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Investigation of mechanical properties and workability of composite materials made of almond fiber

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ABSTRACT

The increasing prevalence of composite materials can be attributed to their exceptional specific strength, making them a superior alternative to many traditional materials. However, the high cost associated with synthetic fibers poses a significant challenge to the widespread adoption of composite materials across various applications. This challenge has redirected research efforts toward the exploration of natural fibers, which offer a promising solution for the integration of composite materials in numerous industries such as furniture, flooring, decoration, and more. This study focuses on natural composite materials derived from Libyan almond shells. The research examines three different particle sizes of ground almond shells: large granules, medium-sized particles, and fine powder. These ground shells were combined with polyester resin in four distinct ratios: 80:20, 60:40, 40:60, and 20:80. To assess the mechanical properties of the resulting composites, three primary tests were conducted: impact testing, tensile testing, and bending testing. The findings revealed that the samples incorporating almond shell powder exhibited the best mechanical performance across all three tests. Building on the previous research, this study also includes machinability tests on all types of fabricated samples. Several machining operations were performed, including cutting, drilling, hammering, threading, and jointing. These operations were also conducted on comparable samples made from compressed wood, with identical dimensions to the composite material samples, to facilitate a direct comparison of results.

دراسة الخواص الميكانيكية وقابلية التشغيل للمواد المركبة المصنوعة من ألياف اللوز

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الكلمات المفتاحية:

المركبات
الألياف الطبيعية
قشور اللوز
قابلية التشغيل
الخواص الميكانيكية

المخلص

يمكن أن يعزى الانتشار المتزايد للمواد المركبة إلى قوتها النوعية الاستثنائية، مما يجعلها بديلاً متفوقاً للعديد من المواد التقليدية. ومع ذلك، فإن التكلفة العالية المرتبطة بالألياف الاصطناعية تشكل تحدياً كبيراً لاعتماد المواد المركبة على نطاق واسع عبر تطبيقات مختلفة. وقد أعاد هذا التحدي توجيه جهود البحث نحو استكشاف الألياف الطبيعية، والتي تقدم حلاً واعدًا لدمج المواد المركبة في العديد من الصناعات مثل الأثاث والأرضيات والديكور والمزيد. تركز هذه الدراسة على المواد المركبة الطبيعية المشتقة من قشور اللوز الليبية. يدرس البحث ثلاثة أحجام مختلفة من جزيئات قشور اللوز المطحونة: حبيبات كبيرة وجزيئات متوسطة الحجم ومسحوق ناعم. تم دمج هذه القشور المطحونة مع راتنج البوليستر بأربع نسب مميزة: 80:20 و 60:40 و 40:60 و 20:80. لتقييم الخصائص الميكانيكية للمركبات الناتجة، تم إجراء ثلاثة اختبارات أولية: اختبار التأثير واختبار الشد واختبار الانحناء. وكشفت النتائج أن العينات التي تحتوي على مسحوق قشر اللوز أظهرت أفضل أداء ميكانيكي في جميع الاختبارات الثلاثة. وبناءً على البحث السابق، تتضمن هذه الدراسة أيضاً اختبارات قابلية التصنيع على جميع أنواع العينات المصنوعة. تم إجراء العديد من عمليات التصنيع، بما في ذلك القطع والحفر والدق والخيوط والتوصيل. كما أجريت هذه العمليات على عينات قابلة للمقارنة مصنوعة من الخشب المضغوط، بأبعاد متطابقة لعينات المواد المركبة، لتسهيل المقارنة المباشرة للنتائج.

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1. Introduction

This scientific paper is an extension of a previous work where we published a paper in an international conference held in Turkey and the title of the paper was "Testing the mechanical properties of composite materials made from almond husk fibers" where we mentioned only the mechanical properties, but in this paper it will be an extension of the paper we mentioned but we will add in it the study of the mechanical properties and workability of composite materials made from almond fibers

Composites are made by mixing two or more component materials with different physical or chemical properties to generate a new material that is better than the sum of its component parts. The components retain their original identities; however, their combination produces a material different from the parts. Due to their high strength, stiffness and low weight, composite materials are widely used in a variety of industries, including sports equipment, aerospace, automotive and construction. Many studies in the literature have shown how synthetic materials harm the environment and contribute to the phenomenon of global warming as a result, companies and academia are placing a great deal of emphasis on the search for alternative materials that are environmentally and economically sustainable. Natural fiber reinforced composites (NFRCs) have different physical or chemical properties to generate a new material that is better than the sum of its component parts. The components retain their original identities, yet their combination produces a material that is different from the parts [1-2].

