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Comparative study on fire retardancy of various wood species treated with PEG 400, phosphorus, and boron compounds for use in cement-bonded wood-based products

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ABSTRACT

The aim of this study was to find suitable fire retardants to increase the fire resistance of Scots pine, poplar, and date palm trees. The fire retardants used in this study were disodium-tetra borate ($Na_2B_4O_7$) (Borax), disodium-hydrogen phosphate (Na_2HPO_4) (DSHP), diammonium-hydrogen phosphate ($(NH_2)_4HPO_4$) (DAHP), and polyethylene glycol 400 (PEG 400). The fire retardants were prepared in different concentrations, and the selected wood species were tested in particle form and as solid wood, both with three different surface roughness: sawn, sanded, and planed. Fire tests were completed with a single flame source test, Lindner test, and calorimeter test. Since the fire retardants may affect cement curing, a cement hydration test was conducted by measuring the temperature of the hydration process. Fire retardant concentrations affected the performance of fire retardancy, while surface preparations proved effective only for Scots pine. Nevertheless, much depended on the type of fire retardants used and the wood species upon which they were applied. For the hydration tests, all samples treated with fire retardants were cured normally with the exception of PEG 400, DAHP and DSHP with high concentration. DAHP with 300 g/l and DSHP with 77 g/l concentrations were found to be suitable fire retardants for CBPB production since they increased fire resistance and had small effect on cement curing.

1. Introduction

Wood is one of the ubiquitous and diverse materials on the planet. Being a renewable natural resource, it possesses a negative carbon footprint, excellent mechanical properties, and is easily workable. In addition to serving as a raw material for near zero emission level energy production, wood can also be utilized in a wide range of applications including furniture, transportation, and construction. Wood is considered the best material for construction because of its excellent compatibility with other building materials such as concrete and steel. On the other hand, wood has low fire resistance [1]. Flames tend to spread faster in wood than in other conventional building materials; however, wood manages to retain its strength to a greater degree than steel under fire conditions. Chemical wood treatment is an effective method for protecting wood from fire [2]. Fire retardant treatments were classified into two groups, coating and impregnating. Fire retardants act in two distinct ways. The first is essentially physical and involves cooling and the formation a protective layer, while the second is chemical in nature and entails dilution in which an interface with the combustion process takes place in the solid and gas phases [3].

Phosphorus compounds are well known chemical fire retardants for wood. The most popular phosphorus compounds used as fire retardants are phosphoric acid and mono and diammonium phosphate salts. In addition, phosphate salts of nitrogen containing organic compounds are also commonly used [4]. Phosphorus fire retardants are generally divided into three categories: inorganic, organic, or halogen. Fire retardants containing halogen components are the least environment friendly. In most cases, their mechanism works in the solid phases of burning material, but can also be active in the gas phase [5]. Phosphorus compounds are efficient fire retardants because they reduce the thermal degradation of wood [6]. Phosphorus chemicals work as fire retardants by forming acids that decrease the wood temperature [7] and, consequently, increase wood dehydration and char formation [8,9]. Char works as a barrier to oxygen and volatile organic

Abbreviations: Sc, Scots pine; P, Poplar; D, Date palm leaflet; Sw, Sawn; P, Planed; S, Sanded

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compounds (VOCs). Hence, low cost, environmentally friendly phosphorus compounds act as fire retardants in the materials containing a high amount of oxygen-like cellulosic [3,10]. This has made phosphorus compounds the most investigated fire retardant chemicals for wood over the years.

Boron, a well-known product used in various agricultural and industrial applications such as glass fibre production and material processing, is the second most popular fire retardant for wood [11]. Boron compounds are durable due to their deep wood penetration [3]. Boron compound-based fire retardants are the best fire retardants for cellulosic materials. Much research proving the effectiveness of boron compounds as fire retardants has been completed over the years. In most cases, two kinds of boron compounds are used: borax and boric acid. These two compounds act as effective fire retardants on wood surfaces and, due to their complementary characteristics, are generally used together. One advantage of borax is flame propagation suppression, but its major disadvantage is the promotion of smouldering. Conversely, boric acid is an effective smouldering suppressant, but its flame spread suppressing ability is low [12]. Borax is also used as a fire retardant with other chemicals such as potassium carbonate and Wolmanit. These three chemicals have been applied on oriented strand board via brushing or dipping. The result of this comparison was that borax has the highest penetration capability and is one of the best choices for fire suppression in oriented strand board [13]. Boron compounds are present in different forms like pure compound or minerals and have many advantages when applied to solid wood and wood-based products. Boron compounds are easy to use and has various advantages like high thermal and biological resistance, low cost, low toxicity, eco-friendliness [14,15].

Polyethylene glycol appeared as a fire retardant many years ago. Compared to the above-mentioned fire retardants, polyethylene is not a well-known fire retardant. A 1995 research study employed polyethylene glycol with phosphate as a fire retardant with positive results, but when the temperature reached 80°C, the phosphate began to decompose and became less stable [16]. A 2013 research study tested the fire resistance of a polyethylene composite and attempted to determine if the composite was a suitable halogen-free fire retardant. Many investigations have been completed on this topic and the results have revealed that polyethylene composite reduces heat. Thermal cycling tests gave the same results. This research proved that polyethylene composite had thermal reliability in the case of thermal energy storage and also possessed a good capacity for slowing the heat combustion rate; hence, as a fire retardant, it performed well [17]. A 2016 study by Wang and Shi, focused on the influence of molecular weight of polyethylene glycol (PEG) on thermal and fire protection of pentaerythritol phosphate (PEPA). Four types of PEG were used with different molecular weights: PEG 150, PEG 200, PEG 400, and PEG 600. The results of the fire protection of fire resistant coatings and the intumescence ratio test showed that PEG 600 had no efficiency on fire resistance, but PEGs with low molecular weights were more efficient as fire retardants for the intumescent coating. For the thermal degradation, the behaviour of fire resistant coatings results showed that char forming capability of intumescent coatings could be enhanced if PEG had low molecular weight [18]. PEG 400 is an inexpensive, eco-friendly fire retardant possessing thermal stability and unhydrolyzation properties, all of which makes it an excellent fire retardant [19,20].

Fire retardant wood treatment technology is capable of converting combustible wood into flame resistant material. This kind of transformation is only possible by adding chemicals substances to wood. The best fire retardant should have many advantageous properties including high potency, eco-friendliness, and durability, and it should deliver these at low cost and low toxicity. The efficiency of flame retardant treatments depends not only on performance and usage, but also on the distribution of these treatments in the wood itself. Therefore, the choice of a suitable application method is crucial [21].

The characteristics of any material depend upon the chemistry of the components within the material itself. For wood, the cell wall polymers such as cellulose, hemicelluloses, and lignin represent the modified components after fire retardation treatment. The chemical modification performed on these components alters the performance of wood. This idea is applied to solid wood and wood-based products as well. The approaches to cell wall modification are numerous and depend on the characteristics are modified. For example, to achieve the objective of flame retardancy, chemical groups can be bonded into cell wall polymers containing retardants or flame suppressants [22]. Petric [23], stated that surface modification by densification and/or resin impregnation can be considered a wood improvement. Surface modification serves the exact same purpose as bulk modification, but the treatments are restricted to only the first few surface layers of wood. Dominkovics et al. studied the effect of surface modification of wood flour on the properties of PP/wood composites. As results, the surface flour modification by benzylation was successful but it decreased its properties [24]. Podgorski et al. tested wood surface modification by using plasma polymerization that is often used in textile industries. the aim of the research is to protect the wood when used outdoor against fungi, weather … ects [25]. Pokorovskaya and Portnov [26], studied the modification of wood by phosphites to increase its fire resistance. As results using 20% of phosphites solutions chemical interaction between wood substrate and phosphorus containing compounds occurs. The increase of surface and capillary structure during chemical modification with the phosphites cause reduction in fire flammability and smoke forming of wood.

