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Investigation of Thermal Insulation and Water Absorption Properties of *Cortaderia selloana* Short Fibers Reinforced Sustainabilit Composite Material

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ABSTRACT

Times In recent years, the use of cellulosic fiber reinforcements in polymer matrix composites has increased. In this study, composites were produced with fibers obtained from the *Cortaderia selloana* plant and the absorption and thermal properties of the obtained samples were investigated. Composite samples were produced by compression molding using a high-performance epoxy polymer matrix of short *Cortaderia selloana* (pampa grass) fibers of different densities. It is aimed to produce materials with improved absorption and thermal properties by producing composites with large amounts of fiber. Thermal properties and water absorption behaviors of *Cortaderia selloana* fiber reinforced epoxy composites of different densities prepared using the compression molding technique were examined. The experiments were carried out by varying the composite density (50, 60, 70, 80, 90 and 100 kg/m^3). In addition, the water absorption behavior was analyzed at different temperatures of 10°C to 40°C. *Cortaderia selloana* fiber reinforced composites with a density of 75 kg/m^3 showed better thermal properties at 30°C. The water absorption rate was better at 40°C in *Cortaderia selloana* fiber reinforced composites with a density of 66.3 kg/m^3. Additionally, by increasing the temperature, the water absorption rate of the composites also increases.

Cortaderia selloana Kısa Elyaf Takviyeli Sürdürülebilir Kompozit Malzemenin Isı Yalıtımı ve Su Emme Özelliklerinin İncelenmesi

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ÖZET

Son yıllarda polimer matrisli kompozitlerde selülozik lif takviyelerin kullanımı artmıştır. Bu çalışmada, *Cortaderia selloana*bitkisinden elde edilen lifler ile kompozit üretilmiş ve elde edilen numunelerin absorpsiyon ve termal özellikleri araştırılmıştır. Farklı yoğunluklarda kısa *Cortaderia selloana* (pampa otu) elyafları yüksek performanslı epoksi polimer matrisi kullanılarak sıkıştırılmış kalıplama yoluyla kompozit numuneler üretilmiştir. Büyük miktarlarda elyaf ile kompozit üreterek absorpsiyon ve termal özellikleri geliştirilmiş malzeme üretilmesi amaçlanmıştır. Basınçlı kalıplama tekniği kullanılarak hazırlanan farklı yoğunlukta elde edilmiş *Cortaderia selloana* elyaf takviyeli epoksi kompozitlerin termal özellikleri ve su emme davranışları incelenmiştir. Deneyler, kompozit yoğunluğu (50, 60, 70, 80, 90 ve 100 kg/ m^3) değiştirilerek gerçekleştirilmiştir. Buna ek olarak, su emme davranışı 10°C ila 40°C'lik farklı sıcaklıklarında analiz edilmiştir. Yoğunluğu 75 kg/m^3 olan *Cortaderia selloana* elyaf takviyeli kompozitler 30°C'lik sıcaklıkta daha iyi termal özellikler göstermiştir. Yoğunluğu 66.3 kg/m^3 olan, *Cortaderia selloana* elyafla güçlendirilmiş kompozitlerde 40°C'lik sıcaklıkta su emme oranı daha iyi çıkmıştır. Ayrıca, sıcaklığının arttırılmasıyla kompozitlerin su emme oranı da artmaktadır.

1. Introduction

The use of cellulosic fiber reinforced polymer matrix composites has increased. Liquid absorption time is the time required for the absorbent material sample to be completely wetted by the test liquid, that is, the time required for a liquid to penetrate its internal structure under specified conditions. Liquid absorption capacity is the expression of the amount of liquid absorbed by a unit mass of the test absorbent, under specified conditions and after a specified time, as a percentage of the mass of the test absorbent.

