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The Effects of Impregnation with Barite ($BaSO_4$) on the Physical and Mechanical Properties of Wood Materials

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Abstract

The aim of the study was to investigate the effects of Barite on the physical and mechanical properties of wood. Barite as an impregnation material was used to be harmless to environment-related human health. Barite ($BaSO_4$) solution was prepared with different concentrations of barite (1%, 3%, 5%), and the impregnation process of the samples were conducted according to ASTM-D 1413-76. Scotch pine (*Pinus sylvestris* L.) and Oriental Beech (*Fagus orientalis* L.) obtained from the Eastern Black sea region in Turkey were used. According to the results, it showed that each wood types, retention ratio, physical properties, and mechanical properties increased with increasing concentration of barite in the impregnation solution. For the Beech wood, the highest air-dried and dried densities were found to the samples impregnated with solution that had a 1% concentration (0.63 g/cm^3); the highest modulus elasticity (MOE) was in samples impregnated with solution that had a 5% concentration (16920 N/mm²); the highest bending strength (MOR) was in samples impregnated with solution that had a 50% concentration (160.40 N/mm²); and the highest dynamic bending strength was in the beech impregnated with solution that had a 50% concentration (2.78 kpm/cm^2).

Keywords: Barite; Impregnation; Retention; Technological properties

Baritle Emprenyenin ($BaSO_4$) Odunun Fiziksel ve Mekanik Özellikleri Üzerine Etkisi

Öz

Bu çalışmada, baritin ahşapta emprenye etme özellikleri ilk kez araştırılmıştır. Çevreyle ilgili insan sağlığına zararsız olduğu için, bu doğal materyali çeşitli alanlarda (ör. Mobilya ve inşaat) kullanımı amaçlanmıştır. Barit ($BaSO_4$) solüsyonu farklı konsantrasyonlarda barit (% 1, % 3, % 5) ile hazırlanmış ve ASTM-D 1413-76 standartlarına göre emprenye işlemi yapılmıştır. Bu çalışmada, ağaç türleri olarak Doğu Karadeniz bölgesinden alınan Sarıçam (*Pinus sylvestris* L.) ve Doğu Kayını (*Fagus orientalis* Lipsky) kullanılmıştır. Sonuçlar; her iki ahşap türünde, emprenye solüsyonundaki barit konsantrasyonunun artmasıyla, retensiyon %, fiziksel özellikler ve mekanik özelliklerin arttığını göstermiştir. En yüksek yoğunluk (0.63 g/cm^3), elastikiyet modülü (16920 N/mm²), eğilme direnci (160.40 N/mm²) ve dinamik eğilme direnci (2.78 kpm/cm^2) değerleri, sırasıyla, %1, %5, %50 ve %50'lik derişime sahip çözeltilerle emprenye edilen Kayın odunu örneklerinde elde edilmiştir.

Anahtar Kelimeler: Barit, Emprenye, Tutunma, Teknolojik Özellikler

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1. Introduction

When compared with concrete, iron, aluminum, polyvinyl chloride (PVC), and other various construction materials, wooden materials are easily treatable and renewable, and also have superior physical and mechanical properties. Wooden materials are used in construction and various industrial areas such as paper-cellulose, plates, and furniture (Baysal 2011). Because of its degree of utilization, wood, which is an organic and lignocellulosic material, should be protected against various destructive factors in terms of types of destructive factors and degrees of risk. The success and protection degree of the process known as "impregnation" depends not only on the impregnation material and properties of the wood, but also on different properties such as retention quantity of the net dry impregnation material and retention depth of the impregnation material (Arsenault 1973; Richardson 1978). It is necessary for wood to be protected from humid environments, as well as prevent to shrinking and swelling of wood to enhance its service period. Many structural and chemical methods used in wood are based on this theory. At present, 2500 different impregnation materials have been discovered (Şen 2007; Koski 2008). Odor is not a problem in wooden material that is impregnated with impregnation material that has been solubilized in water. Also, a surface treatment can be applied to the wooden material after impregnation. As a result of this process, a more reliable material is obtained in the areas of usage and transfer process (Kartal 1998). Barite, the heaviest non-metallic mineral, is widely used in various industries because of its low abrasiveness (Moh's 3 to 3.25), no magnetic properties, and low solubility in water and acid. This helps to preserve its chemical stability under high pressure and temperature, which allows it to be obtained cost-effectively. It is used as a cost-effective and functional filling material in multiple industries such as dye, paper, plastic, rubber, friction materials, glass, and ceramics. In the dye industry, it is used as a bleaching pigment and diluent in oil paint. Barium is used in radiography because of its ability to make X-rays harmless and its resistance to weather conditions, which allows it to be used as an application in high temperatures (Lekili 2002; Şen 2007).

