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PHYSICAL, MECHANICAL, AND THERMAL CHARACTERISTICS OF ALKALINE COPPER QUATERNARY IMPREGNATED ORIENTAL BEECH WOOD

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ABSTRACT

The physical, mechanical, and thermal properties of Oriental beech (*Fagus orientalis*), which had been impregnated with the water-based, copper-containing Korasit KS material from the Alkaline Copper Quaternary group, were investigated in this study. According to ASTM 1413-07el (2007) standard, the wood samples used in the investigation were impregnated with 3 % and 6 % aqueous solutions of Korasit KS. The modulus of rupture, thermal, and water absorption tests were performed on samples of Oriental beech after they had been impregnated. Oriental beech's modulus of rupture values decreased as a result of Korasit KS impregnation. Additionally, Oriental beech had lower modulus of rupture values at greater concentrations of Korasit KS. In every water absorption period, the water absorption values of the Oriental beech impregnated with Korasit KS were higher than those of the control group. Our results showed that Korasit KS impregnation enhanced thermal properties of Oriental beech. Moreover, higher concentration levels of Oriental beech yielded better thermal characteristics of Oriental beech.

Keywords: Impregnation, Korasit KS, mechanical properties, Oriental beech, physical properties, thermal properties.

INTRODUCTION

A range of technical and structural sectors can benefit from the usage of wood, a natural material. Furthermore, wood maintains its significance in the locations where it is employed due of its many exceptional qualities (Örs and Keskin 2001, Khalil *et al.* 2010). Wood material has been a preferred building material for years due to its many superior features such as being natural, beautiful texture and being harmless to health.

On the other hand, wood material is adversely affected by weathering (heat, light, humidity), mechanical effects, biological pests and fire. For this reason, unprotected wood material cannot withstand such effects for a long time (Budakçı and Atar 2001).

Wood decay starts by reacting when unique wood tissues like sapwood and heartwood are subjected to prolonged weather conditions and water intake due to the anisotropic structure of the wood, its texture, yearly ring structure, and the presence of these tissues (Bucur 2011).

The use of chemical compounds to impregnate wood is one of the most important and effective methods recommended to stop or reduce the deterioration of wood under such climatic conditions (Temiz *et al.* 2005).

The impregnated wood material is an important building material due to its aesthetic appearance, being economical, and resistance to biotic and abiotic pests. Wood material is used as a carrier and decorative material in roof elements, joinery and coating materials, molds, and scaffolding. In addition, wood material has many other uses (telecommunications poles, railway sleepers, water cooling towers, marine fortification poles, joinery and siding, roofing materials, and fence posts).

The smell of wood treated with water-soluble impregnation materials is generally not a problem. In addition, surface treatments can be applied to the wood material after the impregnation processes, and safer material can be obtained in the places of use and transportation processes (Kartal 2000).

The focus of the wood preservation business has switched to copper-based preservatives as a result of worries about the environmental consequences of compounds like chromium and arsenic as well as limitations on the usage of chromated copper arsenate (Freeman and McIntyre 2008).

In recent years, the use of copper compounds as preservatives has increased. This is because copper compounds are relatively safe and inhibit the growth of wood pests (Richardson 1997). Some of the new generation impregnation materials that do not show carcinogenic effects consist of chromium-free copper-containing compounds.

In the new generation of impregnation materials, chromium has been replaced with other chemicals that prevent washing. Thus, chrome-free and wash-resistant copper-containing impregnation materials have been developed (Can and Sivrikaya 2019).

One of these new generation impregnation materials, Korasit-KS is included in the Alkaline Copper Quaternary (ACQ) group. It is also a water-based, environmentally friendly impregnation product. It contains copper components and quaternary ammonium. Korasit-KS, which has a strong fixation feature, does not contain chrome and boron. It has preventive and protective properties against insects, fungi, and weather conditions. It also has a protective effect against termites. Since the copper rate is high, the fading problem does not occur in a short time as in its counterparts. The brown color pigment does not fade as it contains UV-resistant pigment. Corrosion is less than water. It does not harm iron, steel, and plants (Varkim 2022).