Liquid transfer behavior of composite materials is important for the performance of a product during production processes and end use. In composite production, liquid absorption and thermal properties of the raw material used, composite formation technique and structural parameters must be taken into consideration. In parallel with the developments in technology, the standards expected from the materials have increased and the expectations have increased. These expectations are related to the liquid absorption properties of the materials that make up the composite, therefore composites with different properties, especially functional materials, are studies aimed at changing the liquid absorption properties of the material from which they are produced (making it liquid absorbent or liquid repellant). For many technical textile fields, the development of which has increased rapidly in recent years, the liquid absorption properties of the products are an important factor affecting their performance. Technical textile products such as geotextiles and agrotextiles and packaging textiles in contact with the soil are expected to have liquid absorption or liquid repellency and breathability properties, depending on the area of use. In order to gain these features, the stated objectives can be achieved through production processes starting from raw materials.

In the absorption event, an interaction occurs between water molecules and the molecules in the structure of the fiber. Therefore, natural fibers with hydrophilic groups that interact with water (including regenerated fibers of natural origin) absorb liquid because they have molecules that can bond with water, while synthetic fibers interact with a very small amount of water. Since they have groups that can enter the liquid, their liquid absorption capacity is quite low. During the interaction between textile material and water, water primarily adheres to hydrophilic groups. Then, water molecules either attach to hydrophilic groups or form a new layer by attaching to previously bonded water molecules. Water molecules that bind directly to hydrophilic groups are tightly bound and their movements are limited. Indirectly bonded water molecules, whose molecular arrangements are more irregular, have a looser structure and move more easily. In the crystalline regions of textile materials, fiber molecules are tightly packed and ordered. Active groups formed cross-links between molecules. For this reason, it is not easy for water molecules to penetrate into the crystalline region, and some of the cross-links between active groups must be broken for water absorption. Water absorption of a material gives an idea about the ratio of crystalline and amorphous regions of the structure. Crystalline regions have the effect of mechanically preventing the penetration of water into the structure and reducing the number of hydroxyl groups suitable for bonding. As absorption increases, cross-links break and are replaced by water molecules. Depending on the resistance mechanism of the fiber structure against change, the breaking and re-formation of cross-links occurs in the form of a hysteresis, and this causes the formation of liquid absorption/desorption hysteresis. Although glucose and cellulose have chemically similar structures, their interactions with water are very different; While glucose dissolves in water, cellulose swells to a certain extent. Limit swelling is caused by the liquid penetrating into the amorphous parts of the structure or between the fibrils and not being able to enter the crystalline regions.