This paper focuses on enhancing cement-bonded wood-based products (CBPB) by finding appropriate fire retardants for three different wood species: Scots pine (*Pinus sylvestris*), poplar (*Populus cv. euramericana I214*), and date palm tree leaflet (*Phoenix dactylifera* .L). These wood species were chosen for the study because they are commonly used raw materials of CBPB [27-29]. Treating wood particles used in CBPB manufacturing is meant to increase fire resistance; however, not all fire retardants are suitable for this task because some may increase the setting time of cement hydration, which weakens the compatibility of wood and cement, thus adversely affecting mechanical properties and initial board strength. Research focusing on increasing the fire resistance of the date palm tree leaflet with DAHP, DSHP, Borax, and PEG 400, or research addressing the effect these fire retardants have on the cement curing process could not be found. Fire retardation has many aspects and can be related to many factors beyond the type of fire retardant utilized; since wood is an orthotropic material, the concentration of fire retardants could make a difference as well. The surface roughness of wood could also affect fire retardation. Based on results of previous literature, various fire retardants with varying concentrations were used in this study. Selected wood species were tested in particle form and as solid wood using three different types of surface roughness – sawn, sanded, and planed. Both the particle and solid wood timber were treated with selected fire retardants.

2. Materials and Methods

2.1. Materials

This study examined three tree species: Scot spine (*Pinus sylvestris*), poplar hybrid I214 (*Populus cv. euramericana I214*), and date palm tree leaflet (*Phoenix dactylifera L.*). The date palm tree leaflet was taken from the oasis of Oued Souf, Algeria. Scots pine was provided by the Falco Zrt. wood industry company in Szombathely, Hungary, and the poplar originated from the Derula Ltd. plywood company in Magyarszecsőd, Szombathely, Hungary. Date palm tree leaflet is used to produce CBPB, which is why the leaflet was chosen over a solid wood trunk for the experiment. A boron compound borax ($Na_2B_4O_7$) with a concentration of 25g/l, and phosphorus compounds DSHP (Na_2HPO_4) with 25g/ and 77g/ concentrations, DAHP ($(NH_2)_4HPO_4$) with 25g/l and 300g/l concentrations, and PEG 400 were employed as fire retardants. The fire retardants utilized were in powder form with the exception of PEG 400, which was in liquid form. The powder-form retardants were dissolved in distilled water to become liquids. All chemicals were prepared at their saturation concentration under solubility temperature of 20°C. Due to a big difference in the solubility of borax and the other chemicals, each solution was prepared in a concentration of 25g/l.

Table 1
Dimensions of test specimens for different species for each test.

Tests	Surface roughness test	Linder test	Single flame source test	Calorimeter test
poplar	Boards (90 × 250 × 10)mm	Boards (100 × 100 × 10)mm	Boards (90 × 250 × 10)mm	particles
Scots pine	Boards (90 × 250 × 10)mm	Boards (100 × 100 × 10)mm	Boards (90 × 250 × 10)mm	particles
date palm tree leaflet	-	-	-	particles

Remark: Only the calorimeter test could be completed on the date palm leaflet.

Portland cement CEM I 42.5 and water glass (Sodium Silicate) (Na_2SiO_3) were used for the hydration test. This research paper aimed to enhance the fire resistance of multiple kinds of wood species; the variables were surface roughness of wood and concentration of fire retardant solutions. Table 1 shows the description of the variation of test samples. The surface roughness test, Linder test, single flame test, and calorimeter test were all performed for the Scots pine and poplar. The shape and dimensions of the date palm tree leaflet restricted its testing possibilities to the calorimeter test.

2.2. Methods

2.2.1. Surface roughness test

Boards from Scots pine and poplar with three types of surfaces – sawn with a band saw, planed with a straightening planer, and sanded with a belt sander (sand paper grit size 120) – were prepared. Surface roughness tests were completed with a MAHR S2 perthometer. Fifteen measurements were taken for each surface type and each wood species. The unfiltered primary profile has been evaluated by the mean roughness R_a, the mean roughness depth R_z, and the maximum roughness R_{max} according to the DIN EN ISO 4288 standard [30].

2.2.2. Lindner test

To perform the Lindner test, six test species for each surface type and wood species were used with each of the fire retardants. In total, 126 specimens for each type of wood were tested, and 18 specimens were left untreated as control. Specimens were kept at a room temperature of 20°C with a relative humidity of 65% for 24 hours. Subsequently, the surface of each of the species was treated by spreading 5g of each fire retardant with a brush. Specimens were allowed to dry for 24 hours in an ambient room conditions. The room conditions (RH = 52%, T = 22°C) were similar to the conditions initially used for the 24-hour period(RH = 65%, T = 20°C), only this time the specimens were left for seven days according to standard MSZ 9607/1-83 [31]. For the test, a 1g pill of hexamethylenetetramine G.R was created for each specimen. In general, this test ignites wood samples via stove fire, but rather than using gas, a 1g pill of hexamethylenetetramine G.R was ignited instead, and the wood specimen was placed on an iron stand above the flame. The burning time was the total burning time of examethylenetetramine pill. Mass loss was measured during the test.

2.2.3. The single flame source test

The surface treatment and preparation for the Lindner test and the single flame source test were achieved in the same manner. The single flame source test was accomplished according to the EN ISO 11925-2:2011 standard, *Reaction to fire tests. Ignitability of products subjected to direct impingement of flame. Part 2: Single-flame source test* with Taurus Instruments [32]. The aim of this test was to measure the ignitability of a vertically-oriented test samples exposed to a small flame. The specimens can be exposed at two different spots, either at the face or at the edge. In our test, the face was used. The specimens for this test were prepared by marking two lines on the surface of each specimen. The first line was 40 mm above the bottom of the specimens and the second line was located 150 mm above that. This space marks the flame area according to the standard. The first line is where the flame should be started. If the flame exceeds the second line, the specimen is out of standard. The test duration is 30s. During the first 15s, the specimen is burned. In the second 15s period, observations concerning the success or failure of ignition are noted.

2.2.4. Calorimeter test

In preparation for the calorimeter test, the date palm tree leaflets were cut into 2cm pieces. Following this, the cuts were ground. The pieces were then kept in a room climate with a relative humidity of 65% and a temperature of 20°C for 24h. Afterward, 8g of the leaflets were soaked into each fire retardant for 1 min, before being drained and left to dry. Poplar and Scots pine hammer-milled particle specimens were prepared in the same manner. The tests were performed with a Parr™ 6200 Compensated Calorimeter. For the test, a bucket was filled with 2000g of water and 1g of particles was put inside a calorimeter bomb, which was filled with oxygen. After that, the calorimeter bomb was put in the water bucket. The total test time was around 15 min.

2.2.5. Hydration test

For the hydration test, a mixture of Portland cement CEM I 42.5, sodium silicate (Na_2Sio_2), mixing water, and fire retardant was created. The mixture was poured into small cups and thermocouples were inserted into the mixture to measure the temperature change during cement curing for 24 hours. The thermocouples were connected to an AHLBORN device that was linked to a laptop via special software that collected the temperature data directly onto an excel sheet with a given sampling rate.

3. Results and discussion

3.1. Surface roughness

According to the primary profile of poplar and Scots pine, the surfaces of these two species differ significantly. As expected, the sanded surface is the smoothest while the sawn surface is the roughest; see Table 2. In addition, the surface roughness of both wood species differs. Poplar is significantly rougher than Scots pine in all surfaces.

3.2. Experimental analysis for the fire tests

Due to the lack of genuine replications of measurement in all of the fire tests, a formal examination of experimental errors, including repeatability and reproducibility, could not be conducted. In order to detect any individual major individual experimental errors, we visualized the spread of measurement results in each series to detect signs of irregular distribution like skewness or outliers. Fig. 1 shows a dot plot diagram for the Lindner test of sanded Scots pine.

Descriptive statistics analysis with Statistica software supported our observations based on the dot plot regarding the distribution of test results and the identification of outliers. In some cases, normal distribution was violated and a few extreme outliers were detected by using criteria given in [34]:

The few extreme outliers were deleted. Descriptive statistics analysis was redone in view of further evaluation of the results; as an example see the mass loss for the Linder test on sanded Scots pine treated with DAHP 300g/L. Fig. 2.

Student t-tests were applied to discover significant differences between the results of different treatments. Welch-tests were applied to

Table 2
Mean roughness R_a, mean roughness depth R_z and maximum roughness R_{max} for Sots pine and poplar.
Source [33].