Sivrikaya and Can studied (2013) water absorption values of 2,4 % copper azole treated Scots pine. They reported that water absorption (WA) values of Scots pine was slightly lower than untreated specimens at the beginning of the soaking period as well as at the end. Modulus of rupture (MOR) values of yellow pine treated with various compounds including copper were examined by Yıldız *et al.* (2004). According to the results, there were no appreciable differences in MOR values between untreated (control) and Wolmanit CX-8 or Tanalith E-3491; however, there was a discernible difference between untreated (control) and ACQ-1900, ACQ-2200, or CCA, while there were none between ACQ-2200, Wolmanit CX-8, or Tanalith E-3491.

The thermal characteristics of Oriental beech (*Fagus orientalis*) impregnated with 0,25 %, 1 %, and 4,70 % were investigated by Baysal *et al.* (2017) using aqueous solutions of different copper-containing compounds, such as Adolit KD-5, Wolmanit CX-8, and Tanalit-E. The results show that, in comparison to the control group, treatment with Adolit KD-5, Wolmanit CX-8, and Tanalit-E decreased the T_{max} (maximum degradation temperature) and increased residual char quantity.

In this study, the physical properties such as water absorption levels, mechanical properties such as modulus of rupture, and thermal properties of Oriental beech (*Fagus orientalis*) impregnated with Korasit KS were investigated.

MATERIALS AND METHODS

Preparation of test specimens

Wood specimens were prepared from the sapwood part of the tree 150 cm above the ground. While wood specimens were being prepared, especially the parts with smooth fibers, no knots and cracks, and which were not damaged by insects and fungi were selected. Air-dried sapwood specimens of Oriental beech (*Fagus orientalis* L.) was prepared for WA, and MOR test dimensions of 20 mm x 20 mm x 20 mm, and 20 mm x 20 mm x 360 mm (tangential, radial, and longitudinal directions), respectively.

Impregnation procedure

Korasit KS, which was preferred in this study, contains 8,4 % N, N-Didesyl-N-methyl-poly (oxethyl) ammonium propionate and 15,2 % copper hydroxide carbonate as impregnation material (Varkim 2022). The Oriental beech was impregnated with Korasit KS in accordance with ASTM D 1413-07el (ASTM 2007). For 30 minutes, Oriental beech was impregnated with a 760 mm Hg pre-vacuum. After that, the specimens were allowed to diffuse in solution for 30 minutes at atmospheric pressure. The amount of Korasit KS retention was determined using equation 1:

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

Where;

$G = T_2 - T_1$

T_2 = After-impregnation specimen weight (g)

T_1 = Pre-impregnation specimen weight (g)

V = Volume of the specimen (cm^3)

C = Solution concentration (percentage)

Water absorption test

Oriental beech was kept in distilled water for 2,5 h, 5 h, 10 h, 20 h, 40 h, 80 h, and 160 h at room temperature as part of the water absorption test. Specimens were removed from the water at the end of each soaking session, dried on paper, and immediately weighed. In order to calculate how much water each specimen absorbed, formula 2 was utilized.

$$WA = \frac{Mf - Moi}{Moi} \times 100 \quad (2)$$

Where;

WA denotes water absorption (%),

M_f denotes specimen weight after water absorption (g),

M_{0i} denotes oven-dry weight after impregnation (g).

Modulus of rupture (MOR)

According to the TSE 2474 (TSE 1976) standard, wooden specimens of 20 mm x 20 mm x 360 mm and 30 wooden materials in total, 10 from each specimen group, were prepared for MOR.

Prior to testing, wood specimens were conditioned for 6 weeks at 20 °C and 60 % relative humidity. Equation 4 was used to calculate the MOR (MPa) of the wood specimens.

$$MOR = \frac{3 \times P \times l}{2 \times b \times h^2} \quad (4)$$

Where;

P is the maximum load (N),

l is the span (mm),

b is the specimen width (mm).

h is the specimen thickness (mm).

Thermal analysis (TGA)

Thermogravimetry analysis (TGA) and differential thermogravimetry (DTG) studies were carried out in this test using the LABSYS TG-DTA analyzer (France). These tests were conducted in an argon environment at 10 °C / min heating and 50 mL / min purging rates. The temperature was raised to 600 degrees Celsius from ambient. During the heating and pyrolysis of approximately 10 mg of specimen, weight loss was continuously monitored. For each specimen group, the analyzer recorded the pyrolysis's starting and bending temperatures. The TG curve is used to calculate the weight loss rate as a function of time, producing a derivative TG curve.

