

## Investigation of Thermal Conductivity and Mechanical Properties of Gypsum Particleboard Reinforced with Fiber-Reinforced Polymers

### Fiber Takviyeli Polimerlerle Güçlendirilmiş Alçılı Levhaların Isıl İletkenlik ve Mekanik Özelliklerinin Araştırılması

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#### Abstract

Engineering composites such as particleboard have widespread use in various fields, but low mechanical strength and sensitivity to environmental factors limit the performance of these materials. In this study, mechanical and thermal properties such as thermal conductivity, density, flexural strength, and modulus of elasticity of wood-reinforced gypsum boards reference boards and fiber-reinforced polymer (FRP) applied wood-reinforced gypsum boards were investigated according to wood and bark ratios. The results showed that the material composition significantly affects these properties. Thermal conductivity increased with increasing wood ratio, while it decreased with increasing bark ratio. FRP application increased thermal conductivity in all samples and was found to be related to density. In terms of density, samples with high wood ratios were heavier and denser with FRP. While flexural strength decreased with increasing bark ratio, FRP application increased the flexural strength. These findings show the positive effects of FRP on wood-reinforced gypsum boards and its high performance potential in the construction industry.

#### Özet

Yonga levha gibi mühendislik kompozitleri çeşitli alanlarda yaygın kullanıma sahiptir, ancak düşük mekanik dayanım ve çevresel faktörlere karşı duyarlılıkları bu malzemelerin performansını sınırlamaktadır. Bu çalışmada, alçı referans levhalar ve fiber takviyeli polimer (FRP) uygulanmış alçı levhaların ısıl iletkenlik, yoğunluk, eğilme dayanımı ve elastisite modülü gibi mekanik ve termal özellikleri odun ve kabuk oranlarına göre incelenmiştir. Sonuçlar, malzeme kompozisyonunun bu özellikleri önemli ölçüde etkilediğini göstermiştir. Isıl iletkenlik, odun oranı arttıkça artarken, kabuk oranı arttıkça azalır. FRP uygulaması, tüm numunelerde ısıl iletkenliği artırmış ve yoğunlukla ilişkili bulunmuştur. Yoğunluk açısından, odun oranı yüksek numuneler FRP ile daha ağır ve yoğun olmuştur. Eğilme dayanımı, kabuk oranı arttıkça azalırken, FRP uygulaması dayanımı artırmıştır. Bu bulgular, FRP'nin ahşap takviyeli alçılı levhalar üzerindeki olumlu etkilerini ve inşaat sektöründeki yüksek performans potansiyelini göstermektedir.

## INTRODUCTION

Natural forest resources have historically been used by humans for various purposes since ancient times. The most important reason for this is that, thanks to the self-renewal feature of forests, materials that are easy to process and cheaper in terms of cost, such as wood raw materials, can be provided (As et al. 2006, Boonstra and Tjeerdsma 2006, Akgül et al. 2009, Akyürek 2019). In addition, the renewable nature of forests provides a significant advantage for wood raw materials compared

to other types of raw materials. The increasing population and the urbanization process that develops in parallel with this cause the demand for forest products to constantly increase (Candelier et al. 2016, Cavus et al. 2019, Chu et al. 2020). Nowadays, wood raw material is used in many sectors (construction, decoration, energy, communication, etc.), which leads the forest products industry to engage in intensive production activities in regions where forest resources are abundant (Kurtoglu

and Sofuoglu 2013, Kardas 2014, Kilincarslan and Turker 2020, Kilincarslan et al. 2020).

In recent years, the rapid increase in demand for wood raw materials, the limited forest areas, and the destruction of forests in many regions have created difficulties in terms of quality and quantity in the supply of this raw material (Brookfield 2001, Brookfield 2007, Ango et al. 2014, Battistoni 2017, Ango et al. 2020, Balée et al. 2020). Many studies are being carried out worldwide and these studies are continuing to prevent further destruction of forests and to research alternative lignocellulosic materials that can be used instead of forest resources. These studies have revealed positive results and predictions that wood residues (branches, bark, needles, etc.) obtained from forests, wastes obtained from agricultural activities, and fast-growing annual plants can be used instead of wood or with wood (Odegard et al. 2014, Dutta et al. 2017, Jafarian et al. 2016, Slätmo and Nilsson 2019).