	Scots pine						Poplar					
	R_z		R_a		R_{max}		R_z		R_a		R_{max}	
	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
Sanded	19.37	1.69	3.05	0.24	23.27	2.53	25.23	5.30	3.20	0.20	28.52	4.82
Sawn	50.09	6.22	6.43	0.32	81.07	20.86	87.53	7.67	13.33	0.87	106	16.19
Planed	34.05	1.92	5.39	0.33	40.65	2.66	46.65	4.90	7.07	0.76	57.69	4.97

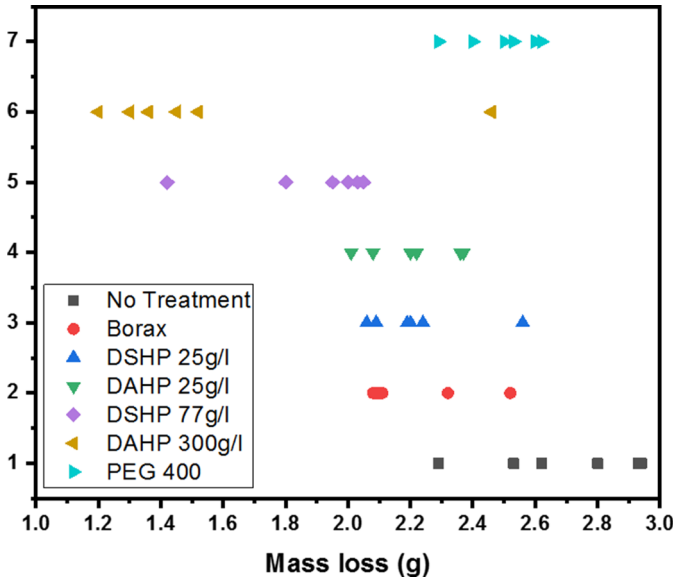

Fig. 1. Dot plot of measurements for Linder test for sanded Scots pine.

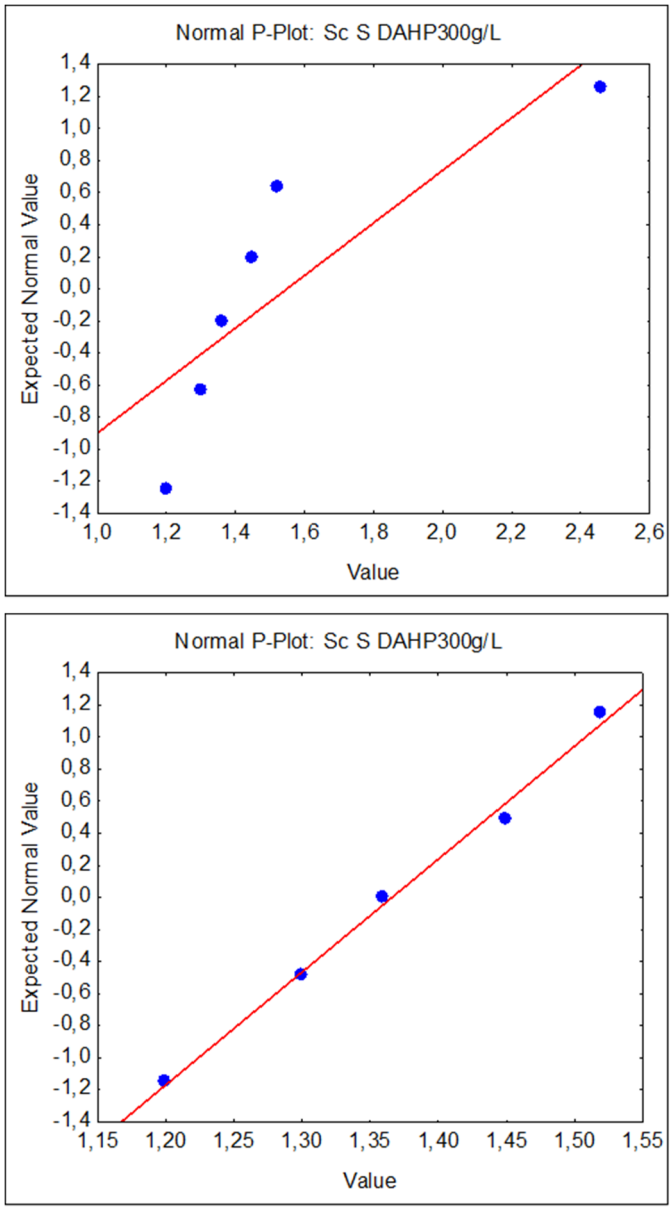

Fig. 2. (a) Descriptive statistics analysis for mass loss for the Linder test on sanded Scots pine treated with DAHP 300g/L with extreme outlier. (b) Descriptive statistics analysis after deleting extreme outlier.

calculate t value whenever the homogeneity of standard deviations could not be verified. A comparison of test results by t-test was only applied for tests within a given type of surface preparation because the untreated specimens of the different surface preparations produced varying results; see the test result summary in Table A.1. Behaviour of the specimens of different types of surface preparation was only compared for untreated specimens; test results are shown in Table A.2 and Table A3. In different series of t-tests, results obtained for treated specimens were converted to percentage values based on the untreated results. In this case, we could compare notable differences in the effect of given types of treatments between the individual surface preparation types, see test results summary in Table A.4.

Factorial analysis of variances was conducted for the Linder and single flame source tests in order to show the effect sizes of the different treatments on specimens of various types of surface preparations. The two factors were treatment type at 7 levels and surface preparation at 3 levels. Tables 3 and 4 give the results of f-tests of significance and the effect sizes.

For the calorimeter tests, the two factors were treatment type at 7 levels and wood species were used at 3 levels. Table 5 lists the results of f-tests of significance and the effect sizes. However, because of lack of homogeneity of variances in most cases, the p-values calculated cannot be taken as true; nevertheless, facts of significance were indicated and the trends of influences of treatments can be accepted. In order to obtain reliable evaluation results, pairwise comparisons were conducted by applying the "Newman-Keuls" test shown in Table B.1

According to the standard MSZ 9607/1-83 [22] for Lindner tests, for absolute protection, mass loss has to be less than 1.5 g. As can be seen in (Fig. 3), only DAHP with a concentration 300 g/l fulfilled the criterion of mass loss for both poplar and Scots pine. For poplar, mass loss was reduced by 54.91% for the sawn surface, by 67.37% for the planed surface, and by 59.45% for the sanded surface, while the decreases for Scots pine were 39.90% for the sawn surface, 46.08% for the planed surface, and 42.53% for the sanded surface. After completing the t-test, DAHP with 300 g/l concentration had the lowest mass loss among all wood specimens, while PEG 400 had the highest mass loss. The mass loss when various surfaces (sanded, planed, and sawn) were compared was significantly different in

Table 3
Univariate tests of significance, effect sizes, and powers for Scots pine and poplar mass loss.

Effect	SS	Degr. of freedom	MS	F	P	Partial eta-squared	non- centrality	observed power alpha = 0.05
Intercept	544.0546	1	544.0546	16961.91	0.000000	0.993964	16961.91	1.000000
Sc Treatment	16.8074	6	2.8012	87.33	0.000000	0.835726	524.00	1.000000
Sc Surface	0.5764	2	0.2882	8.99	0.000253	0.148557	17.97	0.970423
Sc Treatment* Sc Surface	1.9232	12	0.1603	5.00	0.000002	0.367938	59.96	0.999901
Error	3.3037	103	0.0321					
Intercept	888.4032	1	888.4032	11117.16	0.000000	0.990732	11117.16	1.000000
P Treatment	52.9347	6	8.8225	110.40	0.000000	0.864302	662.41	1.000000
P Surface	0.0287	2	0.0144	0.18	0.835773	0.003444	0.36	0.077228
P Treatment* P Surface	4.6654	12	0.3888	4.87	0.000003	0.359534	58.38	0.999861
Error	8.3109	104	0.0799					

Scots pine. In contrast, this difference in poplar was slight. For Scots pine, the planed surface had the lowest mass loss, while the sanded and sawn surfaces had the highest mass loss. The latter two surfaces revealed no substantial differences between them with most treatments. On the contrary, the planed surface of poplar has the highest mass loss and the three surface preparations had no significant differences with most treatments. In general, there was no marked difference between surface preparation on poplar and Scots pine. For poplar, all specimens treated with fire retardants, with the exception of those treated with PEG 400, had significantly lower mass loss than the untreated wood specimens, see Table A.1, which means almost all fire retardants were effective in increasing the fire resistance of the wood specimens. The mass loss of all Scots pine specimens treated with fire retardants was significantly lower than in untreated samples except for samples treated with borax and DSHP 25g/l on planed surface and PEG 400 on all surfaces. With respect to fire retardant concentrations, specimens treated with DAHP 25g/l had a notably higher mass loss than the samples treated with DAHP 300g/l in both wood species. This indicates that the concentration had a positive effect on the performance of fire retardants. Concerning DSHP, there was no marked difference of mass loss between the concentration 25g/l and 77g/l in Scots pine, while in poplar the difference was significant. This implies that efficiency of concentration was influenced by various factors like the wood species itself and the fire retardant used. Comparing the mass loss of wood specimens with different surface preparations by t-tests showed that for poplar there was no noteworthy difference while for Scots pine there was significant difference between planed and sanded surfaces and between sawn and sanded surfaces as shown in Tables A.2 and A.3. ANOVA indicated that all treatments affected mass loss on both wood species, but surface preparations only affected Scots pine.