Statistical evaluation

The data from all tests, the Duncan test at 95 % confidence level, and the analysis of variance were all collected using the computerized SPSS statistical program. In this study, statistical evaluations were carried out on homogeneity groups (HG) containing different letters, with each letter reflecting a distinct statistical significance.

RESULTS AND DISCUSSION

Water absorption levels

Water absorption (WA) levels of Oriental beech impregnated with Korasit KS are given in Table 1.

Table 1: WA of Oriental beech wood specimens impregnated with Korasit KS.

Chemicals	**Water absorption levels (%)**													
	After 2,5 h	**H.G**	**After 5 h**	**H.G**	**After 10 h**	**H.G**	**After 20 h**	**H.G**	**After 40 h**	**H.G**	**After 80 h**	**H.G**	**After 160 h**	**H.G**
Control	27,28	A	40,16	A	54,40	A	62,25	A	73,56	A	76,81	A	79,60	A
Korasit KS (%3)	32,10	A	47,12	A	60,06	A	65,51	A	73,81	A	77,86	A	82,16	A
Korasit KS (%6)	30,81	A	45,99	A	59,31	A	65,43	A	73,67	A	77,84	A	82,05	A

Note: Each group received ten replicas. At a 95% confidence level, homogeneity group was attained. HG: Homogeneity group.

Results showed that the wood specimens absorbed more water during the first time than during the subsequent periods, which is consistent with earlier investigations (Alma 1991, Hafızoğlu *et al.* 1994, Yıldız 1994). These outcomes could be the consequence of WA being injected into wood's empty pores at the beginning of soaking and those spaces being smaller with time (Yalınkılıç *et al.* 1995).

According to the WA values, the highest WA value was determined in the specimens impregnated with 3 % concentration of Korasit KS in all water absorption periods. Korasit KS appeared to facilitate WA in wood. This could be attributed to the chemical components and the hysteresis effect found in wood cavities. Furthermore, specimens of water-based wood preserving-treated wood appeared to be more susceptible to free water retention rather than water impregnation, gave rise to increased WA (Almeida *et al.* 2021).

However, there was no statistical difference was found in WA values between control group and Korasit KS impregnated Oriental beech in all WA periods. Kirkpatrick and Barnes (2006) found that waterborne copper naphthenate treatments increased WA capacity of wood composite panels. Nicholas *et al.* (2000) stated that alkali ammonium compounds caused the wood to absorb more water and expand after impregnation as a result of the same kind of mechanism The findings of Kirkpatrick and Barnes (2006) and Nicholas *et al.* (2000) are all supported by our findings.

Modulus of Rupture (MOR)

Modulus of Rupture (MOR) values of Oriental beech impregnated with Korasit KS are given in Table 2.

Table 2: MOR values of Oriental beech impregnated with Korasit KS.

Chemicals	Retention (%)	Retention (kg/m³)	MOR (MPa)	Standard deviation	Homogeneity group	Change compared to control
Control	-	-	118,04	11,43	A	-
Korasit KS	3	11,26	106,36	9,54	A	-10,97
Korasit KS	6	18,40	103,61	10,98	A	-13,92

Note: Each group received ten replicas. At a 95 % confidence level, homogeneity group was attained.

Table 2 shows that although there is no statistically significant difference between the control and Korasit KS impregnated test specimens, the control specimens have the highest modulus of rupture (MOR) (118,04 MPa) and the Korasit KS-treated specimens have the lowest MOR (103,61 MPa). MOR was higher in the control group than in the impregnated Oriental beech wood. Lower MOR levels of Oriental beech were produced by Korasit KS concentrations that were higher. When wood is treated with fire retardant chemicals or wood preservatives, the strength of the wood is impacted (Winandy *et al.* 1988).

Mechanical factors have an impact on preservative chemical structure, chemical pH, pre- and post-treatment of wood, impregnation parameters, and interactions with microstructure. The Korasit KS treatment had no statistically significant impact on the MOR of the Oriental Beech, supporting the negligible impact of copper and quaternary ammonium compounds on the bending properties of wood. In certain investigations, similar outcomes have been found (Pizzi 1983, Topaloğlu 2019).

It has been discovered that protective impregnation reduces the modulus of fracture of some hardwoods, indicating that applications may have negative impacts on mechanical qualities (Winandy and Lebow 2001).