Gypsum is one of the oldest materials used in the construction sector throughout history. Today, gypsum-based products are used not only for decoration purposes but also for their structural and adhesive properties. Gypsum reserves are sufficient and mostly concentrated in the Central-Northern Anatolia and Eastern Anatolia regions (Ameta et al. 2007, Ahmed and Ugai 2011, Al-Hokabi et al. 2021). Gypsum is chemically composed of calcium sulfate-based minerals and can be divided into two main categories: natural and synthetic gypsum according to its mineral components. In addition, it is possible to divide gypsum into different classes such as alpha, beta, anhydrite I and III according to its setting time and durability properties (Ismail and Hilo 2008, Jaksa

2010, Hastuty 2019, Dubrovina et al. 2021, Dutta and Yadav 2022).

Nowadays, energy stands out as one of the most critical factors in the strategic planning of countries (Jain et al. 2014, Chou and Tran 2018, Bui et al. 2019, Ocampo Batlle et al. 2019). With the rapid depletion of energy resources worldwide, governments have begun to develop various strategies to meet energy demands and use energy more efficiently. According to analyses by the European Commission's Directorate General for Energy and Transport, total energy consumption is distributed as follows: 32% for transportation, 28% for industry, and 40% for buildings. In addition, it has been determined that 85% of the energy used in buildings is for heating purposes. This data clearly shows that the greatest saving potential in terms of energy efficiency is in buildings (Neto and Fiorelli 2008, Deb et al. 2017, Xiao et al. 2018). The dense building stock in Turkey and the rapid growth in the construction sector further emphasize the importance of thermal insulation. Thermal insulation not only reduces energy consumption but also provides climatic and auditory comfort by using the right insulation materials and plays an important role in terms of fire safety for buildings.

The thermal conductivity properties of gypsum particle boards are crucial both theoretically and practically. These boards, made from gypsum, water, and additives, are often used for thermal insulation due to gypsum's low thermal conductivity. However, their thermal conductivity can vary based on factors such as the type of additives, thickness, and density of the board. The conductivity is closely tied to the interaction of the material components and production parameters. To

enhance the thermal performance of gypsum particle boards, it is essential to examine these factors in detail (Kaya et al. 2021, Yalcin and Kaya 2022).

Thermal conductivity, measured in W/m K, is a key parameter that indicates the properties of a material to transfer energy due to a temperature difference. Materials with high thermal conductivity conduct heat quickly, while those with low conductivity provide better insulation (Huang et al. 2012, Jasmee et al. 2021, Yang et al. 2021, Davraz et al. 2024). This property is crucial for the efficiency of building insulation, heating, and cooling systems (Chen et al. 2016, Yang et al. 2016, Zhou et al. 2017, Oluwalowo et al. 2019). In gypsum particleboards, thermal conductivity directly impacts energy savings and indoor comfort. Accurately determining these properties is also essential for setting national and international energy performance standards for buildings. The thermal conductivity of gypsum particleboards depends on factors such as the raw materials used, the additive ratios, board density, and production methods. Understanding these factors is vital for improving the design and production of gypsum particleboards, making them more efficient and environmentally friendly (Kaya et al. 2021, Yalcin and Kaya 2022). The examination of these properties offers opportunities to optimize these materials for better energy performance and sustainability in the building sector.

Today, urea formaldehyde-bonded particleboards are widely used. Engineering composites such as particleboards are widely used in the construction, furniture, and automotive sectors. The mechanical strength of particleboards and their sensitivity to

environmental factors limit the performance of these materials in various applications (Pedzik et al. 2021, Hidayat et al. 2022). In recent years, FRP technologies have come to the fore. Fiber-reinforced polymers consist of high-strength fibers such as glass, carbon or aramid arranged in a polymer matrix. These composites have the potential to significantly increase the strength, rigidity, impact resistance and wear resistance of particleboards (Campbell et al. 2011, Khan and Yousif 2017, Vinod et al. 2018, Sugiman et al. 2020).