In this study, considering its wide usage, barite was impregnated in wood because of its superior properties, positive structure in terms of environmental-human health (e.g., borax, boric acid), and solubility in specific concentrations in water. It is a known impregnation material that is used in many fields (salt dissolved in water, oily impregnation materials, organic solvents). Also, it is known for its long-term protectiveness of wood when impregnated, as well as its positive structure on absorbing radiation. Therefore, the effects of barite (BaSO4) on properties such as retention on wood, density, and some mechanical properties were investigated.

2. Material and Methods

2.1. Material

The Scotch pine and beech wood used in this study were obtained from the Eastern Black sea region. Test samples were randomly selected from wood that had regular fibers and was colour-free TS 2470 (1976). Barite was obtained as dust and was decomposed from other materials. It was obtained from Ersel Heavy Machine Industry and Gulmer Mining Milling and Classification Facility of Calcite-Talc-Barite (Bilecik).

2.1.1. Preparation of samples

Test specimens that were to be used for testing MOR and MOE were prepared with sizes of 20 x 20 x 360±1 mm according to TS 2474 (1976). Specimens that were used to test air-dried and dried densities were prepared with the sizes of 20 x 20 x 30±1 mm according to TS 2472 (1976). Specimens that were used to test for dynamic bending (shock) strength were prepared with the dimensions of 20 x 20 x 360±1 mm according to TS 2477 (1976). Forty test specimens for each test were used.

2.1.2. Impregnation method

The impregnation process was executed in according to ASTM–D 1413-76 (1976) For impregnation, wood samples were placed into the solution under normal atmosphere pressure for 60 min after applying pre-vacuum to the wood samples for 60 min, which is equal to 60 cm Hg-1. The samples were dried before and after impregnation to determine the retention rate of the impregnation material without it being affected by the humidity of the wood. The amounts of impregnation material absorbed by the samples retention percentage amount were calculated with Eqs. 1 respectively,

$$\% R = (Moes - Moeö) / Moeö * 100 \ ) \qquad (1)$$

In Eq. 1, % R is the retention value (%), Moes is the dried weight after impregnation (g), and Moeö is the dried weight before impregnation (g).

2.2. Methods

2.2.1. Air-dried (%12) and dried densities (%0)

The air dryness and full dry density of the samples were determined in accordance with TS 2472 (1976). Samples were scaled by an analytical balance with 0.01 g readability, after the samples were conditioned at 20±2 °C temperature and 65±5% relative humidity. After that, the samples were taken out of the desiccator and cooled in a desiccator filled with CaCl2. All samples were scaled with a analytical balance with 0.01 g readability. Next, their volumes were determined by stereo metric method. From the information acquired, the densities of the samples were able to be determined.

The air-dry density : (Eq. 2)

$$\delta 12 = M12 / V12 \ (g/cm3) \qquad (2)$$

where δ12 is the air-dried density (g/cm3), M12 is the sample weight (g), and V12 is the sample volume (cm3). The dried density was calculated according to Eq. 4,

$$S0 = M0 / V0 \ (g/cm3) \qquad (3)$$

where δ0 is the dried density (g/cm3), M0 is the sample weight in the oven-dried state (g), and V0 is the sample volume in the oven-dried state (cm3).

2.2.2. Bending strength and modulus of elasticity

The experiments that tested bending strength and modulus of elasticity (MOE) were tested on a Universal Testing Machine that had a capacity of 4 tons. The MOR tests were carried out according to TS 2474 (1976) standards.