In our study, specimens impregnated at 3 % and 6 % concentrations showed a respective drop of 10,97 % and 13,92 % from the control. It is well known that the treated wood's lower strength is significantly influenced by the treated wood's initial pH value, treatment solution concentration, and blast furnace drying temperature (Shukla *et al.* 2019).

The MOR values of Oriental beech impregnated with compounds containing copper, such as 2 % aqueous solutions of Wolmanit CX-8 and Celcure AC 500, were examined by Türkoğlu *et al.* (2016). They discovered that the MOR values for Oriental beech impregnated with Wolmanit CX-8 and Celcure AC 500 fell by 15 % and 15,50 %, respectively.

Şimsek *et al.* (2013) examined the MOR of woods treated with copper-containing compounds such 4 % aqueous solutions of Adolit KD 5 and Tanalith-e preservatives on Oriental beech (*Fagus orientalis*) and Scots pine (*Pinus sylvestris*). Their findings showed that the MOR value of the chemically treated wood specimens was lower than that of the untreated control group. Our findings substantially agree with the information provided by Şimşek *et al.* (2013).

Thermal analysis (TGA)

The thermal behavior of the wood which was impregnated with and without Korasit KS under a nitrogen atmosphere was conducted using TGA and DTG. The results were given in Table 3 and Figure 1.

Table 3: Initial and maximum temperature (◦C) of thermal degradation and the char yield (%) after thermogravimetric analysis.

Chemicals	$T_{i\%}$ (ºC)	$T_{max\%}$ (ºC)	% Char yield
Control	280	358	29,42
Korasit KS (%3)	255	349	42,53
Korasit KS (%6)	230	330	50,69

$T_{i\%}$ was found within the temperature range of 230 °C to 280 ºC. $T_{max\ \%}$ was found between 330 °C and 358 ºC. As a result of thermal degradation at 600 ºC, the highest char yield was obtained impregnated with 6 % concentration of Korasit KS with 50,69 %, and the lowest char yield was obtained from the control with 29,42 %. It was shown that the use of Korasit KS which have copper hydroxide enhanced the thermal stability of the specimens. Metal hydroxide compounds increased the amount of residue at 600 ºC (Chen *et al.* 2006; Choi *et al.* 2009). Water and oxide were generated in the environment with the thermal decomposition of copper hydroxide. This endothermic reaction cooled the polymer surface and increased charring (Kong *et al.* 2008; Li *et al.* 2010).

TGA thermographs and derivative thermogravimetry (DTG) curves of control and Korasit KS impregnated Oriental beech were given in Figure 1. DTG curves refer to the velocity of mass loss during thermal degradation.

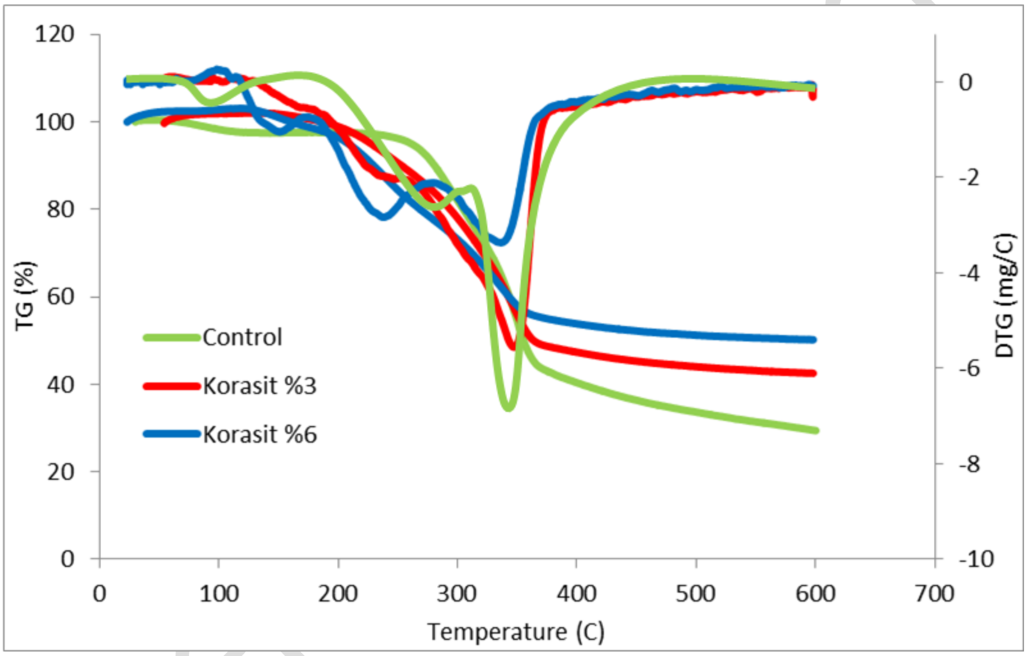

Figure 1: TGA and DTG results of specimens.

