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2 **MECHANICAL AND FIRE PROPERTIES OF ORIENTAL BEECH IMPREGNATED**
3 **WITH FIRE-RETARDANTS AND COATED WITH POLYUREA/POLYURETHANE**
4 **HYBRID AND EPOXY RESINS**

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21
22 **ABSTRACT**

23 This study was performed to investigate some mechanical properties such as modulus
24 of rupture and compression strength parallel to grain and some fire properties such as weight
25 loss and temperature values of Oriental beech (*Fagus orientalis*) treated with fire-retardants
26 and coated with polyurethane/polyurea hybrid resin and epoxy resin were investigated. The
27 coatings are based on epoxy and polyurethane/polyurea hybrid resins. Firstly, an impregnation
28 method was applied by using fire-retardants which are boron chemicals and ammonium sulfate
29 before coating process. Oriental beech was impregnated with 3 % aqueous solution of boric
30 acid, borax, boric acid and borax mixture (1:1), and ammonium sulfate. Oriental beech was
31 primed with epoxy resin by using Sikafloor[®]-156, and then coated with Sikalastic[®]-851, a
32 polyurethane/polyurea hybrid resin. Results showed that modulus of rupture and compression
33 strength parallel to grain values of polyurethane/polyurea and epoxy resin coated Oriental beech
34 wood were higher than that of un-treated and non-coated (control) group. Fire-retardants
35 treatment before polyurethane/polyurea and epoxy resin coatings caused to decrease modulus
36 of rupture and compression strength parallel to grain values of Oriental beech in some extent.
37 Weight loss and temperature values of polyurethane/polyurea and epoxy resin coated Oriental
38 beech were higher than that of un-treated and non-coated (control) group. However, fire-
39 retardants treatment before polyurethane/polyurea and epoxy resin coatings improved fire
40 properties of Oriental beech wood.

41
42 **Keywords:** Boron compounds, epoxy resin, fire retardats, Oriental beech, polyurethane resin.
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44

45

INTRODUCTION

46 Since wood consists of organic based materials containing carbon and hydrogen, is
47 flammable. The temperature for wood must be increased to 275 °C for it to burn itself. However,
48 in the presence of any ignition flame source, it can ignite at much lower temperatures. In the
49 absence of oxygen, heat source, and combustible material, there is no ignition (Kollman and
50 Cote 1968). Although it has superior aspects compared to most structural materials during fire,
51 treatment with impregnation materials that increase resistance to fire is necessary in terms of
52 ensuring safety and preventing burning (LeVan and Winandy 1990, Yalınkılıç *et al.* 1996).

53 The most commonly used fire-retardant chemicals in the wood industry are inorganic
54 salts and include ammonium and ammonium phosphate, ammonium chloride, ammonium
55 sulfate, borax, boric acid, phosphoric acid, and zinc chloride (Woo and Schniewind 1987).
56 These fire-retardant chemicals drastically reduce the rate of flame spread across the wood
57 surface, thereby reducing the capacity of the wood to contribute to a fire (LeVan and Tran 1990,
58 LeVan and Winandy 1990).

59 The fire retardant effectiveness of boron compounds is a physical mechanism achieved
60 by the formation of a coating or protective layer on the wood surface at high temperature, and
61 by forming glassy films that may inhibit mass transfer of combustible gases (LeVan and Tran
62 1990; Wang *et al.* 2004). Boric acid and borax are the most common boron compounds which
63 have found many application areas in the wood preservation industry in order to get the benefit
64 of their biological effectiveness and fire retardancy. Borax tends to reduce flame spread but can
65 promote smoldering or glowing. On the other hand, boric acid suppresses smoldering but has
66 little effect on flame spread (LeVan and Tran 1990).

67 Many of the effective chemicals, which are used for wood protection, are questionable
68 because they are poisonous chemicals. Boron compounds have become up-to-date due to their
69 high activity against biological pests, their ability to be easily applied by dissolving with water,

70 their diffusion ability to wood, being cheap and easy to supply, negligibly low toxicity effects
71 against mammals, and significantly increase the resistance of wood against burning (Thevenon
72 *et al.* 1997, Williams 1980, Arthur and Quill 1992). However, their use has been limited only
73 indoors as they are easily washed from wood due to rain (Yalınkılıç 2000, Hafızoğlu *et al.*
74 1994). Yalınkılıç *et al.* (1998) investigated fire properties of *Cryptomeria japonica* wood
75 impregnated with boric acid prior to vinyl monomers treatment. Styren and methylmethacrylate
76 were used as vinyl monomers. They found that wood samples pre-impregnated with boric acid
77 generated remarkably lesser smoke, and bad smell almost disappeared during burning in
78 comparison to wood treated with monomer only. Baysal (1994) reported that weight loss of
79 Calabrian pine wood borate pre-impregnated and then water repellent chemicals treatment were
80 lower than un-impregnated and only water repellent chemicals treated wood after fire test.
81 Yalınkılıç *et al.* (1996) determined that Douglas wood treated with a boric acid (BA) + borax
82 (BX) mixture (7: 3; weight: weight) had higher fire retardant properties than wood treated with
83 BA or BX. Yalınkılıç (2000) investigated BA, BX and their mixtures (BA+BX, 5: 1, w/w) were
84 added to a urea formaldehyde adhesive during chipboard production from waste tea leaves. The
85 fire test results showed that BA shortened the flash time while BX extended it, and the mixture
86 of these borates increased the overall fire retardant effectiveness. Baysal *et al.* (2007)
87 investigated weight loss of Scots pine impregnated with BA and BX mixture (5: 1;w/w) before
88 vinyl monomers such as styrene, methylmethacrylate, and their mixture (50: 50;
89 volume:volume) after fire test. They found that monomer treatment caused higher weight loss
90 when compared to untreated wood. However, BA and BX mixture pre-impregnation caused to
91 reduce mass loss of wood. Moreover, weight loss of BA and BX mixture impregnated and
92 styrene coated wood were lower than those of monomer only treated wood clarifying the
93 protective effect of boron in combustion.