The bending strength : Eq. 4

$$MOR = (3 \times Fmax \times Ls) / (2 \times b \times h^2) \ (N/mm^2) \qquad (4)$$

where MOR is the bending strength (N/mm2), Fmax is the maximum force during the test (N), b is the width of the specimens (mm), h is the thickness of the specimens (mm), and Ls is the openness between the two supports on the mechanism (mm). The modulus of elasticity was determined according to Eq. 5,

$$MOE = \frac{\Delta F x Ls^3}{4x\Delta f x b x h^3} (N / mm^2) \qquad (5)$$

where MOE is the modulus of elasticity (N/mm2), F is the difference between the first load (F1) with the second load (F2) (N), Ls is the openness between the two supports on the mechanism (mm), Δf is the deflection (mm), b is the width of the specimens (mm), and d is the thickness of the specimens (mm).

2.2.3. Dynamic bending (shock) strength

The dynamic bending (shock) strength of the samples was measured with a pendulum hammer with 10 kg/m workforce according to TS 2477 (1976) standards. The bending strength (Eq. 6)

$$\sigma DE = w / bxh \ (kg.m/cm2) \qquad (6)$$

where σDE is the dynamic bending (shock) strength, w is the spent load during breaking, b is the width of the specimens (cm), and h is the thickness of the specimens (cm).

2.2.4. Statistical evaluation

A statistical software package called SPSS 12.0 was used in the statistical evaluation of the data. ANOVA was used to analyze the effect of the barite material on the air-dried and dried densities, dynamic bending (shock) strength, MOE, and MOR of the Scotch pine and beech wood. It was determined differences between values of total retention and retention % according to the concentration of barite in the impregnation solution and type of wood. The significance level of factors found meaningful according to an analysis of variance was determined using Duncan's test.

3. Results and Discussion

3.1. Properties of Impregnation Solution and Retention % Value

Solution properties are given in Table 1.

Table 1. Properties of Impregnation Solutions

Solvent	Temp (°C)	pH		Density (g/mL)		Barite Concentration (%)
		BI	AI	BI	AI	
DW 1%	23	8.06	8.01	1.021	1.020	1
DW 3%	23	9.11	9.03	1.065	1.060	3
DW 5%	23	8.56	8.50	1.088	1.085	5

DW-Distilled Water; BI-Before Impregnation; AI-After Impregnation

The Duncan test results for % retention are given in Table 2.

Table 2. Mean Values of Retention % and Results of Duncan's Test

Wood Type	Concentration of Barite (%)	Retention (%)	HG
Scotch Pine	1	0.45	a
	3	0.14	c
	5	0.39	b
Beech	1	0.46	c
	3	0.54	b
	5	1.19	a

HG-Homogenous Groups; A-The highest values of total retention and retention; F-The lowest value of retention %; G-The lowest value of total retention

As shown in Table 2, total retention increased with increasing concentration of barite in the impregnation solution. According to the results; the highest retention % in beech was with a 5% concentration (1.19%), and the lowest retention % in Scotch pine was with a 3% concentration (0.14%). Peker *et al.* (1999) reported that in beech that was impregnated with Tanalith CBC, retention % was 2.11% and total retention was 9.90 kg/m^3. As for the Scotch pine impregnated with Tanalith CBC, retention % was 1.60% and total retention was 4.85 kg/m^3. Atar and Keskin (2007) found that as a result of the vacuum-pressure method, in fir wood, retention was 12 kg^3 when impregnated with borax, and 13 kg/m^3 when impregnated with boric acid. Toker (2007) found that in beech, retention was 25.22 kg/m^3 when impregnated with borax and 26.69 kg/m^3 when impregnated with boric acid. In Scotch pine, retention was 24.57 kg/m^3 when impregnated with borax and 27.02 kg/m^3 when impregnated with boric acid.

3.3. Air-dried and Dried Densities (g /cm^3)

The Duncan test results for air and full dry density are given in Table 3.

Table 3. Mean Values of Air-dried and Dried Densities of Samples and Results of Duncan's Test.