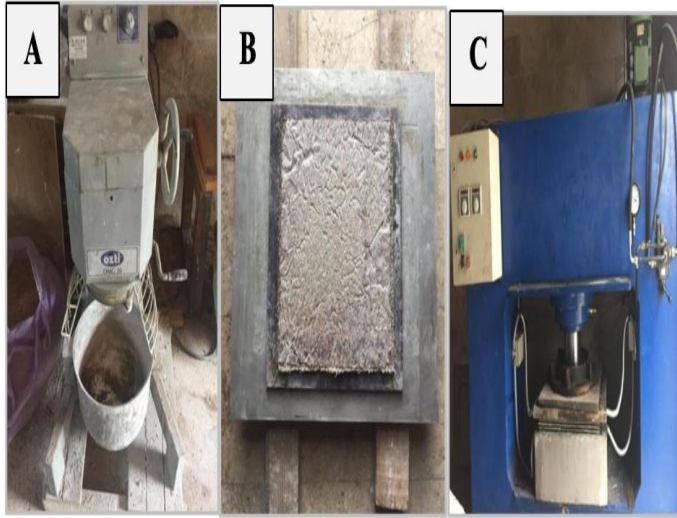
Fiber-reinforced polymers can be combined with gypsum particle boards through surface coatings or internal reinforcement, with glass fiber often chosen for its cost-performance balance and carbon fiber for lightweight, superior mechanical properties. These composites enhance the durability of particle boards and improve their resistance to environmental factors, such as moisture and temperature changes. The polymer matrix strengthens particle boards, making them more robust. Additionally, FRPs and particle boards can be combined using advanced engineering techniques, like sandwich structures, to fully leverage the benefits of both materials. In previous studies, there are few studies on strengthening gypsum particle boards with FRP. The use of innovative properties of fiber reinforced polymers in this field will be an important step for the wooden construction industry. This study investigates the mechanical and thermal conductivity properties of gypsum particleboard reinforced with carbon fiber-reinforced polymers. The paper is organized as follows: Section 2 covers the specimen details, particleboard properties, FRP application, and testing methods; Section

3 presents experimental results; and Section 4 offers the conclusions.

## MATERIALS AND METHODS

### Cedar Wood Chips and Gypsum

The cedar wood used in the study was obtained from cedar forests in the Yalvac-Isparta region, from the idle parts formed during wood harvest. The gypsum used as an adhesive in the production of the test panels was purchased from the market in 35 kg bags as commercially sold and used as supplied. The general properties of the gypsum (perlite gypsum) used in the study are shown in Table 1.



**Figure 1.** Production stages of the wood-reinforced gypsum boards (A): Making the mixture, (B): Making the surface smooth, (C) Pressing process

### Preparation of Raw Material and Production of Boards

Cedar wood was chipped (crumbled) in a hammer mill under laboratory conditions and then dried in the open air until it became air-dry after being brought to appropriate dimensions (1-5 cm). Cedar wood chips were mixed with gypsum, whose weight measurements

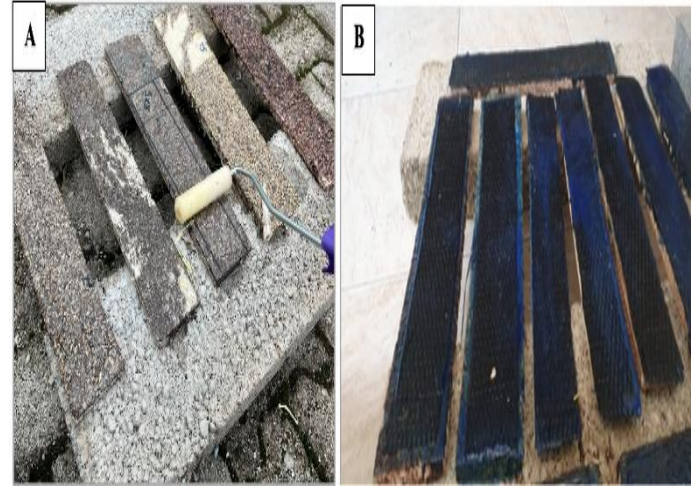
were made on a precision scale ( $\pm 0.10$  gr), in a laboratory-type mixer. The mixing process was generally applied for 5-10 minutes. A metal mold with a width of 400 x 400 mm and a thickness of 10 mm was used in the preparation of the plate draft. The plate was transferred to the pressing mold, which was previously placed with oiled paper. The reason for using these oiled papers is to prevent the sheets from sticking to the press sheets during and after pressing. After the mixture was homogeneous, it was poured into the molds and then the surface was smoothed with a trowel. The sheets were cold pressed in a laboratory-type hydraulic press and removed from the mold after waiting for about 1 day. The pressure of the press used in the production of the test sheets was 2-3 MPa, and the pressing time was 1 day. The thickness of the produced sheets was 10 mm, and the dimensions were 400x400 mm. During the production of the sheets, no hydrophobic material was used to prevent water from entering the sheet draft and increasing the thickness. The production stages of the wood-reinforced gypsum boards produced are given in Figure 1.