94 Baysal (2002) studied fire retardancy of Scots pine wood impregnated with
95 melamine formaldehyde (MF) and boron combinations. Oxygen index (OI), thermal gravimetric
96 analysis (TGA), and differential thermal analysis (DTA) of Scots pine were investigated as fire
97 tests. Results showed that Almost all MF–boron combinations reduced the decomposition
98 temperature to lower levels than untreated wood and limited the exothermic reactions. GA
99 residues increased linearly with the amount of boron addition.

100 Wood strength is affected when wood is treated with preservatives or fire retardant
101 chemicals (Winandy *et al.* 1988). The relative impact of various waterborne preservative
102 systems is directly related to the system's chemistry and the severity of its fixation/precipitation
103 reaction. Şimşek *et al.* (2013) investigated some mechanical properties such as compression
104 strength parallel to grain (CSPG), modulus of rupture (MOR), and modulus of elasticity (MOE)
105 of wood treated with some borates preservatives. Their results showed that CSPG, MOR, and
106 MOE of wood specimens treated with chemicals were lower than that of untreated control
107 specimens. Preservative treatments caused the most decrease in MOR followed by CSPG and
108 MOE of both wood specimens, respectively. Winandy *et al.* (1988) noted that the effects of fire
109 retardant treatments on mechanical properties of Douglas-fir and aspen plywood. They found
110 that FR treatment did not affect modulus of elasticity (MOE) of both species, whereas it reduced
111 the other mechanical properties.

112 Water repellent polymers or hydrophobic reagents and phenolic resins have been tried
113 to reduce boron leachability and increase dimensional stability as well as providing high
114 biological and fire resistance (Ryu *et al.* 1992, Peylo and Willeitner 1999, Su *et al.* 1997,
115 Murphy *et al.* 1995, Yalınkılıç *et al.* 1996, Yalınkılıç *et al.* 1997a). It is well known that vinyl
116 monomers contribute to dimensional stability and strength properties of wood and they are
117 expected to provide a delayed leaching of boron from wood (Lutomski 1975). By adding bulk
118 vinyl monomers to the void spaces in wood; compression strength, hardness, and abrasion

119 resistance greatly improved as well as dimensional stability (Meyer 1981). Yalınkılıç *et al.*
120 (1999) found that addition of boron to low formaldehyde reagents greatly increased both
121 biological resistance and dimensional stability. Fruno (1992) and Fruno *et al.* (1993) found that
122 the application of boron compounds such as boric acid, borax, boron trioxide, ammonium
123 borate, and potassium borate were investigated to produce insoluble organic substances in wood
124 by reacting with water glass by the acid treatment. As a result, it was recognized that the
125 utilization of the water glass–boron compound system made wood into a composite material
126 feasible having dimensional stability with less hygroscopicity as well as having fire resistance.

127 In this study, it was aimed to determine the strength properties of Oriental beech wood
128 coated with PUU (primed with epoxy resin and then coated with a polyurethane/polyurea hybrid
129 resin) and EPR (primed with epoxy resin) coated wood, and influence of FRs (boric acid,
130 borax, and ammonium sulfate) for increasing the fire resistance of wood. As well as PUU and
131 EPR coated wood have high mechanical properties, they are the materials having the low fire
132 properties. Thus, a dual treatment of wood with fire-retardands (FRs) impregnation and
133 followed by PUU and EPR coating may be of advantage in fire properties as well as mechanical
134 properties. Therefore, some mechanical properties such as MOR and CSPG and fire properties
135 such as weight loss and temperature values of Oriental beech impregnated with FRs, and
136 PUU and EPR coated Oriental beech wood were studied.

138 2. MATERIALS AND METHODS

139 *Preparation of test specimens*

140 Oriental beech (*Fagus orientalis* L.) wood was prepared in 20 mm x 20 mm x 360 mm,
141 20 mm x 20 mm x 30 mm, and 9 mm x 19 mm x 1016 mm (radial, tangential, and longitudinal)
142 dimensions for MOR, CSPG, and fire tests, respectively.

143

144 **Impregnation procedure**

145 3 % aqueous solutions of boric acid (BA), borax (BX), boric acid and borax mixture (50
 146 %; BA+BX), and ammonium sulfate were prepared to impregnate the Oriental beech wood
 147 specimens. Oriental beech wood was impregnated according to ASTM D 1413-07 (ASTM
 148 2007). Test specimens were left to diffuse in the solution at atmospheric pressure for 30 minutes
 149 after a pre-vacuum of 760 mm Hg was applied for 30 minutes in the impregnation process. The
 150 FRs retention of Oriental beech was calculated by the following equations (Eq.1-2):

151
$$R = \frac{G.C}{V} 10^3 \text{ (kg/m}^3\text{)} \quad (1)$$

152 Where;

153
$$G = T_2 - T_1 \quad (2)$$

154 Where;

155 $T_2 =$ Wood mass after impregnation (g)

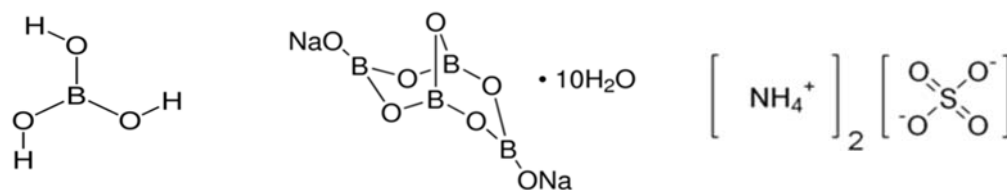
156 $T_1 =$ Wood mass before impregnation (g)

157 $V =$ Wood volume (cm³)

158 $C =$ Solution concentration (%)

159 **Coating procedure**

160 In this study, epoxy and polyurethane\polyurea hybrid resins were used for the coatings.
 161 Firstly, an impregnation method was applied by using FRs which are boron chemicals and
 162 ammonium sulfate before coating process. The structures of BA, BX and ammonium sulfate
 163 (AS) are given in Figure 1a, 1b and 1c.