Wood Type	Barite Concentration (%)	Air-dried (12% MC)	HG	Dried (0% MC)	HG
Scotch Pine	(Control)	0.51	e	0.46	d
	1	0.43	f	0.40	e
	3	0.50	e	0.41	e
	5	0.44	f	0.42	e
Beech	(Control)	0.68	a	0.64	a
	1	0.63	b	0.58	b
	3	0.56	d	0.55	c
	5	0.61	c	0.58	b

HG-Homogenous Groups; A-The highest values of air-dried and dried densities; F-The lowest value of air-dried density; G-The lowest value of dried density

As shown in Table 2, total retention increased with increasing concentration of barite in the impregnation solution. The highest retention % in beech was with a 5% concentration (1.19%), lowest retention % in Scotch pine was with a 3% concentration (0.14%). Peker *et al.* (1999) reported that in beech that was impregnated with Tanalith CBC, retention % was 2.11% and total retention was 9.90 kg/m^3. As for the Scotch pine impregnated with Tanalith CBC, retention % was 1.60% and total retention was 4.85 kg/m^3. Atar and Keskin (2007) found that as a result of the vacuum-pressure method, in fir wood, retention was 12 kg^3 when impregnated with borax, and 13 kg/m^3 when impregnated with boric acid Toker (2007) found that in beech, retention was 25.22 kg/m³ when impregnated with borax and 26.69 kg/m³ when impregnated with boric acid. In Scotch pine, retention was 24.57 kg/m³ when impregnated with borax and 27.02 kg/m³ when impregnated with boric acid.

3.4. Mechanical Properties

The Duncan test results of the mechanical tests are given in Table 4.

Table 4. Mean Values of Mechanical Properties of Samples and Results of Duncan's Test

Wood type	Barite Concentration (%)	Bending Strength (N/mm²)	HG	Elastic Modulus (N/mm²)	HG	Shock Strength (kpm/cm^2)	HG
Scotch Pine	0 (Control)	68.23	g	8800	f	0.38	h
	1	102.62	e	9970	e	0.71	g
	3	106.04	d	10602	d	0.97	c
	5	104.00	d	11600	c	0.80	f
Beech	0 (Control)	83.00	f	13300	b	0.85	e
	1	129.60	b	11766	c	2.01	a
	3	115.88	c	10728	d	1.92	b
	5	152.00	a	16920	a	0.92	d

HG-Homogenous Groups; A-The highest values of MOR, MOE, and shock strength; F-The lowest value of MOE; H-The lowest value of MOR; I-The lowest value of shock strength

The highest MOR was found in beech impregnated with 5% barite solution (152.00 N/mm²), and the lowest MOR was found in Scotch pine 1% barite solution (102.62 N/mm²). The highest MOE was in beech wood 5% barite (16920 N/mm²), and the lowest MOE was in Scotch pine 1% barite solution (8800 N/mm²). The highest dynamic bending strength was in beech impregnated with 50% barite solution (2.78 kpm/cm^2), and the lowest dynamic bending strength was in Scotch pine impregnated with 1% barite solution (0.71 kpm/cm^2). It was determined that the mechanical properties increased with the amount of barite concentration in the impregnation solution. Le Van and Winandy (1990) reported that the bending strength of southern maritime pine treated with fire retardant impregnation materials decreased by 10% to 20%. As a result of research on the effects of various impregnation materials on MOE of Scotch pine, Yıldız et al. (2004) reported that there is no statistical difference between MOE values of control samples with that of test samples treated with ACQ-1900, ACQ-2000, and Tanalith E 3491. Bal (2006) reported that there was a decrease of 10.86% in shock strength as a result of the full cell method, and the results of average shock strength decreased in contrast with the increase in immersion time. Kartal (1998) determined that the effect of 1% concentration CCA treated solution used in impregnation on dynamic bending strength was not important in terms of statistics.

4. Conclusions

- The MOR values of Scotch pine wood impregnated with barite solution increased between the ranges of 48% to 55%, approximately.
- The MOR values of beech wood impregnated with barite solution increased between the ranges of 39% to 93%, approximately.
- The MOE values of Scotch pine wood impregnated with barite solution increased between the ranges of 13% to 32%, approximately.
- The MOE values of beech wood impregnated with 1% and 3% concentrations of barite solution decreased, while the MOE values of beech wood impregnated with 5% concentrations of barite solution increased.
- The dynamic bending (shock) strength of Scotch wood impregnated with barite solution increased between the ranges of 86% to 155%, approximately.
- The dynamic bending (shock) strength of beech wood impregnated with barite solution increased between 8% and 227%, approximately.

Teşekkür

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