### Application of Fiber-Reinforced Polymer to the Produced Wood-Reinforced Gypsum Boards

Carbon FRP was applied to the surface of the produced sheets. Carbon fiber-reinforced fabrics were used to strengthen the boards. The carbon-based MasterBrace fabric is sourced from ÜNAL TEKNİK®. FRP fabric reinforcement was primarily done in four steps. The surface of gypsum particleboard was first cleaned, then primer was applied to it (Figure 2(A)). Following the application of primer, adhesive was applied to the surface within one to one and a half hours. The adhesive

used in the study is a special epoxy adhesive produced for carbon fiber reinforced polymers. This adhesive was mixed with the hardener at a ratio of 1/2 and applied to the surface. The next step involves winding fiber polymer textiles onto the adhesive-coated surface. In the last step, adhesive is applied on the fiber-reinforced fabric (Figure 2(B)). The thickness of the carbon fiber reinforced fabrics applied to the surface is 500 mm, and the elasticity modulus is 230000 MPa.

The IDs, mixing ratios, and FRP application conditions of the board produced in the study are given in Table 2.



**Figure 2.** FRP application (A) Applying primer to the surface, (B) Wood-reinforced gypsum boards after FRP application

**Table 1.** Technical properties of the gypsum used in the study TS EN 13279-1(2009) light gypsum for building with high gypsum ratio (manually applied)

<b>Water/gypsum usage ratio (volume, lt. /weight, kg)</b>	6.0–6.5/10
<b>Initial setting time (Minutes, according to)</b>	> 20 dk.
<b>Usage time after the mixture is prepared (minutes)</b>	60
<b>Freezing time after application (minutes)</b>	150
<b>Compressive strength (minimum; 4x4 block, 4x4x16 cube block)</b>	25 kgf/cm <sup>2</sup>
<b>Flexural fracture strength (minimum)</b>	10 kgf/cm <sup>2</sup>
<b>The amount passing through 150 Micron sieve (min., %)</b>	60
<b>Loose unit weight (powder)</b>	750 – 850 kg/m <sup>3</sup>
<b>Dry unit weight (powder)</b>	950 – 1000 kg/m <sup>3</sup>
<b>Thermal conductivity value</b>	0.34 W/mK
<b>Fire response</b>	A1
<b>Standard</b>	TS EN 13279-1 B4/20/2

**Table 2.** ID of the sheets, mixing ratios (%), and FRP application conditions

Particle ID	Wood (gr)	Bark (gr)	Gypsum (gr)	FRP Application	FRP-Layer Number
W5B0-R	500	0	1000	-	-
W4B1-R	400	100	1000	-	-
W3B2-R	300	200	1000	-	-
W2B3-R	200	300	1000	-	-
W1B4-R	100	400	1000	-	-
W0B5-R	0	500	1000	-	-
W5B0-C	500	0	1000	Carbon FRP	2
W4B1-C	400	100	1000	Carbon FRP	2
W3B2-C	300	200	1000	Carbon FRP	2
W2B3-C	200	300	1000	Carbon FRP	2
W1B4-C	100	400	1000	Carbon FRP	2
W0B5-C	0	500	1000	Carbon FRP	2

Firstly, the thermal conductivity values of the produced wood-reinforced gypsum board were determined, and then their mechanical properties were examined. Particleboard samples are kept in standard ambient conditions before mechanical properties and thermal conductivity coefficient tests. In this study, gypsum boards were kept at  $20 \pm 2$  °C temperature and  $65 \pm 5\%$  relative humidity. Samples were kept in this environment until humidity reached equilibrium before the experiments, and the equilibrium was checked with daily mass measurements. When less than 0.1% mass change was observed in 24 consecutive hours, the sample was considered ready for testing.

#### Determination of Density

In this study, the density values of gypsum-bonded particleboards were determined in accordance with standard testing procedures commonly applied for wood-based composite materials. Prior to testing, all specimens were conditioned in a climate-controlled room at  $20 \pm 2$  °C temperature and  $65 \pm 5\%$  relative humidity until reaching equilibrium moisture content, in line with TS EN 322 (1996) and TS EN 634-2 (2009) Standards. For the density determination, specimens were cut into standard-sized rectangular pieces, and both their dimensions and mass were precisely measured. The density ( $\rho$ ) of each sample was calculated using the following equation:

$$\rho = \frac{m}{V} \quad (1)$$

where:

$\rho$  is the density of the specimen ( $\text{kg}/\text{m}^3$ ),

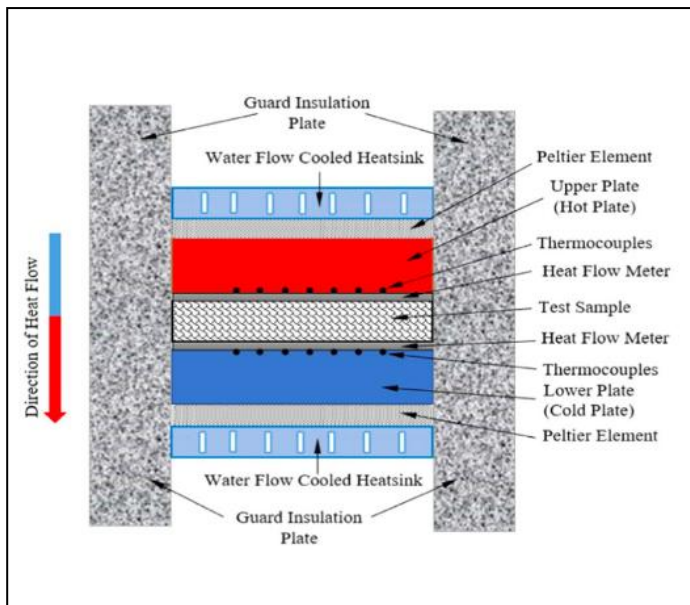
$m$  is the oven-dry mass of the specimen (kg),

$V$  is the volume of the specimen ( $\text{m}^3$ ), calculated as the product of its length, width, and thickness.

The mass of the specimens was measured using a precision balance with an accuracy of 0.01 g, while the dimensions were determined with a digital caliper to an accuracy of 0.01 mm. The volume was computed by multiplying the length, width, and thickness values obtained for each specimen.

#### Determination of Thermal Conductivity (k)

A Lasercomp HFM Fox-50 heat flow meter device has been used to test thermal conductivity under the parameters specified in ASTM C518 and ISO 8301 standards. Thermal conductivity varies depending on the content of the samples. Figure 3 shows the device's operating principle.



**Figure 3.** Schematic diagram of heat flow meter

In the HFM device test, a sample is placed between two plates of varying temperatures. The Peltier effect maintains these plates at a stable, constant temperature. The heat flow meter now uses thermocouples on the upper and lower plates of the apparatus to monitor temperatures and thermal flow along the sample. Thermal conductivity is calculated when HFM produces a

uniform temperature gradient and thermal equilibrium. The Fourier thermal conductivity equation below determines the thermal conductivity as measured by the HFM instrument. The numerical analysis also resolved the 1D steady-state heat transport equation.

$$Q = -k_x A \frac{\Delta T}{\Delta x} \text{ and } Q = -k_y A \frac{\Delta T}{\Delta y} \dots\dots\dots(2)$$

Heat flow is represented by Q (W), thermal conductivity by k (W/mK), total surface area by A (m<sup>2</sup>), temperature differential between surfaces by ΔT (K), and sample thickness by x and y (m) in this equation. Using this formula and the calibrated software, HFM measures, logs, and prints the results. Before beginning the studies, the device is calibrated using a Pyrex calibration file and Pyrex-7740, whose thermal conductivity is known for a few temperatures. Furthermore, the reproducibility of the measurements and the dependability of the results have been examined.

By EN 12664 standards, thermal conductivity was measured using a Fox-50 HFM. Measurements were made starting at -10 °C and increasing by 5 °C at a time to 50 °C. The density of samples in the research ranged from 8.9 kg/m<sup>3</sup> to 60 kg/m<sup>3</sup>. The entire active surface (100 x 100 mm) is integrated by the heat flux transducer to provide a precise measurement of the overall heat flow. Since the transducer is less than 1 mm thick overall, heat flow distortion is impossible. To ensure accuracy over the instrument's lifetime, a type E thermocouple is glued in the center of each transducer, and both are sealed. Because the thermocouples are all positioned within 0.1 mm of the sample surface, they provide precise measurements of the sample's surface temperature (with

a resolution of 0.1 °C) and heat flow (Qiu et al. 2018, Qiu et al. 2021).

The same thermocouples are also used to regulate plate temperature. The HFM-type Fox-50 thermal conductivity-measuring instrument has a repeatability value of ±0.5% and an accuracy of ±3% to 5%.

### Determination of Mechanical Properties

Bending strength tests (MOR) were performed on samples prepared in appropriate dimensions by EN 310 (1999). The sample taking and cutting of the test pieces were adjusted according to EN 326-1 (1993) as follows; 50 mm wide and 20 times the nominal thickness of the test piece (± 50 mm) with a maximum of 1050 mm and a minimum of 150 mm. The load was applied at a constant speed throughout the test, and the speed of the loading head was adjusted to reach the maximum force per second. The value of the applied force is measured with 0.01 precision, and the “load-slope” diagram is drawn. The bending strength of each test piece is calculated by the ratio of the moment of maximum force “Fmax” to the cross-sectional area “M”.