Temperature values corresponding to initial and maximum mass loss were obtained to be considerably lower in impregnated specimens compared to control specimens. Baysal *et al.* (2017) found that while the amount of some commercial wood preservatives increased in the wood, the maximum decomposition temperature decreased.

The initial weight loss in the TG and DTG curves occurred at about 100 ºC because of moisture removal. Cellulose and hemicelluloses were dramatic diminished in the range of 200 ºC - 350 ºC. Hemicellulose occurred acetic acid through deacetylation during thermal degradation (Bianchi *et al.* 2010).

Degradation of cellulose which led to the production of volatile flammable components were taken place through dehydration, decarboxylation, oxidation, hydrolysis, and free radical formation. Free radicals led to the production of hydrogen peroxide, carboxyl, and carbonyl groups, and these groups were responsible for the thermal degradation (Junges *et al.* 2019).

The degradation of lignin started at approximately 200 °C, however, the mass loss occurred across a wide temperature range. Temperatures above 600 °C, which are higher than the maximum degradation temperatures of cellulose and hemicellulose, can be reached during the slow disintegration of lignin. The literature revealed similar three-stage thermal degradation processes (Shebani *et al.* 2008, Kim *et al.* 2010, Popescu *et al.* 2011).

Korasit KS impregnated Oriental beech wood specimens that included copper ions had a lower weight loss than the control specimens. The copper ions can expedite the decomposition of wood at lower temperatures and char oxidation (Fu *et al.* 2009, Hirata *et al.* 1992).

Cellulose was catalyzed by metals and decomposed rapidly. In this case, it caused to increase in the char yield (Helsen and Bulck 2000). Also, charring was very slow due to metal compounds complexed with or precipitated on lignin (Tomak *et al.* 2012). Previous studies determined that as the amount of copper impregnated into wood increased, thermal degradation of wood decreased (Lu *et al.* 2008, Koo *et al.* 2014, Junges *et al.* 2019).

CONCLUSIONS

The purpose of this study was to ascertain the results of mechanical, thermal, and physical tests on wood that had been impregnated with Korasit KS from Oriental beech (*Fagus orientalis*).

The findings showed that the water absorption levels of the impregnated specimens were higher than the control group, particularly during the initial soaking period.

The impregnation with Korasit KS facilitated water absorption in the wood, which could be attributed to the chemical components and hysteresis effect in wood cavities. However, no statistically significant difference was discovered in the WA values between the control group and the Korasit KS impregnated Oriental beech in any of the WA periods.

Regarding the modulus of rupture (MOR), the impregnated specimens exhibited lower values compared to the control group, indicating a decrease in the strength of the wood. Higher concentrations of Korasit KS resulted in a greater reduction in MOR. However, statistical analysis did not show a significant difference in MOR values between the control and impregnated groups. However, statistical analysis did not show a significant difference in MOR values between the control and impregnated groups.

Thermal analysis through TGA and DTG revealed that impregnation with Korasit KS improved the thermal stability of the wood specimens. The impregnated specimens exhibited lower initial and maximum temperature values for thermal degradation compared to the control group. Moreover, the specimens treated with Korasit KS demonstrated a considerably higher char yield during thermal degradation at elevated temperatures, compared to the control group.

Overall, the impregnation increased water absorption, decreased MOR, and improved the thermal stability of the wood. These findings contribute to the understanding of the effects of wood impregnation with copper-containing compounds and provide insights for potential applications in wood preservation and modification.

AUTHORSHIP CONTRIBUTIONS

Ç. A.: Investigation, Writing – review & editing. **E. B.:** Supervision, Methodology. **M. E. E.:** Data curation, Visualization. **H. T.:** Resources, Validation**.**

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