This makes them suitable for a wide range of industrial uses, including construction, packaging, furniture, automotive, and aerospace [3]. The importance of research into composite materials made from natural and synthetic fibers has increased in recent years due to their potential applications in sustainable and environmentally friendly construction. This has been the main reason for the author and others to conduct numerous studies on this issue [4-15]. Natural fibers have gained popularity in composite materials due to their biodegradability, low cost, and renewable nature. However, natural fiber composites have disadvantages, such as lower strength and stiffness than synthetic composites. Natural fiber composites are those composed of natural fibers and a matrix material, such as a polymer.

Generally, many kinds of fibers which are abundantly available in the natural nature such as jute, sisal, coir, kneaf, oil palm, banana, wheat, bamboo, and flax straw etc. Most of those fibers are studied and investigated by researchers [16-19]. Natural fiber proved an effective and easily available reinforcement material in the thermoset and thermoplastic matrices [20-21]. Long plant, fibers such as hemp, flax, and bamboo that have considerable potential for the production of natural fiber reinforced composite materials [22-23]. Researchers focusing and paying more attention in investigating the potential use of new vegetable fibers as reinforcements in polymeric materials [24].

2. Materials

The materials used to make testing samples include epoxy resin (EP-10) and almond outer shells (hard almond peels). Epoxy resin provides outstanding mechanical qualities, such as low viscosity, high adhesion, and low creep rate under permanent stresses. As specified by the manufacturer, the resin was combined with a hardness ratio of 3:1. However, Libyan solid almond peels collected from almond trees are cleaned with water to eliminate dirt and dust before being sun-dried. Finally, it is ground into three sizes: large, medium, and powder, as shown in Figure 1.

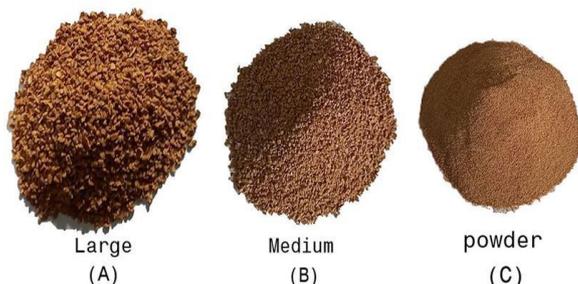


FIGURE 1. Types of grounded almond shells

3. Experimental Work

A composite plate made from each type of almond peel. Matrix material (epoxy resin) combined with almond peels in four distinct

ratios, as shown in Table 1. Mixed mixture was put into a metallic mould, covered, and allowed to cure at room temperature for one day (24 hours). The mould cavity has a rectangular shape with dimensions of (283 mm × 125 mm × 15 mm). The specifications mentioned form the shape of the composite plate, with the exception of its thickness, which is 6mm. Four metallic nuts were inserted into the corners of the die chamber to control the thickness of the produced composite plate. Finally, composite plates were made using metallic dies, and these plates served as the raw material for tested specimens Figure 2.



FIGURE 2. Types produced composite plate with three different sizes of almond peels

TABLE 1. Types of tested samples with their codes

Ratio of almond peels (%)	Ratio of resin (%)	Hardener weight (g)	Sample code for large size almond peels	Sample code for medium size almond peels	Sample code for powder form almond peels
80%	20%	1.37	A1	B1	C1
60%	40%	2.75	A2	B2	C2
40%	60%	4.136	A3	B3	C3
20%	80%	5.51	A4	B4	C4

4. Testing Of Mechanical Properties

Composite materials in general differ from isotropic materials like metals. As a result, it is prudent to test the mechanical properties of composite materials. Many factors influence the properties of composite materials, including the reinforcing material, matrix material, fiber type, fiber direction, and so on. In the current study, three major mechanical tests were performed: tensile, impact, and flexural.

Tensile tests were done in accordance with ISO 527-4 [25]. Natural composite samples including varying sizes of almond peels were made and analyzed under identical conditions. Testing samples measure 200 mm long, 20 mm wide, and 6 mm thick. Tensile testing is performed using universal tensile testing machines with a maximum load capacity of 50 kN. Each test was done four times, using equal samples for each type of material. Finally, the collected results are recorded, and the average value for each test is determined.

Impact test samples are prepared in accordance with the standard (ASTM - A370). The samples have dimensions of 55 mm in length, 10 mm in breadth, and 6 mm in thickness according to the standard Charpy impact test.

Flexural tests are commonly used to measure the degree of brittleness of a material. Brittle materials tend to shatter abruptly and without warning, whereas ductile fractures show indications of breakage before the fracture point. For the current study, testing specimens are constructed in accordance with ASTM D 790 - 03 [26], with dimensions of 200 mm in length, 20 mm in breadth, and 6 mm in thickness. A three-point flexural testing equipment with a maximum load of 20 kN is utilized to conduct this type of test. The maximum load measured during flexural testing of composites, as well as the breaking load of tested specimens, are documented.

5. Testing Of Workability

Composite plates made of natural fiber has a wide range of applied thus testing of workability is are the main objective of the current research, it is aimed that tested samples of the research are suitable for different application such as furniture, doors, decoration,...etc.