All specimens fulfilled the criteria according to the EN ISO 11925-2:2011 [23] standard as none of the burning lengths exceeded 15 cm see (Fig. 4). DAHP with concentration of 300g/l had the lowest burning length among all treated and untreated specimens of both wood species. This resulted in burning lengths that were reduced by 50% on the sawn surface, 43.46% on the planed surface, and 42.53% on the sanded surface for Scots pine, and by 47.87% on the sawn surface, 51.28% on the planed surface, and 45.62% on the sanded surface for poplar as compared to the allowable value. Borax also achieved good results, especially on Scots pine, in which it decreased burning length by 40.62% on the sawn surface and by 46.13% for both planed and sanded surface. For poplar, borax decreased the burning length by 40.90%, 22.71%, and 35.85% for sawn, planed and sanded surface respectively. All specimens treated with fire retardants had a lower burning length than untreated samples, but PEG 400 had almost the same results as untreated wood specimens. This means that PEG 400 is ineffective as a fire retardant for both poplar and Scots pine. The burning lengths of wood specimens prepared with different surface preparations were compared with the t-test; results indicated no significant difference in Scots pine while in poplar there was significant difference between planed and sawn surfaces and among sawn and sanded surfaces. According to ANOVA results, treatments do have an effect on burning length on both wood species, while influence of surface preparation was important only in Scots pine. The interaction between treatment and surface had no effect on Scots pine specimens.

Calorimeter test results (see Fig. 5) showed that the heat of combustion for specimens treated with DAHP 300g/l was significantly lower than that of other specimens in all wood species, while PEG 400 had the highest heat of combustion, which was even higher than that of the untreated wood specimens. Specimens treated with DSHP 77g/l had the second lowest heat of combustion. Date palm leaflet, poplar, and Scots pine specimens treated with DSHP 25 g/l had substantially higher heat of combustion than the specimens treated with DSHP 77 g/l, especially in poplar. With date palm leaflet, poplar, and Scots pine specimens treated with DAHP 25 g/l, the heat of combustion was significantly higher than it was in specimens treated with DAHP 300 g/l, which indicated that the concentration of fire retardants had an effect on the heat of combustion. No noteworthy difference emerged between specimens treated with borax and specimens treated with DSHP 25 g/l for any of the two wood species. Similarly there was no significant difference in heat of combustion for date palm leaflet poplar specimens treated with DAHP 25 g/l and specimens treated with borax, but a substantial difference was noted for Scots spine. Significant differences in heat of combustion between all treated specimens treated with various fire retardants with the exception of borax; whereas there was no significant difference between date palm leaflet and Scots pine. Among all treated or untreated specimens, poplar had the lowest heat of combustion except with PEG 400. Among all the fire retardants, DAHP 300 g/l and DSHP 77 g/l performed the best and also displayed the lowest heat of combustion. For both, the lowest heat of combustion was measured in poplar, while the

Table 4
Univariate tests of significance, effect sizes, and powers for Scots pine and poplar burning length.

Effect	SS	Degr. of freedom	MS	F	P	Partial eta-squared	non- centrality	observed power alpha = 0.05
Intercept	3807.541	1	3807.541	9857.691	0.000000	0.989461	9857.691	1.000000
Sc Treatment	180.165	6	30.028	77.741	0.000000	0.816256	466.447	1.000000
Sc Surface	9.413	2	4.707	12.186	0.000017	0.188381	24.371	0.994804
Sc Treatment* Sc Surface	7.212	12	0.601	1.556	0.116208	0.150971	18.671	0.788611
Error	40.556	105	0.386					
Intercept	4173.984	1	4173.984	10418.79	0.000000	0.990117	10418.79	1.000000
P Treatment	184.613	6	30.769	76.80	0.000000	0.815869	460.82	1.000000
P Surface	1.434	2	0.717	1.79	0.172083	0.033276	3.58	0.366935
P Treatment* P Surface	15.456	12	1.288	3.22	0.000598	0.270591	38.58	0.991502
Error	41.665	104	0.401					

Table 5
Univariate tests of significance, effect sizes, and powers for Scots pine, poplar, and date palm leaflet heat of combustion.

Effect	SS	Degr. of freedom	MS	F	P	Partial eta-squared	non- centrality	observed power alpha = 0.05
Intercept	31568.86	1	31568.86	69301.52	0.00	0.998789	69301.52	1.000000
Treatment	865.02	6	144.17	316.49	0.00	0.957638	1898.93	1.000000
Wood Species	100.69	2	50.34	110.51	0.00	0.724617	221.03	1.000000
Treatment*Wood Species	88.63	12	7.39	16.21	0.00	0.698450	194.56	1.000000
Error	38.26	84	0.46					

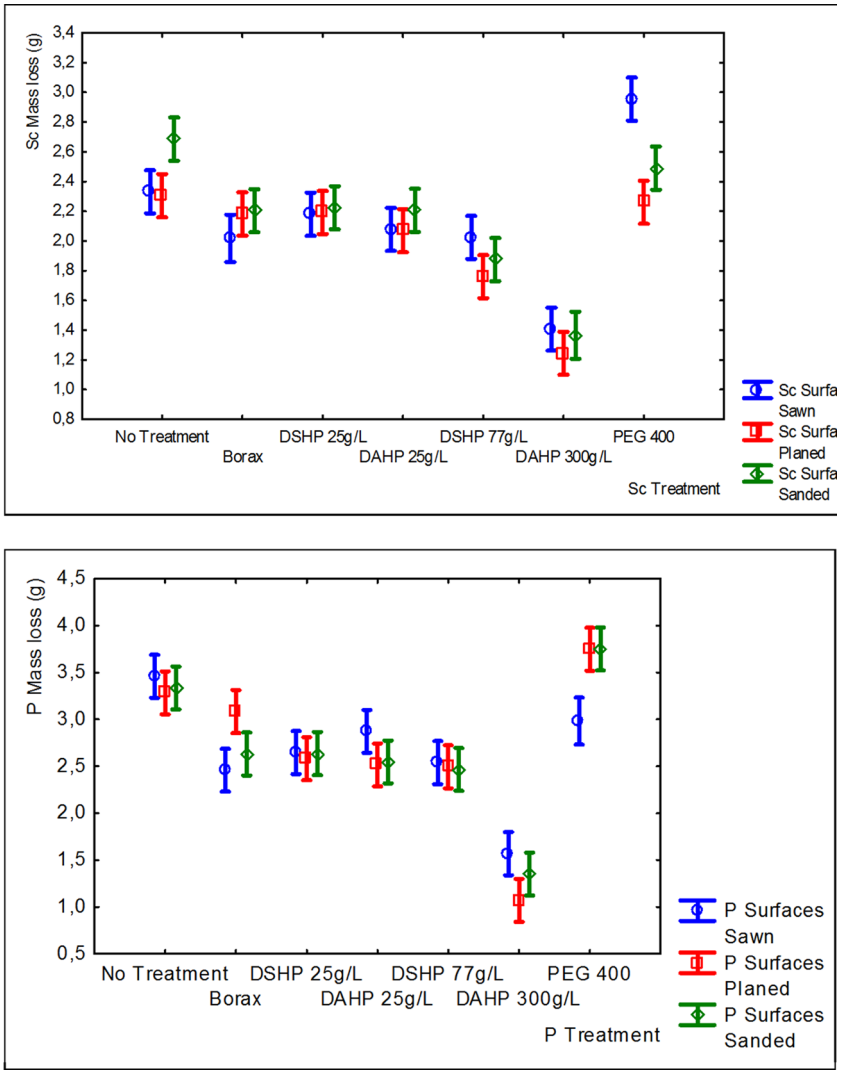

Fig. 3. Mass loss (g), Scots pine results (a), results of poplar (b).

highest was measured in date palm leaflet. DSHP 300 g/l reduced the heat of combustion for poplar by 47.05%, by 33.01% for Scots pine, and by 19.80% for date palm leaflet. DSHP 77g/l, decreased the heat of combustion by 31.04% for poplar, by 10.77% for Scot spine, and by 5.37% for date palm leaflet. According to t-test results for untreated wood specimens, poplar showed no notable difference compared to Scots pine and date palm tree leaflet. On other hand, there was significant difference between Scots pine and date palm leaflet. Considerable differences between the heat of combustion in the treated wood species samples emerged, with poplar having the lowest while Scots pine the highest heat of combustion. DAHP 300 g/l concentration and DSHP 77 g/l concentration treated date palm leaflets presented the highest heat of combustion, while poplar had the lowest value. ANOVA analysis indicated that both treatment and wood species have an effect on heat of combustion.