165 **Figure 1: a)** Structure of boric acid (left), **b)** Structure of borax (center), **c)** Structure of
 166 ammonium sulfate (right).
 167

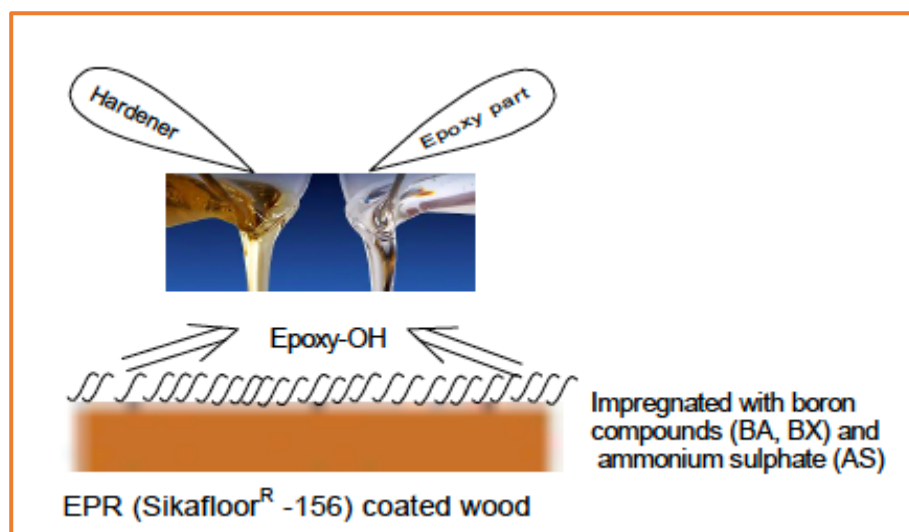
168 While the impregnated test specimens were primed with epoxy resin (Sikafloor®-156) for the
169 EPR coatings, they were coated with polyurethane/polyurea hybrid resin (Sikalastic®-851 R)
170 to obtain the PUU coatings. PUU coatings were primed with epoxy resin (Sikafloor®-156)
171 before coating with polyurethane/polyurea hybrid resin (Sikalastic®-851 R).

172 During the study, epoxy coated specimens are labelled as EPR and
173 polyurethane/polyurea coated specimens are labelled as PUU, as well.

174

175 ***EPR Coatings***

176 Sikafloor®-156 resin obtained from Sika company in Turkey was used as an epoxy resin
177 for EPR coatings. Sikafloor®-156 is well-known as an epoxy primer with two ingredients,
178 which consists of an epoxy part (A) and a hardener part (B), low-viscosity and solvent-free.
179 The mixtures were obtained from the epoxy and hardener with a 3:1 ratio of epoxy to hardener
180 as follows the manufacturer's instruction. Then they were applied to the wood specimens which
181 are impregnated with FRs (boron compounds and ammonium sulfate). The coating procedure for
182 EPR is illustrated in Figure 2.



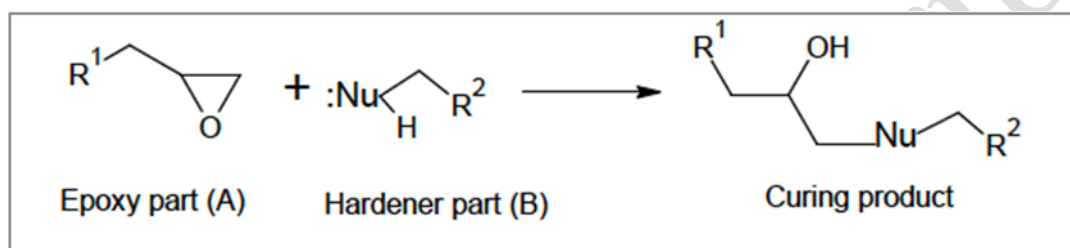
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Figure 2: EPR coated wood.

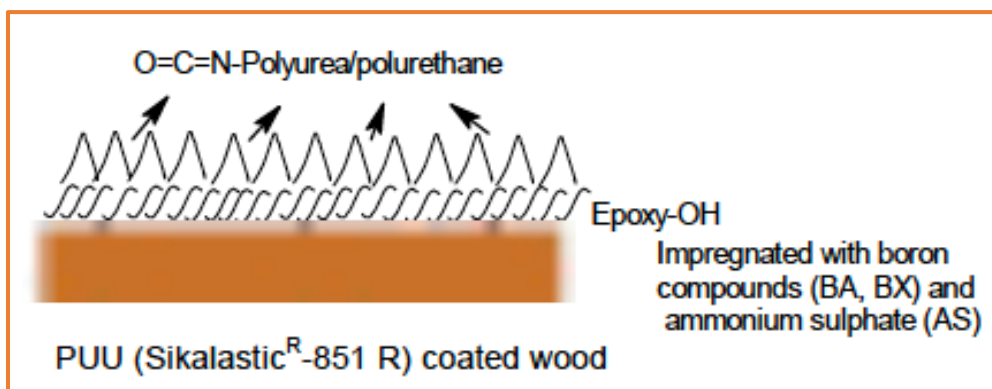
186 The possible cure reaction between an epoxy part and a hardener part is given in Figure
187 3. The hardeners are known the chemicals which are converted epoxy resin to thermosets, have
188 usually bear active hydrogen attached to an electronegative atom such as, N, O or S. The curing
189 reaction is a ring opening reaction between the oxirane ring and a nucleophile (Figure 2b). The
190 ring opening reaction occurs via nucleophilic attack by the hardener to the oxirane ring, then a
191 second reaction follows until the remaining active hydrogens attached to the hardeners are fully
192 reacted (Babahan *et al.* 2020).