Ramesh et al. (2021) and various research studies have predicted the benefits of using natural fibers as reinforcement instead of artificial fibers in the production of composites (Ramesh et al., 2021). Compression molding method has been used to produce composites and they have been subjected to water absorption and mechanical property tests such as bending, tensile and impact tests. It has been observed that the water absorption and mechanical properties of the composites are at the same level as other natural fiber reinforced composites tested in past literature studies. In their studies, the mechanical properties, high water uptake or water solubility of PVA-based composites containing PVA mixture polymers with particles or fiber used as reinforcement materials were examined (Jain et al., 2017). Ajithram et al. (2022), they determined the fiber extraction methods from different types of water hyacinth plants and investigated the effects of each of these methods on the mechanical, absorption and morphological properties of water hyacinth fiber composites (Ajithram et al., 2022). In the study conducted by Diaz et al. (2010), the sound absorption of reed panels was investigated and they found that reed panels provided the best absorption at high and medium frequencies. Showed that the composite material produced by utilizing cotton textile wastes such as stubble and landfill wastes such as sunflower stalks can be used as an insulation material by mixing it with sufficient epoxy (Binici et al., 2013). Investigated the acoustic properties of natural fiber reinforced composites in his article. The pulps produced using fibers obtained from the orange tree have been subjected to different processes. These pulps were used as reinforcement for a polypropylene matrix. The resulting composite materials were subjected to acoustic tests. Transmission losses were obtained and soundproofing properties were investigated (Reixach et al., 2015). Examined the acoustic properties of natural fibers in their research and determined that they have good sound insulation properties as a result of measurements made with natural fibers. As the thickness of the fibers increased, the sound insulation value in the low frequency range increased. Kenaf, Ijuk, coconut kernel and 2% alkaline treated palm oil were examined using the impedance tube test method to determine the sound absorption coefficients of natural fibers (Kaya & Dalgar, 2017). As a result, it has been stated that natural fibers can be a good alternative sound absorber compared to synthetic fibers (Yahya et al., 2017). In a study, it was determined that the sound absorption coefficient characteristic did not change with environmental conditioning, but the sample temperature caused a significant change in the sound absorption coefficient of the materials (Seçgin et al., 2017). A comparison of thermal insulation materials containing various agricultural wastes is presented. Three types of binders were used, along with wheat straw, rye straw, flax, oat straw, barley straw, rice straw and rice husk. It has been stated that the plates prepared with rye straw and flax and liquid glass as a binder have the best physical and mechanical properties due to the formation of the optimal composite structure (Bakatovich et al., 2018). In his study, chrome-tanned leather waste was added to natural rubber and styrene-butadiene rubber and their mixtures in various proportions. Thermal, rheological, mechanical and morphological effects of wastes were investigated. Various factors that affect acoustic performance are length, thinness, fiber type, thickness, density, orientation, compression level, volume fraction in the composite, and design (Şaşmaz et al., 2019). Details of various factors affecting the acoustic behavior of fiber-based composites are explained. Natural fiber-based composites exhibit relatively good sound absorption capacity. Acoustic, thermal and hygrothermal properties of panels made from leather waste were investigated (Hassan et al., 2021). Thermal conductivity values were measured in the range of 0.064-0.078 W/mK at 10 °C, depending on the composition and adhesive (Merli et al., 2023). Investigated the acoustic performance of MPP absorbers made of biodegradable natural fiber-reinforced composites using 3D printing. For biocomposite Micro Perforated Panel (MPP) types, Cork fiber-based MPP has been indicated to show significant promise for application as an acoustic improvement material, either independently or in combination with Kenaf materials (Rezaieyan et al., 2024). Onyekachi & Iwuozor (2019), mechanical and water absorption properties of polyacrylic resin and a mixture of polyacrylic resin and barite (Onyekachi & Iwuozor, 2019).

Various properties of various cellulosic fibers and their composites have been extensively investigated in the literature. It has been determined that changes in fiber length and density ratios have a significant effect on the absorption and thermal properties of composites. In general, cellulosic fibers are more sensitive to moisture; Therefore, the water absorption behavior of composites obtained from cellulosic fibers was investigated and it was determined that such composites were products that could be used in humid environments. The effect of fiber density and temperature on water absorption depending on time was investigated. Due to the hydrophilic behavior of cellulosic fibers, the water uptake behavior of composites occurs. The increase in water absorption will affect the fiber-matrix interface, which causes the properties of the composites to decrease. At high temperatures, the permeability of water increases, thus causing microcracks to form at the fiber-matrix interface, which causes premature deterioration of the composite (Çeven et al., 2018).

In recent years, the use of cellulosic fiber reinforcements in polymer matrix composites has been increasing due to various factors such as environmental concerns and awareness (Kodaloğlu & Kodaloğlu, 2024a). In addition, cellulosic materials have a wide range of uses. Since natural fibers have many advantages for plant-based fibers with good potential for developing polymer matrix, fibers in fiber-reinforced composite materials offer properties such as biodegradability, renewability, wide availability, low density and low cost (Kodaloğlu & Akarslan Kodaloğlu, 2024b). Environmentally friendly fiber-reinforced composites lead to the search for a new type of natural fiber with desirable properties, so the *Cortaderia selloana* fiber-reinforced composite used in our study is lightweight and environmentally friendly. Developing new class of natural fiber composites, the strength of the fiber mainly depends on its chemical composition, matrix bonds and environmental factors.