3.3. Hydration test

In a normal curve, a small rise appears in the initial state of the cement hydration process. Following this, the curve becomes constant before rising at the end when the cement reaches its hardening stage. The hydration test indicated that all specimens treated with fire retardants were cured after 24 hours, with the exception of PEG 400-treated specimens. The best result was achieved with borax, as the curve of temperature change during cement curing was similar to the untreated cement mixture. For the other fire retardants, the smallest concentration achieved the same results as the high concentration with high temperature peak in the beginning of the cement curing, followed by a decrease in temperature. On the other hand, the PEG400 curve had no increase in temperature from the initial stage of the cement hydration process; this prevented the cement from curing. The

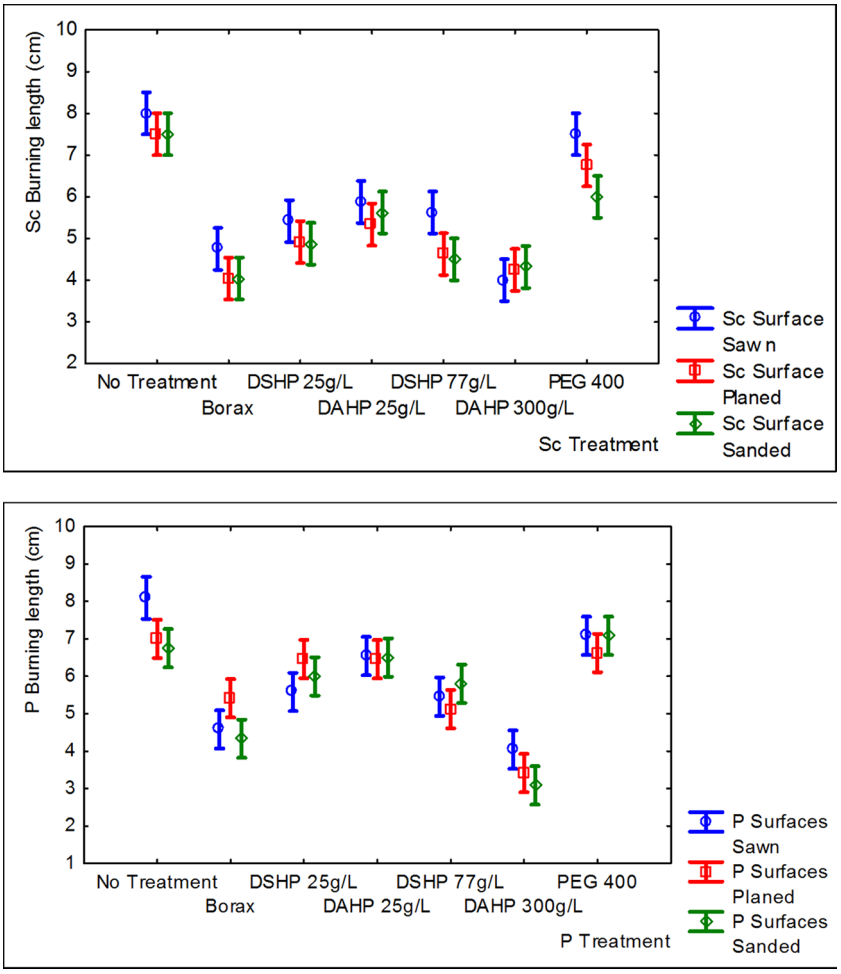

Fig. 4. Burning length (cm), Scots pine results (a), results of poplar (b).

specimen treated with PEG 400 did not reach the hardening stage even after 6 months of drying, which means PEG 400 is unsuitable for CBPB production, see Fig. 6. According to the results, PEG 400 will increase the setting time of cement hydration and even prevent it from curing, while the high concentration of DAHP and DSHP will increase the setting time by a short period, leading to a worsening of the compatibility of wood and cement by adversely affecting mechanical properties and initial board strength. On other hand, borax, DAHP and DSHP with 25 g/l concentration are expected to have no effect on the setting time of cement hydration and to have no effect on the mechanical and initial board strength.

3.4. Discussion

Surface roughness results indicated that poplar had higher surface

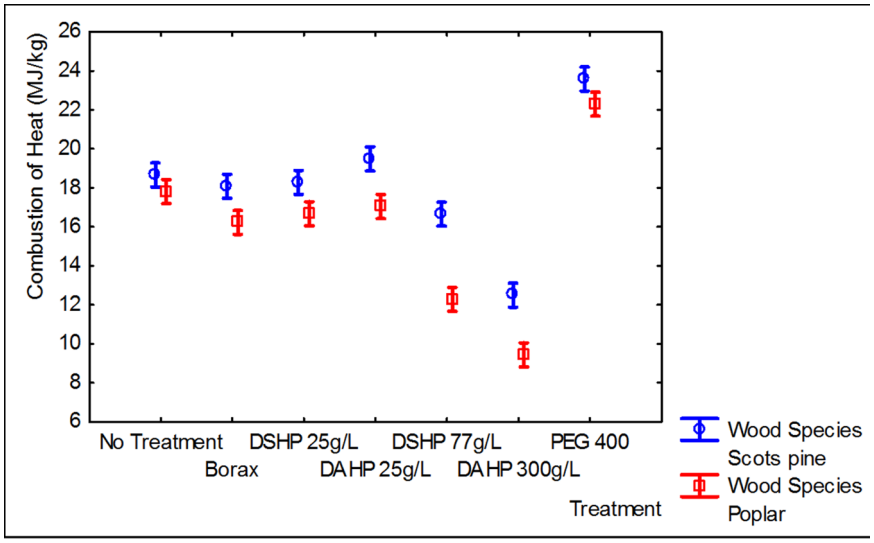

Fig. 5. Heat of combustion (MJ/kg) for Scots pine and poplar.

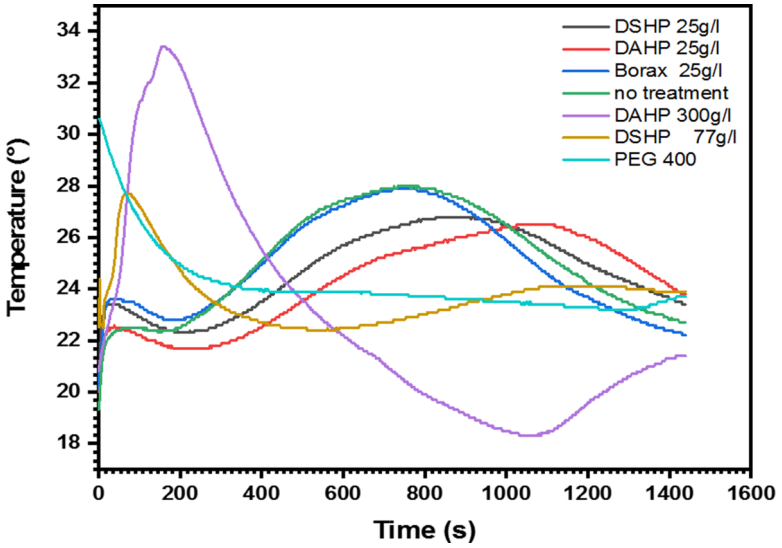

Fig. 6. Hydration test of cement treated with different fire retardants; temperature change within 24 hours of cement curing.

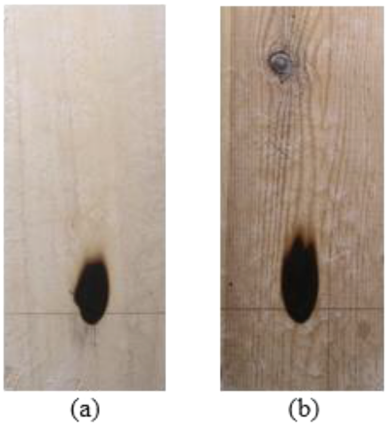

Fig. 7. (a) Sample of poplar treated with DAHP 300 g/l. (b) Sample of Scots pine treated with DAHP 300 g/l. Both figures show a thin film on the surface of samples that is caused by DAHP 300 g/l.

roughness than Scots pine; which aligns with results in the literature [35]. Nevertheless, the results for surface roughness of specimens used in this study were lower than the results found in the literature. The difference between poplar and Scots pine was caused by the difference of the anatomical structure of wood species. In addition, the density of poplar was lower (320 kg/m^3) than that of Scots pine (500 kg/m^3). There are many factors that affect the surface roughness of wood, like the machining, moisture content, density, and anatomical structure [36-38]. Since all samples were machined in the same manner and had the same moisture content, density and anatomical structure were the only remaining influencing factors.