Accordingly;

$$F = \frac{3 P_{max} L}{2 b h^2} \quad (3)$$

Where; F: Bending resistance value (N/mm<sup>2</sup>): Pmax: Maximum load at break (N): L: Support span (mm): b: Sample width (mm): h: Sample thickness (mm).

The modulus of elasticity in bending is applied according to EN 310 (1999). While bending resistance is performed with a measuring device on the same samples used in

bending resistance, the amount of bending is measured with 0.01 mm precision from the middle of the test piece. Accordingly, the modulus of elasticity in bending (E);

$$E = \frac{P L^3}{4 b h^3 f} \quad (4)$$

Where: E: Elasticity modulus in bending (N/mm<sup>2</sup>): P: Load applied under elasticity limit (N): L: Distance between support points (mm), b: Sample width (mm), h: Sample thickness (mm), f: Deformation in the sample against the P load (mm).

In this study, 3 samples were produced from each sample. The average values of the produced samples are given in the results section.

### RESULTS AND DISCUSSION

In this study, the thermal conductivity values of the wood-reinforced gypsum boards were first examined. The thermal conductivity coefficient and density values of the gypsum particle boards are given in Figures 4 and 5, respectively.

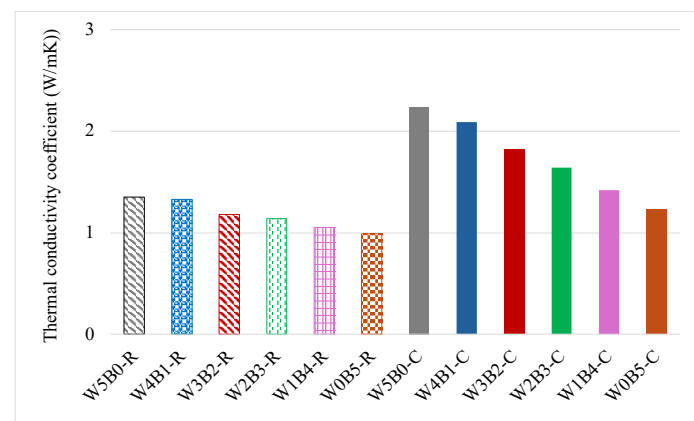
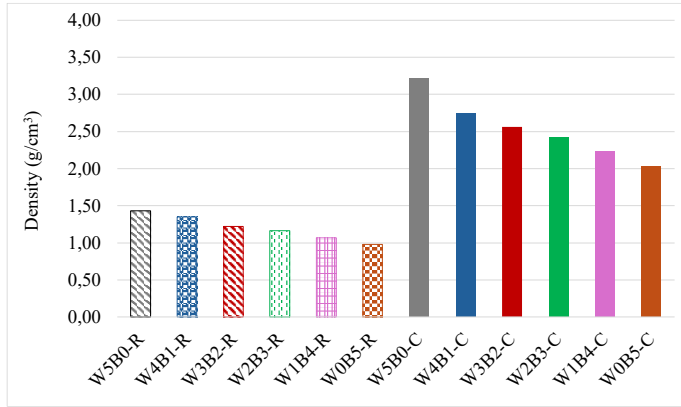


Figure 4. Thermal conductivity values of the wood-reinforced gypsum boards



**Figure 5.** Density values of the wood-reinforced gypsum boards

The given thermal conductivity values cover reference and FRP-applied samples determined according to different wood (W) and bark (B) ratios. In general, it is observed that in both reference and FRP-applied samples, thermal conductivity values are higher when the wood ratio is high, and that thermal conductivity values decrease as the bark ratio increases. This shows that wood is a better heat conductor, and the bark increases insulation performance by reducing thermal conductivity. When the reference samples are examined, the sample with the lowest thermal conductivity coefficient is W0B5-R with a thermal conductivity value of 0.99 W/mK.

The sample with the highest thermal conductivity value is W5B0-R with a thermal conductivity value of 1.35 W/mK. When the thermal conductivity values of wood-reinforced gypsum boards reinforced with fiber reinforced polymers are examined, the sample with the lowest thermal conductivity coefficient is W0B5-C, with a thermal conductivity value of 2.23 W/mK. The sample with the highest thermal conductivity value is W5B0-C, with a thermal conductivity value of 3.24 W/mK.