When current applications are examined in the literature, composite material studies produced by adding *Cortaderia selloana* fibers are rarely encountered (Çeven & Günaydin, 2018a). The absorption and thermal insulation properties of the developed new *Cortaderia selloana* fiber-added composite materials were compared with each other and with their densities (Çeven & Günaydin, 2019). *Cortaderia selloana* fibers reinforced epoxy filler composites are seen to be used as high performance insulation materials for thermal insulation and waterproofing purposes (Çeven & Günaydin, 2018b). For this study, *Cortaderia selloana* grass was collected and the produced composite samples were subjected to various characterizations to examine their thermal and absorption properties.

2. Materials and Methods

Cortaderia selloana is a flowering plant commonly known as pampas grass. Cortaderia is a tall grass that can reach a height of 3 m and the leaves are silver gray in color. The plant *Cortaderia selloana* is shown in Figure 1.

Figure 1. *Cortaderia selloana* plant

Pampas grass collected from different regions around Lake Eğirdir was divided into small pieces to ensure homogeneity, then soaked in water, the fibers were separated by combing using a thin wire brush and dried in sunlight to remove moisture. *Cortaderia selloana* fiber reinforced epoxy composite samples of different densities, prepared using the compression molding technique, were produced. The produced composite sample is shown in Figure 2.

Figure 2. Produced composite sample

3. Result and Discussion

3.1. Thermal conductivity coefficient measurement

Thermal conductivity is the rate of heat transfer at unit temperature difference from unit area through unit thickness of a material. Thermal conductivity was measured according to the international standard ASTM C518. The device consists of two plates, upper and lower, the temperature of the upper part of the plates is 40℃ and the temperature of the lower part is 10℃. The sample is placed between these plates and measurements are taken. The hot plate touches the composite. *Cortaderia selloana* fiber reinforced composite samples maintained their form during pressing. Therefore, it has been observed that the density of the porous composite structure improves the heat conduction coefficient. The thermal conductivity coefficient measuring device is shown in Figure 3.

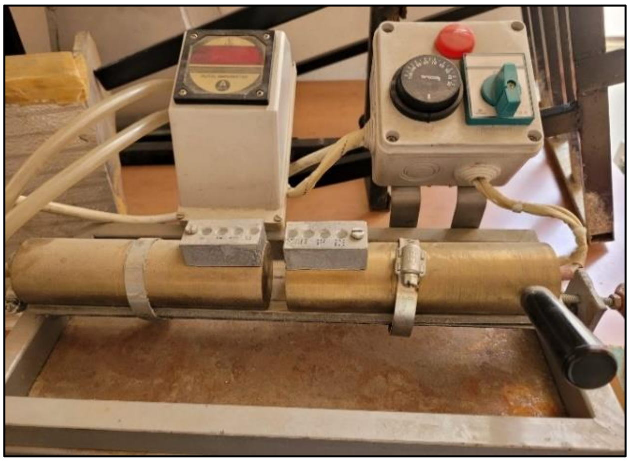

Figure 3. Thermal conductivity coefficient measuring device

Composite materials have a large amount of empty space, which traps a large amount of stagnant air. As a result of the much lower conductivity of still air, when comparing composites, the thermal insulation performance is determined by the air trapped in the gaps between the fibers as the density increases.

It can be said that the reason why the composite structure obtained in the study has a low conductivity coefficient is due to the structure becoming more dense as a result of pressing. Because the weight of the sample increased but its thickness remained constant as a result of pressing. Figure 4 shows the graph showing the change between Thermal conductivity coefficient (W/mK) and mean temperature and bulk density.