Phosphorus compounds are well-known fire retardants for wood because they reduce thermal degradation [6], form acids that decrease wood temperature [7], and, as a result, increase its dehydration and char formation [8,9]. DAHP and DSHP barely improved the fire resistance at lower concentration of fire retardants in each fire test and for all wood species, both in particle and solid wood forms. When the concentration was increased, they became very effective fire retardants especially on poplar. Both DAHP and DSHP in high concentrations formed a thin white layer on the surface of treated specimens, which worked as a protective layer against fire; see Fig. 7. The thin layer was created because of the low wettability of the used fire retardants on wood [33]. These results confirm those noted in previously published literature [38-40].

DAHP with a concentration of 300 g/l had the best results in all fire tests. When measuring the heat of combustion of Scots pine treated with the DAHP 300 g/l, results were the same as the results found by Terzi et al [41]. The DAHP and DSHP were suitable fire retardants for wood, but only in high concentrations. Borax is one of the known boron compounds. Bysal et al [12] reported that borax had the advantage of supressing fire propagation, but also promoted smouldering. Therefore, it is usually recommended to use borax with boric acid, which supresses smouldering. In this study, borax was first tested with the Lindner test, where mass loss was measured. Borax did not improve the fire resistance of the wood species. The same results were observed with the heat of combustion during the calorimeter test. Both tests offered insights into wood smouldering. For testing fire propagation, the single flame source test was performed to check the burning length. In this test, borax had one of the best results among all the tested fire retardants, which means that borax is good at supressing fire propagation. To be an effective fire retardant, borax has to be applied together with the boric acid because borax alone will not protect against fire. Borax always had lower fire retardation than DAHP 300g/l on poplar and Scots pine. Demir and Aydin (2019) [35] tested these fire retardants on poplar and Scots pine and found that the thermal conductivity of DAHP is higher than the thermal conductivity of Borax. A fire retardant's thermal conductivity allows chemicals to absorb heat, thus preventing the ignition of the wood surface. Since DAHP has higher thermal conductivity, it will impart better fire retardation than Borax. PEG is not known as a fire retardant, but one of the research [18] reports proved PEG to be an effective fire retardant, but only if its molecular weight was lower than 600. In this study, PEG 400 was used, but in almost all of the fire tests completed, the wood samples treated with PEG performed even worse than the untreated samples. This means that PEG 400 is not a suitable fire retardant for wood. In addition, PEG 400 is unsuitable for CBPB production because the hydration test of cement with the use of PEG 400 showed that the cement could not be cured even after 6 months.

Thus, it can be concluded that fire retardants containing the phosphorus compounds DSHP and DAHP were not only effective fire retardants for wood, but could also be introduced in CBPB production. While these compounds enhance the fire resistance of wood, they do not affect the curing of cement. They must be used at high concentrations for effective fire protection. Since particles are used in CBPB production particles, better results can be expected with poplar.

4. Conclusion

This study concentrated on borax, DAHP, DSHP, and PEG 400, which are all popular, low cost, and low toxicity fire retardants for wood. The fire resistance of these fire retardants was tested on wood species that are

known in CBPB production. The retardants were tested in different concentrations on varying surface roughness of both solid and particle form wood, using two kinds of natural wood modification via soaking and coating the specimens. A hydration test considered the influence of the fire retardants on cement. Results demonstrate poplar achieved the best fire resistance. As fire retardants, DAHP and DSHP in high concentrations obtained the best results in all wood species. Borax displayed excellent flame spread prevention qualities and had no adverse effect on cement curing. On the other hand, PEG 400 had the worst fire resistance and it prevent cement from curing, make it not suitable for CBPB production. DSHP and DAHP with high concentration negatively influenced cement curing, which lead to decreases in the mechanical properties of CBPB. Nevertheless, using the proper amounts of curing agents can alleviate this problem. However, with decreasing the DAHP and DSHP concentration to 25g/l, cement-setting time of cement hydration increased and it is expected to have no effect on mechanical properties of CBPB. Future studies can focus on producing CBPB with particles treated with the fire retardants tested in this study except PEG 400. Testing the fire resistance of boards and analysing their effect on the density and mechanical properties of boards could be another future focus.

Author Contributions

Statistical analysis K.Zs and F.Z.B, Fire tests F.Z.B and P.Gy.H., Hydration test F.Z.B and T.L.A

CRediT authorship contribution statement

Fatima Zohra Brahmia: Investigation, Writing - original draft, Writing - review & editing. **Kovács Zsolt:** Writing - review & editing. **Péter György Horváth:** Funding acquisition, Project administration, Resources, Supervision. **Tibor László Alpár:** Funding acquisition, Project administration, Resources, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.surfin.2020.100736.

Appendix A

Note: In Tables A.1 and A.4, the non-significant difference results deleted.

Table A.1
T-test of mass loss for sawn scots pine treated with different fire retardant.