According to the results of one-way variance analysis (One-Way ANOVA) performed on thermal conductivity values, it was determined that there was a statistically highly significant difference between different sample groups ( $F = 5220.98$ ,  $p < 0.001$ ). The p-value obtained is well below the 0.05% significance level and shows that the thermal conductivity values between the samples differ significantly from each other. It was observed that the thermal conductivity values, especially in fiber-reinforced (FRP) samples, increased significantly compared to the reference samples. In addition, it was determined that the thermal conductivity increased as the wood ratio increased in the sample composition, and this value decreased as the bark ratio increased. This result supports the direct relationship between the density and microstructural properties of the material and thermal conductivity; It reveals that heat conduction increases due to the easier movement of energy carriers (electrons or phonons) in high-density and more compact composites.

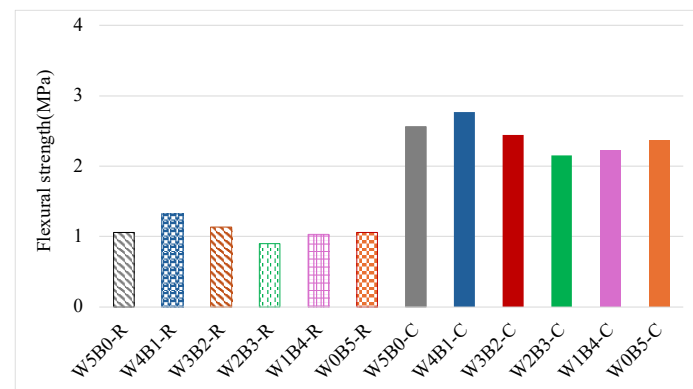
Bisby (2015) examines the use of FRP composites in the construction sector in his study. FRP materials have advantages such as lightness, high strength and corrosion resistance. However, their thermal conductivity varies depending on the reinforcement material and matrix resin used. For example, the thermal conductivity values of glass fiber reinforced FRP panels can vary between 0.158 W/mK and 3.51 W/mK. This wide range indicates that the insulation performance of FRP panels can vary significantly depending on their design. Lukomski and Zajac (2017) This study investigate the thermophysical properties of OSB (Oriented Strand Board) boards, especially depending on the moisture content. Thermal

conductivity, thermal diffusion and specific heat capacity of OSB boards with moisture content ranging from 0% to 10% were measured. The results show that thermal conductivity increases with increasing moisture content. This indicates that the insulation performance of OSB boards may vary depending on the moisture content.

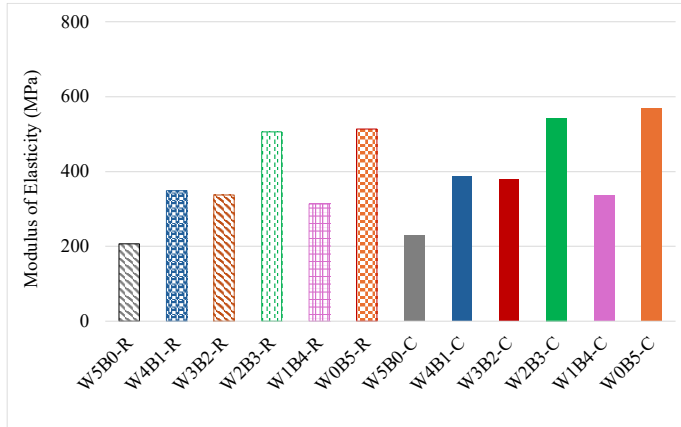
When the density values are examined, it is seen that the density increases as the wood ratio increases in both reference and FRP-applied samples, and the density decreases as the bark ratio increases. The highest density in the reference samples was determined as W5B0-R (1.43 g/cm<sup>3</sup>), and the lowest density was determined as W0B5-R (0.98 g/cm<sup>3</sup>). The density values in FRP-applied samples are generally quite high compared to the reference samples. The highest density was measured as W5B0-C (3.21 g/cm<sup>3</sup>), and the lowest density was measured as W0B5-C (2.03 g/cm<sup>3</sup>). The reinforcement process significantly increased the density of the materials. When the data are examined, it is observed that the thermal conductivity values increase as the density increases in both reference and FRP-applied plates. This relationship is related to the microstructural properties of the material. A denser structure allows the energy carriers that carry heat (electrons or phonons) to move with less resistance, which increases thermal conductivity. In a study conducted by Kaya et al. (2021), the thermal conductivity of boards produced with a mixture of red pine wood and gypsum varied between 0.5021–0.7404 W/mK. In this study, it was observed that density and thermal conductivity increased with the increase in the wood ratio, while these values decreased with the increase in the bark ratio. These findings show that wood is a better heat conductor and that the bark

increases its insulation performance. In a study conducted by Tsalagkas et al. (2019), the effects of applying glass fiber and paper layers to the surface of bark-based panels on thermal conductivity, physical and mechanical properties were investigated. In the study, it was stated that glass fiber reinforcement increased thermal conductivity but decreased insulation performance.