193
194 **Figure 3:** Possible curing reaction between epoxy part (A) and hardener part (B) for EPR
195 coatings.
196

197 *PUU Coatings*

198 Sikalastic[®]-851 R resin was used for PUU coatings. Sikalastic[®]-851 R is also obtained
199 from Sika company in Turkey. PUU coated by using Sikalastic[®]-851 R resin were made after
200 test specimens were primed with epoxy resin (Sikafloor[®]-156). Before primed with epoxy, an
201 impregnation process with boron chemicals and ammonium sulfate was applied to the wood
202 specimens (Figure 4). The coating was done professionally by the manufacturer. Two layers
203 were applied to the floor using special polyurea coating machines (GAMA G-30 H) at a
204 consumption of 1,7 kg – 2,2 kg per m² and the second layer application was started within
205 maximum 6 hours after the first layer application.
206



207

208

Figure 4: PUU coated wood.

209 Sikalastic®-851 R is known as a two component hybrid resin. Component A consists of

210 isocyanate derivative and component B consists of polyol/amine derivatives. The reaction

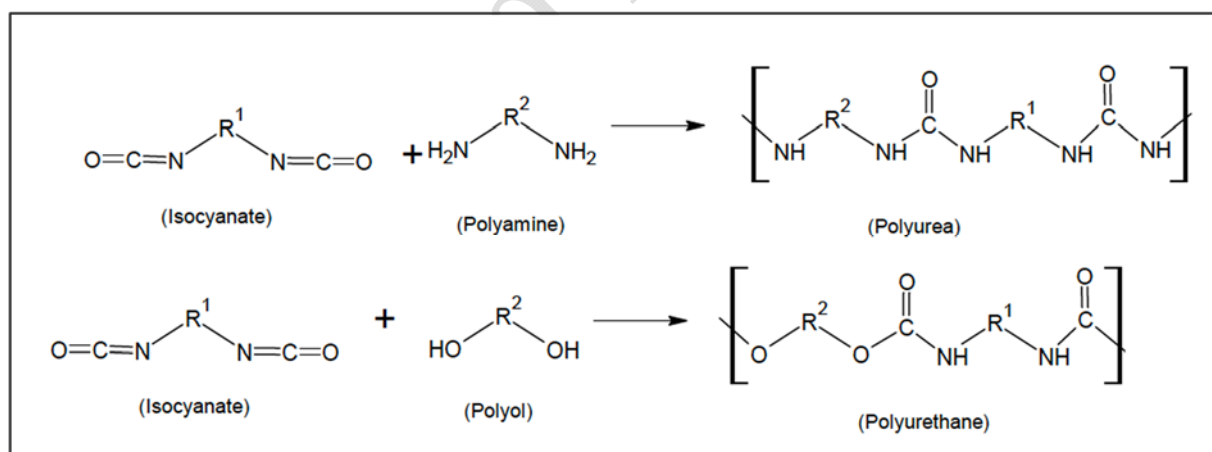
211 between isocyanate and a mixture of polyols and polyamines is given Figure 5. A polyurethane

212 is formed by the reaction of an isocyanate and a polyol. A polyurea is formed by the reaction

213 between an isocyanate and an amine. PUU coating is a hybrid coating, a mixture of polyurethanes

214 and polyureas. Hybrids are unique options for the largest range of applications, as they have

215 superior performance, moisture insensitivity, and low cost.



216

217 **Figure 5:** The reaction between isocyanate and a mixture of polyols and polyamines.

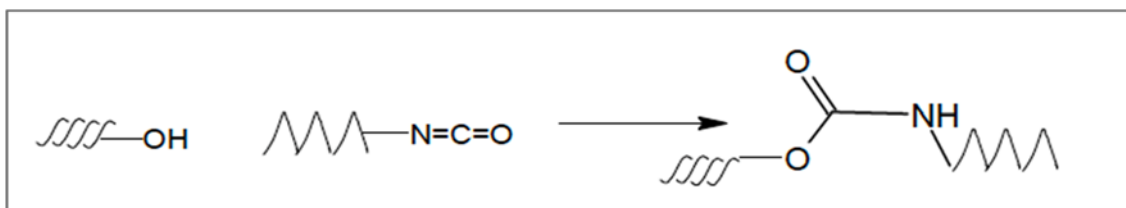
218

219 The new interfacial chemical reaction between Sikafloor®-156 and Sikalastic®-851 R

220 on the surface of PUU coatings based on an epoxy-urea bond is occurred (Figure 6).

221 Polyurea/polyurethane and epoxy moieties are formed an epoxy-urea bond (Attard *et al.* 2019).

222



223

224

Figure 6: Reaction between epoxy and polyurea/polyurethane moieties.