Group 1 vs. Group 2	T-test for Independent Samples (Spreadsheet t-test) Note: Variables were treated as independent samples										
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	P Variances
Sc Sw No Treatment vs. Sc Sw Borax	23,30,000	20,18,000	4,48,695	9	0,001517	6	5	0,136675	0,079498	29,557	0,315928
Sc Sw No Treatment vs. Sc Sw DAHP25g/L	23,30,000	20,78,333	4,41,038	10	0,001314	6	6	0,136675	0,029269	2,18,054	0,004171
Sc Sw No Treatment vs. Sc Sw DSHP77g/L	23,30,000	20,23,333	4,73,322	10	0,000800	6	6	0,136675	0,080664	28,709	0,271862
Sc Sw No Treatment vs. Sc Sw DAHP300g/L	23,30,000	14,06,667	9,57,910	10	0,000002	6	6	0,136675	0,192527	19,843	0,470023
Sc Sw No Treatment vs. Sc Sw PEG400	23,30,000	29,53,333	-3,54,538	10	0,005309	6	6	0,136675	0,408395	89,286	0,031279
Sc Sw Borax vs. Sc Sw No Treatment	20,18,000	23,30,000	-4,48,695	9	0,001517	5	6	0,079498	0,136675	29,557	0,315928
Sc Sw Borax vs. Sc Sw DSHP25g/L	20,18,000	21,80,000	-2,52,446	9	0,032530	5	6	0,079498	0,123126	23,987	0,417078
Sc Sw Borax vs. Sc Sw DAHP300g/L	20,18,000	14,06,667	6,59,965	9	0,000099	5	6	0,079498	0,192527	58,650	0,111279
Sc Sw Borax vs. Sc Sw PEG400	20,18,000	29,53,333	-4,99,921	9	0,000740	5	6	0,079498	0,408395	2,63,903	0,007353
Sc Sw DSHP25g/L vs. Sc Sw Borax	21,80,000	20,18,000	2,52,446	9	0,032530	6	5	0,123126	0,079498	23,987	0,417078
Sc Sw DSHP25g/L vs. Sc Sw DSHP77g/L	21,80,000	20,23,333	2,60,709	10	0,026171	6	6	0,123126	0,080664	23,299	0,374739
Sc Sw DSHP25g/L vs. Sc Sw DAHP300g/L	21,80,000	14,06,667	8,28,889	10	0,000009	6	6	0,123126	0,192527	24,450	0,348866
Sc Sw DSHP25g/L vs. Sc Sw PEG400	21,80,000	29,53,333	-4,44,089	10	0,001253	6	6	0,123126	0,408395	1,10,018	0,019861
Sc Sw DAHP25g/L vs. Sc Sw No Treatment	20,78,333	23,30,000	-4,41,038	10	0,001314	6	6	0,029269	0,136675	2,18,054	0,004171
Sc Sw DAHP25g/L vs. Sc Sw DAHP300g/L	20,78,333	14,06,667	8,44,843	10	0,000007	6	6	0,029269	0,192527	4,32,685	0,000813
Sc Sw DAHP25g/L vs. Sc Sw PEG400	20,78,333	29,53,333	-5,23,468	10	0,000382	6	6	0,029269	0,408395	19,46,926	0,000020
Sc Sw DSHP77g/L vs. Sc Sw No Treatment	20,23,333	23,30,000	-4,73,322	10	0,000800	6	6	0,080664	0,136675	28,709	0,271862
Sc Sw DSHP77g/L vs. Sc Sw DSHP25g/L	20,23,333	21,80,000	-2,60,709	10	0,026171	6	6	0,080664	0,123126	23,299	0,374739
Sc Sw DSHP77g/L vs. Sc Sw DAHP300g/L	20,23,333	14,06,667	7,23,629	10	0,000028	6	6	0,080664	0,192527	56,967	0,079087
Sc Sw DSHP77g/L vs. Sc Sw PEG400	20,23,333	29,53,333	-5,47,227	10	0,000272	6	6	0,080664	0,408395	2,56,332	0,002850
Sc Sw DAHP300g/L vs. Sc Sw No Treatment	14,06,667	23,30,000	-9,57,910	10	0,000002	6	6	0,192527	0,136675	19,843	0,470023
Sc Sw DAHP300g/L vs. Sc Sw Borax	14,06,667	20,18,000	-6,59,965	9	0,000099	6	5	0,192527	0,079498	58,650	0,111279
Sc Sw DAHP300g/L vs. Sc Sw DSHP25g/L	14,06,667	21,80,000	-8,28,889	10	0,000009	6	6	0,192527	0,123126	24,450	0,348866
Sc Sw DAHP300g/L vs. Sc Sw DAHP25g/L	14,06,667	20,78,333	-8,44,843	10	0,000007	6	6	0,192527	0,029269	4,32,685	0,000813
Sc Sw DAHP300g/L vs. Sc Sw DSHP77g/L	14,06,667	20,23,333	-7,23,629	10	0,000028	6	6	0,192527	0,080664	56,967	0,079087
Sc Sw DAHP300g/L vs. Sc Sw PEG400	14,06,667	29,53,333	-8,39,099	10	0,000008	6	6	0,192527	0,408395	44,996	0,124418
Sc Sw PEG400 vs. Sc Sw No Treatment	29,53,333	23,30,000	3,54,538	10	0,005309	6	6	0,408395	0,136675	89,286	0,031279
Sc Sw PEG400 vs. Sc Sw Borax	29,53,333	20,18,000	4,99,921	9	0,000740	6	5	0,408395	0,079498	2,63,903	0,007353
Sc Sw PEG400 vs. Sc Sw DSHP25g/L	29,53,333	21,80,000	4,44,089	10	0,001253	6	6	0,408395	0,123126	1,10,018	0,019861
Sc Sw PEG400 vs. Sc Sw DAHP25g/L	29,53,333	20,78,333	5,23,468	10	0,000382	6	6	0,408395	0,029269	19,46,926	0,000020
Sc Sw PEG400 vs. Sc Sw DSHP77g/L	29,53,333	20,23,333	5,47,227	10	0,000272	6	6	0,408395	0,080664	2,56,332	0,002850
Sc Sw PEG400 vs. Sc Sw DAHP300g/L	29,53,333	14,06,667	8,39,099	10	0,000008	6	6	0,408395	0,192527	44,996	0,124418

Table A.2
t-test of mass loss for untreated scots pine with different surface preparation.

Group 1 vs. Group 2	T-test for Independent Samples (Spreadsheet t-test) Note: Variables were treated as independent samples										
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Sc Sw No Treatment vs. Sc Sw No Treatment	23,30,000	23,30,000	0,00000	10	10,00,000	6	6	0,136675	0,136675	10,00,000	10,00,000
Sc Sw No Treatment vs. Sc P No Treatment	23,30,000	23,05,000	0,32907	10	0,748890	6	6	0,136675	0,126293	11,71,160	0,866584
Sc Sw No Treatment vs. Sc S No Treatment	23,30,000	26,85,000	-3,01,487	10	0,013009	6	6	0,136675	0,253988	34,53,426	0,199956
Sc P No Treatment vs. Sc Sw No Treatment	23,05,000	23,30,000	-0,32907	10	0,748890	6	6	0,126293	0,136675	11,71,160	0,866584
Sc P No Treatment vs. Sc P No Treatment	23,05,000	23,05,000	0,00000	10	10,00,000	6	6	0,126293	0,126293	10,00,000	10,00,000
Sc P No Treatment vs. Sc S No Treatment	23,05,000	26,85,000	-3,28,148	10	0,008268	6	6	0,126293	0,253988	40,44,514	0,151324
Sc S No Treatment vs. Sc Sw No Treatment	26,85,000	23,30,000	3,01,487	10	0,013009	6	6	0,253988	0,136675	34,53,426	0,199956
Sc S No Treatment vs. Sc P No Treatment	26,85,000	23,05,000	3,28,148	10	0,008268	6	6	0,253988	0,126293	40,44,514	0,151324
Sc S No Treatment vs. Sc S No Treatment	26,85,000	26,85,000	0,00000	10	10,00,000	6	6	0,253988	0,253988	10,00,000	10,00,000

Table A.3
t-test of mass loss for untreated poplar with different surface preparation.

Group 1 vs. Group 2	T-test for Independent Samples (Spreadsheet t-test) Note: Variables were treated as independent samples										
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
P Sw No Treatment vs. P Sw No Treatment	34,60,000	34,60,000	0,00000	10	10,00,000	6	6	0,180776	0,180776	10,00,000	10,00,000
P Sw No Treatment vs. P P No Treatment	34,60,000	32,83,333	2,06,333	10	0,066017	6	6	0,180776	0,106333	28,90,330	0,268930
P Sw No Treatment vs. P S No Treatment	34,60,000	33,36,667	0,96628	10	0,356689	6	6	0,180776	0,255082	19,91,024	0,467872
P P No Treatment vs. P Sw No Treatment	32,83,333	34,60,000	-2,06,333	10	0,066017	6	6	0,106333	0,180776	28,90,330	0,268930
P P No Treatment vs. P P No Treatment	32,83,333	32,83,333	0,00000	10	10,00,000	6	6	0,106333	0,106333	10,00,000	10,00,000
P P No Treatment vs. P S No Treatment	32,83,333	33,36,667	-0,47272	10	0,646562	6	6	0,106333	0,255082	57,54,717	0,077518
P S No Treatment vs. P Sw No Treatment	33,36,667	34,60,000	-0,96628	10	0,356689	6	6	0,255082	0,180776	19,91,024	0,467872
P S No Treatment vs. P P No Treatment	33,36,667	32,83,333	0,47272	10	0,646562	6	6	0,255082	0,106333	57,54,717	0,077518
P S No Treatment vs. P S No Treatment	33,36,667	33,36,667	0,00000	10	10,00,000	6	6	0,255082	0,255082	10,00,000	10,00,000

Table A.4
t-test of mass loss of scots pine for different treatments with different surface preparation.

Group 1 vs. Group 2	T-test for Independent Samples (Spreadsheet t-test1) Note: Variables were treated as independent samples										
	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
Sc Sw DSHP25g/L vs. Sc S DSHP25g/L	64,378	1,71,943	-31,000	10	0,011250	6	6	5,28,438	6,65,685	1,59	0,624682
Sc Sw DAHP25g/L vs. Sc S DAHP25g/L	1,08,011	1,78,150	-30,985	10	0,011279	6	6	1,25,617	5,40,059	18,48	0,006131
Sc Sw DSHP77g/L vs. Sc P DSHP77g/L	1,31,617	2,44,635	-30,184	10	0,012930	6	6	3,46,197	8,49,308	6,02	0,070907
Sc Sw DSHP77g/L vs. Sc S DSHP77g/L	1,31,617	3,01,676	-43,421	10	0,001462	6	6	3,46,197	8,94,708	6,68	0,057452
Sc Sw PEG400 vs. Sc P PEG400	-2,67,525	30,043	-40,866	10	0,002191	6	6	17,52,769	3,30,221	28,17	0,002277
Sc Sw PEG400 vs. Sc S PEG400	-2,67,525	72,626	-45,930	10	0,000991	6	6	17,52,769	4,67,556	14,05	0,011490
Sc P Borax vs. Sc S Borax	63,662	1,79,392	-26,683	10	0,023562	6	6	8,25,293	6,69,010	1,52	0,656213
Sc P DSHP25g/L vs. Sc S DSHP25g/L	59,371	1,71,943	-33,715	10	0,007103	6	6	4,75,149	6,65,685	1,96	0,476987
Sc P DSHP77g/L vs. Sc Sw DSHP77g/L	2,44,635	1,31,617	30,184	10	0,012930	6	6	8,49,308	3,46,197	6,02	0,070907
Sc P PEG400 vs. Sc Sw PEG400	30,043	-2,67,525	40,866	10	0,002191	6	6	3,30,221	17,52,769	28,17	0,002277
Sc S Borax vs. Sc P Borax	1,79,392	63,662	26,683	10	0,023562	6	6	6,69,010	8,25,293	1,52	0,656213
Sc S DSHP25g/L vs. Sc Sw DSHP25g/L	1,71,943	64,378	31,000	10	0,011250	6	6	6,65,685	5,28,438	1,59	0,624682
Sc S DSHP25g/L vs. Sc P DSHP25g/L	1,71,943	59,371	33,715	10	0,007103	6	6	6,65,685	4,75,149	1,96	0,476987
Sc S DAHP25g/L vs. Sc Sw DAHP25g/L	1,78,150	1,08,011	30,985	10	0,011279	6	6	5,40,059	1,25,617	18,48	0,006131
Sc S DSHP77g/L vs. Sc Sw DSHP77g/L	3,01,676	1,31,617	43,421	10	0,001462	6	6	8,94,708	3,46,197	6,68	0,057452