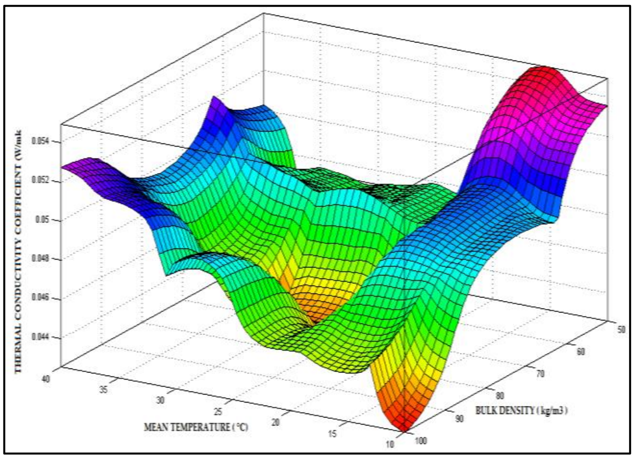

Figure 4. Graph showing thermal conductivity coefficient change

When examined in terms of density, considering the lowest transmission coefficient and the highest transmission coefficient values, the transmission coefficient at density 100 kg/m^3 temperature at 40 °C is 0.0527 W/mK, density 50.7 kg/m^3 temperature at 10 °C transmission coefficient is 0.0535. Between W/mK, *Cortaderia selloana* fiber reinforced composite samples appear to contribute to thermal insulation. Figure 5 shows the relationship graph between Thermal conductivity coefficient (W/mK) and mean temperature.

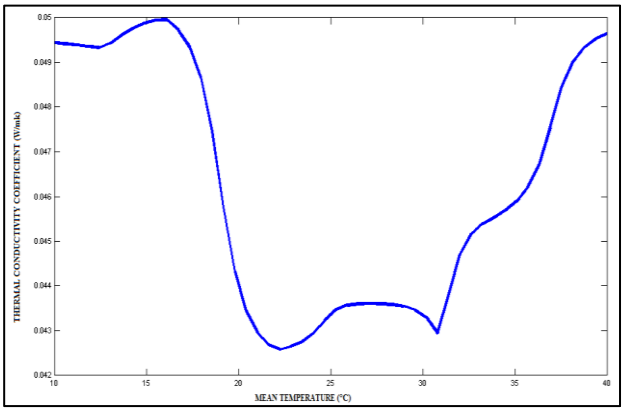

Figure 5. The relationship between thermal conductivity coefficient and mean temperature

When the relationship between thermal conductivity coefficient (W/mK) and mean temperature is examined, the conduction coefficient is 0.0475 W/mK when the density is 50 kg/m^3 and the temperature is 22.1 °C, and the conduction coefficient is 0.0475 W/mK when the density is 50 kg/m^3 and the temperature is 30.9 °C. 0.0472 W/mK, density 100 kg/m3, temperature 22.1 °C, thermal conduction coefficient 0.0456 W/mK, density 100 kg/m^3, temperature 30.9 °C, conduction coefficient 0.0482 W/mK was found as.

It was observed that the composite material with 100% density showed better performance. In general, the denser the sample will have lower thermal resistance. The 75% density had lower thermal resistance than other densities and provided higher thermal insulation compared to composites made according to other densities. Figure 6 shows the graph showing the relationship between Thermal conductivity coefficient (W/mk) and bulk density (kg/m^3).

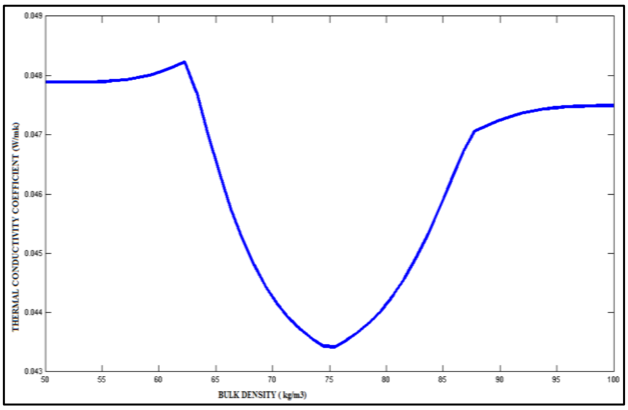

Figure 6. Graph showing the relationship between thermal conductivity coefficient and bulk density

When the relationship between thermal conductivity coefficient (W/mk) and bulk density (kg/m^3) is examined, when the density is 75 kg/m^3, the temperature is 10°C, the thermal conductivity coefficient is 0.0494 W/mK, the density is 75 kg/m^3, the temperature is 40°C. The heat conduction coefficient reached 0.0496 W/mK. Among the developed composites, the composite with a density of 75 kg/m^3 had a higher thermal conduction coefficient value than the composite with a density of 50-70 kg/m^3 and 80-100 kg/m^3. Thermal conductivity coefficient was maximum at 40 °C temperature and 100 kg/m^3 density, and reached its minimum value at 75 kg/m^3 density. Thermal conductivity coefficient reached its optimal value at a density of 75 kg/m^3.