225

226 **Modulus of rupture (MOR)**

227 The modulus of rupture (MOR) of wood specimens was determined according to TS
228 2474 (TS 1976). A total of 110 wooden materials were prepared, 10 from each specimen group,
229 with dimensions of 20 mm x 20 mm x 360 mm. Wood specimens had been conditioned at 20°C
230 and 60% RH for 6 weeks prior to testing. The MOR of wood specimens was calculated using
231 the following formula (Eq. 3);

232

$$233 \text{ MOR} = \frac{3PX1}{2Xbh^2} \text{ (MPa)} \quad (3)$$

234 Where;

235 **P** is the maximum load (N),

236 **I** is span (mm),

237 **b** is width of specimen (mm),

238 **h** is thickness of specimen (mm).

239

240 **Compression strength parallel to grain (CSPG)**

241 The compression strength parallel to grain test was determined according to the TS 2595
242 (TS 1977) standard by using a 4000-kp capacity universal test machine, and applying 6 mm/min
243 loading time. A total of 110 wooden materials were prepared, 10 from each specimen group,
244 with dimensions of 20 mm x 20 mm x 30 mm. Before tests, wood specimens had been condi-
245 tioned at 20 °C and 60 % RH for 6 weeks.

246 ***Fire test***

247 The fire test was performed according to ASTM E 69 (ASTM 1975). A total of 55
248 wooden materials were prepared, 5 from each specimen group, with dimensions of 9 mm x 19
249 mm x 1016 mm. Butane gas was used to make the ignition flame. The gas flow was kept
250 standard with the flame 25 cm high, and the temperature was held at 100 °C. Before the fire
251 test, wood specimens had been conditioned at 20 °C and 60 percent relative humidity (RH) for
252 6 weeks. During the test, mass loss and temperature values were measured every 30 seconds.
253 Average mass loss and temperature readings were obtained 10 minutes after the flame source
254 was taken away. The mass losses of test specimens after fire test were calculated from the
255 following equation (4):

256

$$257 \text{ Mass losses} = \frac{M_{bf} - M_{af}}{W_{bf}} \times 100 \quad (4)$$

258 Where;

259 M_{bf} is the mass (g) of a wood specimen before fire test,

260 M_{af} is the mass (g) of a wood specimen after fire test.

261

262 ***Statistical evaluation***

263 Test results were analysed by a computerized SPSS statistical program (Statistics 2019)
264 include analysis of variance and Duncan test applied at 95 % confidence level. Statistical
265 evaluations were made on homogeneity groups (HG) where different letters reflected statistical
266 significance.

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268

269

270

271

RESULTS AND DISCUSSION

272 *MOR and CSPG of Oriental beech*

273 The MOR values of Oriental beech wood impregnated with FRs and coated with PUU
 274 and EPR are given in Table 1. The highest MOR value was obtained as 131,48 N/mm² for PUU
 275 coated Oriental beech wood. MOR values of PUU coated Oriental beech were higher than that
 276 of EPR coated Oriental beech wood. Moreover, MOR values of PUU and EPR coated Oriental
 277 beech were higher than that of un-treated and non-coated (control) Oriental beech wood.
 278 Results showed significant improvements in the modulus of rupture with using the coated
 279 polymer consist of polyurethane and polyurea (PUU). PUU (Sikalastic®-851 R) is a mixture
 280 resin of an isocyanate and a polyol/amine derivatives.

281

282 **Table 1:** MOR values of Oriental beech wood impregnated with FRs and coated with PUU
 283 and EPR.

FRs and coating materials	Retention (kg/m ³)	MOR (MPa)	Standard deviation	Homogeneity group	Percentage change compare to control
Control (un-treated and non-coated)	-	116,29	10,30	BCD	-
PUU	-	131,48	17,05	A	(+)13,06
BA+ PUU	12,16	121,96	17,69	AB	(+)4,87
BX+ PUU	11,37	124,39	13,33	AB	(+)6,96
AS+ PUU	8,19	124,49	16,22	AB	(+)7,05
(BA+BX)+PUU	15,02	123,82	13,51	AB	(+)6,47
EPR	-	120,75	3,08	AB	(+)3,83
BA+ EPR	16,84	116,45	4,05	BCD	(+)0,13
BX+ EPR	16,88	117,85	2,32	BCD	(+)1,34
AS+EPR	11,33	116,39	11,03	BCD	(+)0,08
(BA+BX)+EPR	11,23	116,33	11,69	BCD	(+)0,03

Note: PUU: Polyurethane/Polyurea hybrid resin (Sikalastic®-851 R), EPR: Epoxy resin (Sikafloor®-156), BA: Boric acid, BX: Borax, AS: Ammonium sulfate.
 Ten replicates were made for each group. Homogeneity group was realized at 95 % confidence level.

284

285 The isocyanates are particularly reactive and the urethanes can form bonds with the
286 hydroxyls in the wood surface. Polyols and amines also can make H bonding with the wood
287 surface. Changes can be produced in the wood, with the biodegradable cellulose hydroxyls
288 being replaced by isocyanates. That a small quantity of isocyanates can react with the cellulose
289 hydroxyls to give covalent bonds (Pommier and Elbez 2006) increases the modulus of rupture
290 (MOR).