Appendix B

Appendix B

Table B.1
Newman-keuls test for mass loss of scots pine

Cell No.	Newman-Keuls test; variable Sc Mass loss (Spreadsheet Anova) Approximate Probabilities for Post Hoc Tests Error: Between MSE =,03208, df = 103,00										
	Sc Treatment	Sc Surface	{1} 2,3300	{2} 2,3050	{3} 2,6850	{4} 2,0180	{5} 2,1817	{6} 2,2033	{7} 2,1800	{8} 2,1917	{9} 2,2233
1	No Treatment	Sawn		0,811294	0,002826	0,143147	0,845546	0,829409	0,880766	0,838628	0,737103
2	No Treatment	Planed	0,811294		0,002470	0,218045	0,899613	0,866378	0,930971	0,886075	0,714725
3	No Treatment	Sanded	0,002826	0,002470		0,000140	0,000342	0,000396	0,000379	0,000354	0,000456
4	Borax	Sawn	0,143147	0,218045	0,000140		0,621366	0,637872	0,531488	0,641477	0,623650
5	Borax	Planed	0,845546	0,899613	0,000342	0,621366		0,976605	0,987389	0,923962	0,994622
6	Borax	Sanded	0,829409	0,866378	0,000396	0,637872	0,976605		0,996102	0,911316	0,980050
7	DSHP 25g/L	Sawn	0,880766	0,930971	0,000379	0,531488	0,987389	0,996102		0,993213	0,998452
8	DSHP 25g/L	Planed	0,838628	0,886075	0,000354	0,641477	0,923962	0,911316	0,993213		0,990327
9	DSHP 25g/L	Sanded	0,737103	0,714725	0,000456	0,623650	0,994622	0,980050	0,998452	0,990327	
10	DAHP 25g/L	Sawn	0,330443	0,431959	0,000121	0,938550	0,584931	0,752833	0,332453	0,699053	0,806452
11	DAHP 25g/L	Planed	0,313065	0,419109	0,000133	0,879949	0,699053	0,788093	0,534998	0,761919	0,813755
12	DAHP 25g/L	Sanded	0,761919	0,782331	0,000367	0,677208	0,995207	0,974679	0,999104	0,988765	0,873543
13	DSHP 77g/L	Sawn	0,143426	0,215347	0,000138	0,959437	0,554044	0,601470	0,440748	0,592207	0,604425
14	DSHP 77g/L	Planed	0,000170	0,000204	0,000160	0,039775	0,002619	0,001980	0,002146	0,002368	0,001435
15	DSHP 77g/L	Sanded	0,002470	0,005006	0,000147	0,173768	0,060207	0,053344	0,047789	0,058903	0,044130
16	DAHP 300g/L	Sawn	0,000147	0,000139	0,000166	0,000139	0,000131	0,000170	0,000119	0,000157	0,000131
17	DAHP 300g/L	Planed	0,000166	0,000160	0,000163	0,000121	0,000170	0,000131	0,000157	0,000118	0,000139
18	DAHP 300g/L	Sanded	0,000160	0,000147	0,000160	0,000116	0,000157	0,000118	0,000131	0,000170	0,000137
19	PEG 400	Sawn	0,000139	0,000116	0,011681	0,000147	0,000170	0,000131	0,000118	0,000157	0,000119
20	PEG 400	Planed	0,781132	0,667421	0,000958	0,429745	0,974977	0,948330	0,987664	0,965451	0,726226
21	PEG 400	Sanded	0,128485	0,184081	0,064684	0,001398	0,088189	0,097372	0,100376	0,092364	0,086803

Cell No.	Newman-Keuls test; variable Sc Mass loss (Spreadsheet Anova) Approximate Probabilities for Post Hoc Tests Error: Between MSE =,03208, df = 103,00											
	{10} 2,0783	{11} 2,0683	{12} 2,2067	{13} 2,0233	{14} 1,7600	{15} 1,8750	{16} 1,4067	{17} 1,2450	{18} 1,3660	{19} 2,9533	{20} 2,2600	{21} 2,4900
1	0,330443	0,313065	0,761919	0,143426	0,000170	0,002470	0,000147	0,000166	0,000160	0,000139	0,781132	0,128485
2	0,431959	0,419109	0,782331	0,215347	0,000204	0,005006	0,000139	0,000160	0,000147	0,000116	0,667421	0,184081
3	0,000121	0,000133	0,000367	0,000138	0,000160	0,000147	0,000166	0,000163	0,000160	0,011681	0,000958	0,064684
4	0,938550	0,879949	0,677208	0,959437	0,039775	0,173768	0,000139	0,000121	0,000116	0,000147	0,429745	0,001398
5	0,584931	0,699053	0,995207	0,554044	0,002619	0,060207	0,000131	0,000170	0,000157	0,000170	0,974977	0,088189
6	0,752833	0,788093	0,974679	0,601470	0,001980	0,053344	0,000170	0,000131	0,000118	0,000131	0,948330	0,097372
7	0,332453	0,534998	0,999104	0,440748	0,002146	0,047789	0,000119	0,000157	0,000131	0,000118	0,987664	0,100376
8	0,699053	0,761919	0,988765	0,592207	0,002368	0,058903	0,000157	0,000118	0,000170	0,000157	0,965451	0,092364
9	0,806452	0,813755	0,873543	0,604425	0,001435	0,044130	0,000131	0,000139	0,000137	0,000119	0,726226	0,086803
10		0,923962	0,821482	0,858404	0,033749	0,299111	0,000120	0,000131	0,000119	0,000131	0,661047	0,006642
11	0,923962		0,838628	0,667421	0,031211	0,255328	0,000121	0,000119	0,000119	0,000137	0,658235	0,005655
12	0,821482	0,838628		0,650552	0,002120	0,058496	0,000118	0,000137	0,000131	0,000119	0,866247	0,081140
13	0,858404	0,667421	0,650552		0,062371	0,333970	0,000116	0,000119	0,000121	0,000139	0,419109	0,001458
14	0,033749	0,031211	0,002120	0,062371		0,273238	0,001123	0,000153	0,000880	0,000166	0,000499	0,000147
15	0,299111	0,255328	0,058496	0,333970	0,273238		0,000155	0,000116	0,000157	0,000160	0,017912	0,000142
16	0,000120	0,000121	0,000118	0,000116	0,001123	0,000155		0,272748	0,697773	0,000160	0,000137	0,000160
17	0,000131	0,000119	0,000137	0,000119	0,000153	0,000116	0,272748		0,249133	0,000160	0,000147	0,000160
18	0,000119	0,000119	0,000131	0,000121	0,000880	0,000157	0,697773	0,249133		0,000163	0,000139	0,000166
19	0,000131	0,000137	0,000119	0,000139	0,000166	0,000160	0,000160	0,000160	0,000163		0,000121	0,000165
20	0,661047	0,658235	0,866247	0,419109	0,000499	0,017912	0,000137	0,000147	0,000139	0,000121		0,129228
21	0,006642	0,005655	0,081140	0,001458	0,000147	0,000142	0,000160	0,000160	0,000166	0,000165	0,129228	

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