3.2. Water absorption strength test of samples

Water absorbance is the amount of water absorbed by a given sample under certain conditions. Generally, the entry of water into polymer matrix composites is due to the penetration of water molecules into the capillaries. To determine the liquid absorption capacities (%) of epoxy composites, *Cortaderia selloana* natural fiber reinforced composite samples, with dimensions of 50 mm × 20 mm × 3 mm according to ASTM D570, were dried in a vacuum oven at 30 °C for 18 hours. The samples were kept in pure water at room temperature (20°C) and between 10 and 40°C, and weight changes were determined periodically every hour for a total of 10 hours. To remove water on the film surface during weighing, the samples were kept on the blotting paper for a short period of a few seconds. With periodic measurements, the liquid uptake behavior of the films was examined. Absorption capacity was calculated as a percentage of the difference between wet and dry weights at the end of the period and the ratio of dry weight. Measurements were performed in triplicate for each sample. Figure 7 shows the water absorption behavior of *Cortaderia selloana* fibre-reinforced composite samples.

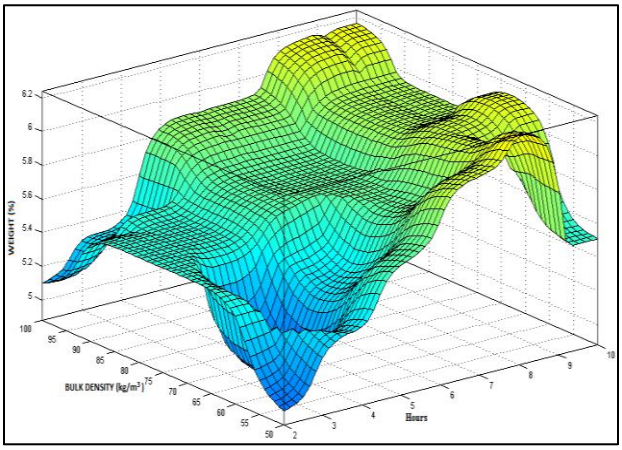

Figure 7. Water absorption behavior of composite samples

When the density value was 50 kg/m^3, after 10 hours the sample weight percentage increased by 5.51%, and when the density value was 100 kg/m^3, after 10 hours the sample weight percentage increased by 6.17% and reached the saturation level, which indicates that the water absorption value of *Cortaderia selloana* composites is low. showed that it was. It has been observed that the composites have a hydrophobic structure due to this low water absorption property of *Cortaderia selloana* fiber. Figure 8 shows the connection chart between weight (%) and hours.

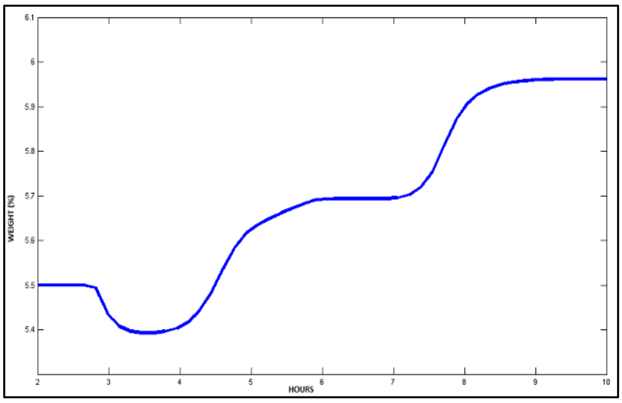

Figure 8. The connection between weight (%) and hours

When the connection between weight (%) and hours is examined, while the density value was 50 kg/m^3, the sample weight percentage increased by 5.3% after 3.30 hours. When the density value was 100 kg/m^3, the sample weight percentage increased by 5.31% after 3.30 hours. The final weight percentage of the composite sample of *Cortaderia selloana* fiber reached saturation after 10 hours was 6.10%. Figure 9 shows the graph showing the relationship between weight (%) and bulk density.