291 Results showed that FRs treatment before PUU and EPR coatings decreased the MOR
292 values of Oriental beech than those of only PUU and EPR coated Oriental beech. For example,
293 MOR of only PUU and EPR coated Oriental beech were 131,48 MPa and 120,75 MPa,
294 respectively, they were decreased from 118,41 MPa to 124,49 MPa and 116,33 MPa to 117,85
295 MPa for FRs impregnated and PUU and EPR coated Oriental beech, respectively. As,
296 treatments with boron derivatives before PUU and EPR coatings increase the rate of hydrolysis
297 in the wood, MOR levels of PUU and EPR coatings are lower (Toker *et al.* 2008). There was a
298 statistically significant difference in MOR values between PUU coated Oriental beech and un-
299 treated and non-coated (control) group. However, no statistically significant difference in MOR
300 values between only PUU coated Oriental beech and FRs impregnated and PUU coated
301 Oriental beech. Yalınkılıç *et al.* (1999) investigated MOR values of borate impregnated and
302 vinyl monomers coated wood. They used boric acid, borax, and their mixture as borates.
303 Styrene which is derivative of benzene (ST), methylmethacrylate which is methyl ester of
304 methacrylic acid (MMA) and their mixture were used as a vinyl monomers. They were found
305 that styrene and methylmethacrylate mixture was the most effective monomer followed by ST
306 and MMA in increasing MOR levels of wood. It was found that wood specimens pre-treated
307 with BA and BX mixture (boron derivatives) generated lesser MOR levels than that of without
308 BA and BX mixture pre-treatment. Baysal *et al.* (2007) investigated MOR of Scots pine pre-
309 treated with boric acid (BA) and borax (BX) mixture prior to vinyl monomer coating. Styrene,

310 methylmethacrylate, and their mixture (50: 50; volume: volume) were used as vinyl monomers.
 311 It was found that vinyl monomers considerably improved MOR of Scots pine than that of un-
 312 treated control specimens. MOR of only vinyl monomers coated Scots pine were higher than
 313 pre-treated with BA and BX mixture and then coated vinyl monomers coated Scots pine. Geçer
 314 *et al.* (2015) investigated MOR levels of wood polymer composites (WPCs) were prepared by
 315 styrene (ST) and different boron compounds impregnated sapwood of Oriental beech (*Fagus*
 316 *orientalis*) Boric acid (BA), Borax (BX) and their mixture (1:1; w/w) aqueous solutions at 0,25
 317 %, 1,00 %, and 4,70 % concentrations were prepared and then impregnated into wood prior to
 318 styrene treatment. The MOR levels of WPCs pre-impregnated with borates were decreased to
 319 some extent. It can be said that boric acid and borax mixture pretreatment increased the rate of
 320 hydrolysis in the wood, thereby causing loss in strength (Toker *et al.* 2008). Our results are
 321 compatible with these researchers' findings.

322 The CSPG values of Oriental beech wood impregnated with FRs and coated with
 323 PUU and EPR are given in Table 2.

324

325 **Table 2:** CSPG values of Oriental beech wood impregnated with FRs and coated with PUU
 326 and EPR.

FRs and coating materials	Retention (kg/m ³)	CSPG (MPa)	Standard deviation	Homogeneity group	Percentage change compare to control
Control (un-treated and non-coated)	-	61,71	7,64	C	-
PUU	-	79,63	2,93	A	(+)29,03
BA+ PUU	13,36	68,19	4,44	CDEF	(+)10,50
BX+PUU	15,54	67,99	3,20	B	(+)10,17
AS+PUU	12,11	66,41	5,79	FG	(+)7,61
(BA+BX)+PUU	10,56	66,15	4,19	FG	(+)7,19
EPR	-	65,97	6,22	FG	(+)6,90
BA+ EPR	11,53	62,13	6,40	CD	(+)0,68
BX+ EPR	15,50	61,98	9,09	C	(+)0,43
AS+EPR	13,60	61,82	3,96	C	(+)0,17
(BA+BX)+EPR	14,23	62,49	1,92	CD	(+)1,26

Note: PUU: Polyurethane/Polyurea hybrid resin (Sikalastic®-851 R), EPR: Epoxy resin (Sikafloor®-156), BA: Boric acid, BX: Borax, AS: Ammonium sulfate. Ten replicates were made for each group. Homogeneity group was realized at 95 % confidence level.

327
328 The highest CSPG value was obtained as 79,63 MPa for PUU coated Oriental beech
329 wood. There were statistically significant difference in CSPG values between un-treated and
330 non-coated (control) group and PUU coated Oriental beech. CSPG values of PUU coated
331 Oriental beech were also higher than that of EPR coated Oriental beech wood. Moreover, CSPG
332 values of PUU and EPR coated Oriental beech were higher than that of un-treated and non-
333 coated (control) group. Results showed that FRs treatment before PUU and EPR coating
334 decreased the CSPG values of Oriental beech than those of only PUU and EPR coated Oriental
335 beech. For example, CSPG of only PUU and EPR coated Oriental beech were 79,63 MPa and
336 65,97 MPa, respectively, they were changed from 61,82 MPa to 68,19 MPa for FRs
337 impregnated and PUU and EPR coated Oriental beech, respectively. It may be due to the fact
338 that waterborne preservative formulations do react with the cell wall components by undergoing
339 hydrolytic reduction upon contact with wood sugars. This process, known as fixation, oxidizes
340 the wood cell wall components and may reduce wood strength (Winandy *et al.* 1988). There
341 was a statistically significant difference in CSPG values between PUU coated Oriental beech
342 and un-treated and non-coated (control) group. Our results showed that there was a statistically
343 significant difference in CSPG values between PUU coated Oriental beech and FRs
344 impregnated and PUU coated Oriental beech. Also, there was a statistically significant
345 difference in CSPG values between EPR coated Oriental beech and FRs impregnated and EPR
346 coated Oriental beech. Geçer *et al.* (2015) investigated CSPG values of Oriental beech wood
347 impregnated with borates and than coated with styrene. Results showed that wood specimens
348 only styrene impregnated generated higher CSPG level ($887 \text{ kg}\cdot\text{cm}^{-2}$) than that of borates pre-
349 impregnated and styrene coated Oriental beech ($814 \text{ kg}\cdot\text{cm}^{-2}$ - $860 \text{ kg}\cdot\text{cm}^{-2}$). Also, there is a
350 statistical difference between styrene only impregnated wood specimens and borates pre-
351 impregnated and styrene coated oriental beech. Our results are in good agreement with data
352 Geçer *et al.* (2015). Winandy (1995) determined that there appears to be a little relative

