorded for the fire retardant-treated plywood panels were lower than those of untreated control panels. The shear strength values decreased with the increasing of the solution concentration. In spite of that drawback on the shear strength, the shear strength of the fire retardant-treated Poplar and Scots pine plywood panels still met the standard requirements (DIN 68705-3). However, most of the shear strength values of Scots pine plywood panels were less than 1N/mm^2 determined according to DIN 68705-3 (2003). In the specialty literature it was stated that the reasons for the reduction in shear strength of the fire-retardant plywood could be related to the fire retardant acidity influencing the strength of the veneers. There is a poor compatibility between the fire retardant and the UF adhesive, which is accelerated by the fire retardant. Such fact could theoretically prevent a direct and effective contact between the veneer and the UF adhesive, and hence could affect the adhesive penetration into the veneer (Cheng and Wang 2011).

The second drying process performed after the impregnation may also contribute to the decrease in shear strength. Aydin (2004) indicated that the impregnation material layer, in the form of crystals remaining on the veneer surface after drying, adversely affected the wettability with glue and as a result, the shear strength values decreased.

The results listed in Table 3 show that the bending strength and modulus of elasticity values of the fire retardant-treated plywood panels were lower than those of untreated control panels. The bending strength and modulus of elasticity values decreased with the increasing of the solution concentration. In spite of this drawback on the bending strength and modulus of elasticity, their values obtained for the fire retardant-treated plywood panels still met the standard requirements.

Similar results were found in the specialty literature. The fire retardant chemicals caused reduction of bending strength and modulus of elasticity (Colakoglu *et al.* 2003, Aytaskin 2009, Winandy 1995, Gerhards 1970).

According to Table 3, the fire retardant chemicals increased the surface roughness of the veneer sheets when compared to the control groups. The surface roughness was influenced by the increased concentrations of fire retardants. The highest values of the surface roughness were found for poplar and scots pine panels treated with zinc borate. Ayrilmis *et al*. (2006) reported that the fire retardant chemical concentrations increased the surface roughness of the veneer sheets. Dundar *et al*. (2008) also found that the surface roughness of LVLs made from fire-retardant treated veneers was significantly increased when compared to untreated control specimens. Such difference was found to increase with the increasing of the drying temperature. The second drying process performed after the impregnation may also contribute to the increase in the surface roughness. Aydin (2004) indicated that the effects of fire retardant chemicals on the surface roughness varied according to the steaming pre-treatment and the veneer drying temperature.

Among the fire retardant chemicals, zinc borate generally caused less decrease of the shear strength for all wood species when compared to other chemicals. MAP generally caused less decrease of the bending strength and modulus of elasticity. However, the lowest decrease for the modulus of elasticity values of Scots pine panels was obtain when using ammonium sulfate as a fire retardant. Moreover, the highest values of the surface roughness were found for poplar and scots pine samples treated with zinc borate.

CONCLUSIONS

This study indicated that all the mechanical strength values of panels made of veneers treated with fire retardant chemicals were lower than those of control panels. Overall, with the increase of the solution concentration the mechanical strength values decreased while the surface roughness values increased.

As a result, the technological properties of the panels can be adversely affected by increased concentrations. Therefore, the chemical concentration should be carefully adjusted to provide sufficient fire retardant chemicals for the treated plywood, but also providing minimal negative effects on its mechanical strength values. The surface roughness of veneer sheets is extremely important for the product quality. It can significantly affect the wettability of the surface, the quality of gluing, and the adhesion in plywood manufacture. Therefore, the effect of fire retardant chemicals on the surface roughness should be considered during manufacturing. Further studies are to be performed with a view to evaluate more than three concentrations of chemicals, to gain a better understanding of the effect of such treatment variables on the technological properties of the panels.

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