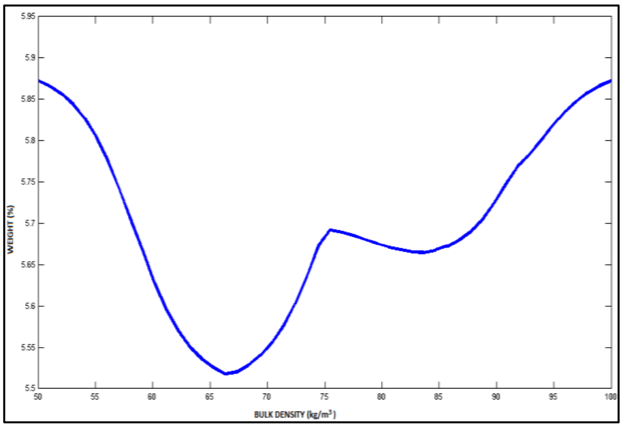

Figure 9. Relationship between weight (%) and bulk density

In the water absorption test for composites, water absorption increased with increasing fiber density, depending on the changes in fiber density and soaking times in water. Water absorption rate increased in 10 hours. Regardless of the fiber density fraction, it showed a very low water absorption rate for all periods due to the hydrophobic epoxy.

At points where *Cortaderia selloana* fibrous composites rapidly reach saturation, water is absorbed at a density of 66 kg/m^3 and in relatively small amounts (5.54%). When the connection between weight (%) and bulk density (kg/m^3) was examined, while the density value was 66.3 kg/m^3, the sample weight percentage increased by 5.52% after 10 hours.

Due to the hydrophobic structure of epoxy resin and *Cortaderia selloana* fibers, the water absorption rate of the composites is low. Similar water absorption tendency was observed in all temperature ranges, but the water absorption rate increased with increasing bath temperature. The increase in temperature and the spreading phenomenon resulting in the formation of microcracks at the interface caused an increase in the water absorption rate in the fiber and matrix region.

4. Conclusions

In this study, the thermal properties and water absorption properties of *Cortaderia selloana* fiber reinforced epoxy polymer matrix composites were investigated. *Cortaderia selloana* composite has the advantage of replacing synthetic fibers in structural applications due to its water absorption properties. At 40°C, the water absorption value of *Cortaderia selloana* fiber reinforced epoxy polymer matrix composites increases up to 6.14%. Since *Cortaderia selloana* has a rough outer surface, it can be used as a potential natural fiber in environmentally friendly composites.

It was observed that *Cortaderia selloana* fiber reinforced epoxy polymer matrix composites showed better thermal performance at a density value of 100 kg/m^3. In general, the denser sample will have a lower thermal conduction coefficient. However, the thermal conduction coefficient value of *Cortaderia selloana* fiber reinforced epoxy polymer matrix composites with a density of 75 kg/m^3 provides better thermal insulation than the composite with a density of 100 kg/m^3. *Cortaderia selloana* fiber reinforced epoxy polymer matrix composites with a density of 66 kg/m^3 have the highest water absorption resistance value compared to the composite with a density of 100 kg/m^3.

Environmental awareness directs producers and consumers to biocompatible and recyclable products, focusing on the production and consumption of nature-based biodegradable products. *Cortaderia selloana* fibers have a minimum water absorption rate due to their shorter length, lower density and low hydrophilicity, and composite products that provide high thermal insulation are obtained.

Conflict of Interest

The authors declared that there is no conflict of interest.

Author Contributions

The authors declare that they have contributed equally to the article.

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