353 difference in their effect on strength when retention levels of chemicals were between 4,0 kg/m³
 354 and 9,6 kg/m³. Mourant *et al.* (2008) reported that wood samples with salts retention values
 355 ranging from 24 kg/m³ to 40 kg/m³ had a significantly lower than the untreated control samples.
 356 According to our results, retention values of MOR wood specimens were changed from 8,19
 357 kg/m³ to 16,88 kg/m³ and while FRs treatment decreased from 5,31 % to 7,24 % MOR of FRs
 358 treated and PUU coated Oriental beech, it decreased 2,40 % to 3,66 % (Table 3).

359

360 **Table 3:** Percentage MOR changes of FRs impregnated and PU/EPR coated Oriental beech
 361 wood compared to only PUU or EPR coating.

FRs and coating materials	MOR (MPa)	Percentage change compare to only PUU or EPR coating
PUU	131,48	-
BA+ PUU	121,96	(-)7,24
BX+ PUU	124,39	(-)5,39
AS+ PUU	124,49	(-)5,31
(BA+BX)+PUU	123,82	(-)5,82
EPR	120,75	-
BA+ EPR	116,45	(-)3,56
BX+ EPR	117,85	(-)2,40
AS+EPR	116,39	(-)3,61
(BA+BX)+EPR	116,33	(-)3,66

Note: PUU: Polyurethane/Polyurea hybrid resin (Sikalastic®-851 R), EPR: Epoxy resin (Sikafloor®-156), BA: Boric acid, BX: Borax, AS: Ammonium sulfate.

362

363 Retention values of CSPG wood specimens were changed from 10,56 kg/m³ to 15,54
 364 kg/m³ and while FRs treatment decreased from 14,36 % to 16,92 % CSPG of FRs treated and
 365 PUU coated Oriental beech, it decreased from 5,27 % to 6,29 % CSPG of Oriental beech
 366 impregnated with FRs and EPR coated Oriental beech (Table 4).

367 The National Forest Products Association (NFPA) (1973) recommends that the
 368 allowable stresses for fire-retardant treated wood for design purposes be reduced by 10 % as
 369 compared to untreated wood; the allowable loads for fasteners are also reduced by 10 %. Also,

370 it requires a 10 % to 20 % reduction in allowable design stress, depending on mechanical
 371 property under consideration (NFPA 1986). Generally, our results met the NFPA requirements.

372

373 **Table 4:** Percentage CSPG changes of FRs impregnated and PU/EPR coated Oriental beech
 374 wood compared to only PUU or EPR coating.

FRs and coating materials	CSPG (MPa)	Percentage change compare to PUU/EPR coating
PUU	79,63	-
BA+ PUU	68,19	(-)14,36
BX+PUU	67,99	(-)14,61
AS+PUU	66,41	(-)16,60
(BA+BX)+PUU	66,15	(-)16,92
EPR	65,97	-
BA+ EPR	62,13	(-)5,82
BX+ EPR	61,98	(-)6,04
AS+EPR	61,82	(-)6,29
(BA+BX)+EPR	62,49	(-)5,27

Note: PUU: Polyurethane/Polyurea hybrid resin (Sikalastic®-851 R), EPR: Epoxy resin (Sikafloor®-156), BA: Boric acid, BX: Borax, AS: Ammonium sulfate.

375

376 ***Fire properties of Oriental beech***

377 Weight loss and temperature values of Oriental beech impregnated with FRs and
 378 coated with PUU and EPR after fire test are given in Table 5.

379 Weight loss and temperature values of PUU coated Oriental beech were higher than that of EPR
 380 coated Oriental beech wood. The highest weight loss and temperature values were obtained for
 381 PUU coated Oriental beech wood. Polyurethane resins are known as highly cellular polymers,
 382 are easily ignitable and highly flammable. This knowledge explains why PUU coated woods
 383 have higher weight loss during fire tests. The flammability of polyurethanes has long been a
 384 factor that limits their greater uses. FRs impregnation before PUU and EPR coatings caused to
 385 lower weight loss and temperature values than those of only PUU and EPR coated Oriental
 386 beech wood. PUU and EPR coatings caused higher weight loss when compared to un-treated
 387 and non-coated (control) group. However, FRs impregnation before PUU and EPR coatings

388 played an important role in reducing weight loss of wood. Moreover, weight loss of Oriental
 389 beech FRs impregnated before PUU and EPR coating were lower than those of only PUU and
 390 EPR coated Oriental beech wood clarifying the protective effect of FRs in combustion. These
 391 findings are consistent with earlier reports on the weight loss of un-treated and boron–vinyl
 392 monomer combination-treated wood (Ayrılmış *et al.* 2005). In other words, wood became more
 393 difficult to ignite and more oxygen was needed to burn the treated materials as consistent to the
 394 effect of boron reported earlier (Wen-Yu 1997).

395 **Table 5:** Weight loss and tempreture values of FRs impregnated and PU/EPR coated Oriental
 396 beech after fire test.