This shows that FRP application increased thermal conductivity by increasing density. In a study conducted by Pásztor et al. (2019), the thermal conductivity values of insulation panels produced from the bark of different tree species were reported as 0.0645 W/mK. These values show that bark-based panels have high insulation potential. After determining the thermal conductivity and density values, the mechanical properties of the board were determined. The bending strength and elasticity modulus values of the board are given in Figures 6 and 7, respectively.



**Figure 6.** Bending strength values of the wood-reinforced gypsum boards



**Figure 7.** Modulus of elasticity values of the wood-reinforced gypsum boards

The highest bending strength value of the wood-reinforced gypsum boards without FRP application was obtained with W4B1-R (1.32 MPa). Among the other samples without FRP applications, the flexural strength values ranged between 1.06 and 0.9 MPa. Especially, the W2B3-R (0.9 MPa) value shows lower flexural strength compared to the other samples. This shows that the flexural strength decreases with the increase in the bark ratio. The highest flexural strength value of the wood-reinforced gypsum boards with FRP application was obtained with W4B1-C (2.77 MPa). The flexural strength values in FRP-applied samples ranged between 2.37 and 2.15. The flexural strengths of FRP-applied samples are generally much higher than the boards without FRP application. This increase shows that the mechanical strength of the material increased significantly thanks to the reinforcement process. The highest elasticity modulus value was obtained with W0B5-R (513.84 MPa). The lowest modulus of elasticity value was observed with W5B0-R (206.72 MPa). Modulus of elasticity is the resistance of the material against deformation and this value indicates the hardness of the material. The modulus of elasticity values in FRP-applied samples was measured

as the highest with W0B5-C (568.53 MPa) and the lowest with W5B0-C (228.93 MPa). The modulus of elasticity of FRP-applied samples is generally higher than the reference samples, and especially the modulus of elasticity of the W0B5-C sample shows a very high value. This indicates the hardening and increased rigidity resulting from the reinforcement process.

It is observed that FRP-applied samples present much higher values in terms of both bending strength and modulus of elasticity. This indicates that the FRP application process increases the durability and rigidity of the material. As a result of the one-way variance analysis (One-Way ANOVA) performed on the obtained flexural strength data, it was determined that there was a statistically significant difference between the different sample groups ( $F=5.20$ ,  $p=0.0003$ ). The p-value obtained was well below the 0.05 significance level, indicating that there was a significant difference in flexural strength between the samples.

This result revealed that both the reinforcement application and the wood and bark ratios used in the sample composition had a significant effect on flexural strength. According to the results of one-way analysis of variance (One-Way ANOVA) performed on the modulus elasticity (elasticity modulus) values, it was determined that there was a statistically significant difference between different sample groups ( $p < 0.001$ ). This result shows that the reinforcement method (FRP application) applied to the samples and different wood-bark ratios have a significant effect on the elasticity modulus. It was determined that the elasticity modulus values, especially

in the samples with FRP reinforcement, increased significantly compared to the reference samples.

## CONCLUSIONS

In this study, mechanical and thermal properties such as thermal conductivity, density, bending strength, and modulus of elasticity of wood-reinforced gypsum boards with fiber-reinforced polymer and different wood and bark ratios were investigated.

- The ratios of wood and bark significantly affected the thermal conductivity, density, flexural strength, and modulus of elasticity of the boards.
- Thermal conductivity increased with higher wood content and decreased as the bark ratio increased. The lowest value was recorded in W0B5-R (0.99 W/mK) and the highest in W5B0-UR (2.24 W/mK).
- Density increased with wood content and decreased with bark content. The highest density was found in W5B0-C (3.21 g/cm<sup>3</sup>) and the lowest in W0B5-R (0.98 g/cm<sup>3</sup>).
- Flexural strength decreased with increasing bark content. Among reference samples, the highest value was W4B1-R (1.32 MPa), while in FRP-reinforced samples, it reached W4B1-(2.77 MPa).
- The modulus of elasticity increased with bark content in reference samples. The highest modulus was obtained in W0B5-R (513.84 MPa) and the lowest in W5B0-R (206.72 MPa). FRP application further improved the modulus, with the highest value in W0B5-C (568.53 MPa).

- FRP reinforcement improved the mechanical properties and increased the thermal conductivity of the wood-reinforced gypsum boards.

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