FRs and caoting materials	Retention (kg/m ³)	Weight loss (%)	Standard deviation	Homogeneity group	Percentage change compare to control	Temperature values (°C)	Standard deviation	Homogeneity group	Percentage change compare to control
Control (un-treated and non-coated)	-	83,26	2,66	AB	-	292,55	77,95	A	-
PUU	-	86,24	2,41	A	(+)3,57	308,28	126,33	A	(+)5,37
BA+ PUU	15,75	82,69	0,66	AB	(-)0,68	152,15	60,30	CD	(-)47,99
BX+ PUU	13,66	84,97	0,41	A	(+)2,05	155,46	20,52	CD	(-)46,86
AS+ PUU	15,51	84,13	1,39	AB	(+)1,04	175,04	32,46	BC	(-)40,16
(BA+BX)+PUU	15,33	83,80	0,94	AB	(+)0,64	129,76	23,82	D	(-)55,64
EPR	-	85,62	2,10	A	(+)2,83	298,78	72,32	A	(+)2,12
BA+ EPR	15,12	71,05	0,95	C	(-)14,66	199,00	87,02	B	(-)31,97
BX+ EPR	13,85	73,83	1,24	C	(-)11,32	250,15	115,02	A	(-)14,49
AS+EPR	15,28	73,57	4,93	C	(-)11,63	260,49	98,67	A	(-)10,95
(BA+BX)+EPR	15,02	69,89	2,05	C	(-)16,05	164,76	21,25	C	(-)43,68

Note: PUU: Polyurethane/Polyurea hybrid resin (Sikalastic®-851 R), EPR: Epoxy resin (Sikafloor®-156), BA: Boric acid, BX: Borax, AS: Ammonium sulfate. Ten replicates were made for each group. Homogeneity group was realized at 95 % confidence level.

397

398 Moreover, boron compounds (H₃BO₃ (BA) and Na₂B₄O₇·10H₂O (BX); Figures 1a,b)
 399 used as fire retardant chemicals in this study dehydrates above 75 °C to metaboric acid (HBO₂)
 400 and finally boric oxide occurs, thereby generating water, which acts as a heat sink and dilutes
 401 oxygen and flammable gases (Wang 2016). There was no statistically significant difference in
 402 weight loss values and temperature values between PUU and EPR coated Oriental beech and
 403 un-treated and non-coated (control) group. While, there was a statistically significant difference

404 in weight loss values between EPR coated Oriental beech and FRs impregnated and EPR coated
405 Oriental beech, there was no statistically significant difference in weight loss between PUU
406 coated Oriental beech and un-treated and non-coated (control) group.

407 Baysal *et al.* (2003) found that the weight loss of *Ailanthus altissima* wood pre-
408 impregnated with boric acid before styrene coating was reduced approximately 5 % – 6 % levels
409 compare to only styrene coated *Ailanthus altissima* wood. Another study, Yalinkılıç *et al.*
410 (1997b) determined the fire properties of particleboard made from waste tea leaves which boric
411 acid and borax added to ureaformaldehyde adhesive. Fire test results showed that boron–
412 monomer combination treatment may be of advantage in fire-resistance. Baysal *et al.* (2007)
413 studied fire properties of wood polymer composite (WPC) was obtained by vinyl monomers
414 such as styrene (ST), methlmethacrylate (MMA), and their mixture (50:50; volume: volume)
415 of treated sapwood of Scots pine (*Pinus sylvestris.*). Boric acid (BA) and borax (BX) mixture
416 was impregnated into wood at 1% concentration prior to monomer treatment. They found that
417 borate impregnation before monomer treatment improved fire properties of WPC. Atar and
418 Keskin (2007) investigated the combustion properties of Uludağ fir wood, which was varnished
419 after being impregnated with boron compounds. For this purpose, test samples prepared from
420 Uludağ fir wood were impregnated with boric acid and borax. After impregnation, the surfaces
421 are covered with cellulosic, synthetic, polyurethane, water-based, acrylic and acid hardening
422 varnishes. As a result, they determined that the process of impregnation with boron compounds
423 before varnishing reduces the burning temperature of wood. Atar (2008) investigated the
424 combustion properties of oak wood impregnated with boron compounds and then varnished.
425 The impregnated test samples were prepared from oak wood (*Quercus petraeae*) with boric acid
426 and borax. After the impregnation process, it was coated with cellulosic, synthetic,
427 polyurethane, water-based, acrylic and acid hardening varnishes. As a result, it has been

428 determined that impregnation of wood material with boron compounds before varnishing
429 reduces the burning temperature. Our results were compatible with these researchers findings.

430

431

CONCLUSIONS

432 Some mechanical, and fire properties of Oriental beech impregnated with FRs and PUU
433 and EPR coated Oriental beech were studied.

434 Results showed that while coating with PUU and EPR improved MOR and CSPG values
435 of Oriental beech than that of un-treated and non-coated (control) group, it showed negative
436 effect on fire properties of Oriental beech. MOR and CSPG values of PUU coated Oriental
437 beech were higher than that of EPR coated Oriental beech. FRs treatment before PUU and EPR
438 coatings resulted in to decrease MOR and CSPG values of Oriental beech. Results showed that
439 FRs pre-treatment was combined with PUU and EPR coatings to enhance fire properties of
440 Oriental beech.

441 In conclusion, Oriental beech impregnated with FRs before PUU and EPR coatings
442 enhanced fire properties. They caused lower weight loss and temperature values of FRs
443 impregnated and PUU and EPR coated Oriental beech than un-treated and non-coated (control)
444 group. However, they caused to lower MOR and CSPG of Oriental beech. PUU and EPR coated
445 wood is an alternative structural material for exterior use, where high mechanical properties
446 required. But, these products have low fire properties. Thus, FRs impregnation before PUU
447 and EPR coatings of wood will provide improvements fire properties of the wood.

448

449

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