There for it is wise to test it for different essential workability operations. In current research following workability operations have been tested: cutting, drilling, hammering, threading, nailing, joining and grinding process. In order to obtain confidential results, all mentioned processes have been carried out on wood plate made of compressed wood particles have been set as a reference for workability

operations.

6. Results And Discussion

6.1 Tensile Test

As is generally known, composite materials are categorized as brittle materials, hence there is little to no flexibility throughout the test. This fact was clearly demonstrated by the acquired results. Tensile test findings are typically extracted in the form of a stress strain diagram or a force displacement diagram; however, due to a malfunction in the machine's plotter, such graphs could not be displayed. As a result, the obtained data was recorded in the form of maximum applied force and visually represented. Tensile strength was estimated using the force and cross-sectional area of the tested specimens; four tests were performed for each type of specimen, and the average value of applied force was used to determine tensile strength. The obtained results are compiled and displayed in block form diagrams, as shown in Figures 3-4, for specimens of large and medium size, respectively, as a representative for the overall outcomes of the research.

Composites containing almond peel powder exhibit greater tensile strength values than composites with medium and large almond peel sizes. The specimen type (C2 60%) has the highest tensile strength of all evaluated specimens, measuring 11341 N/m². However, a specimen of big grain size with Vf of 80% (A1 80%) had the lowest tensile strength, which was 1750 N/m². These results were expected and logically explained: as the fiber size decreases (powder form), the surface area increases, resulting in better adhesion and strong bonding between matrix material (resin) and fiber (almond grains), causing the mixture to bond strongly and thus increasing the strength of the composite product. On the other hand, composites with big grain sizes of almond peels have a decreased possibility of total adhesion and will not be strongly bound. Furthermore, gaps may form between big grains, reducing composite strength.

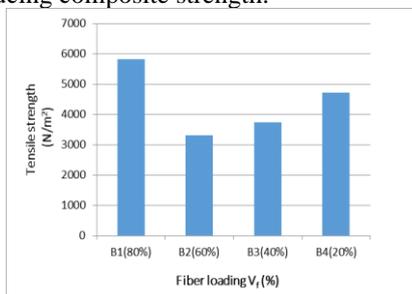


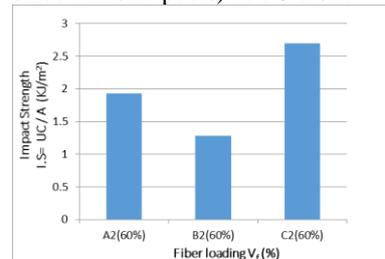
FIGURE 4. Tensile strength for B-type specimen

6.2 Impact Test

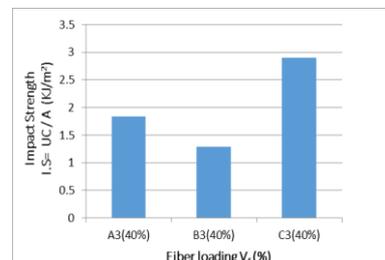
As previously stated, an impact test was completed in accordance with normal procedures. As a result, the impact strength (I.S) is computed using the equation $(I.S = UC / A)$, where UC represents fracture energy and A represents cross-sectional area. Four specimens were tested for each type of tested material. The recorded fractural energy was measured, and the average value of fractural energy was used to calculate impact strength. The cross-sectional area of the tested specimen is 0.00006 m², or 60 mm². Table 2 shows the average impact strength for all tested specimens. Figure 5 depicts a graphical comparison of As, Bs, and Cs specimens at Vf values of 60% and 40%.

It has been shown that Cs specimens (specimens with powdered almond peels) have a higher impact strength than specimens with large or medium-sized almond peels. The highest value of impact strength was recorded by specimen C3 at 2.9 kJ/m², followed by specimen C2 at 2.7 kJ/m². Specimens B2 and B3 (with medium-sized almond peels) had the lowest

impact ratio of 1.2 kJ/m², followed by specimen A4 (with large-sized almond peels) at 1.3 kJ/m².



(a)



(b)

FIGURE 5. Impact strength for all specimens at: (a) Vf = 60%, and (b) Vf = 40%

6.3 Flexural Test

The results in Table 3 show that flexural strength values vary across practically all tested specimens. Group B specimens had the highest and lowest values of flexural strength at the same time. Flexural strength for specimen B2 is 0.3112 N/mm², the highest of all examined specimens. In addition, specimen B1 had the lowest impact strength of 0.041 N/mm². This implies that almond grain size has no major effect on flexural strength. Furthermore, fiber volume fraction (Vf) has no discernible influence on flexural strength.

TABLE 3. Results of Flexural strength for all types of specimens

Fiber Volume Fraction (Vf) (%)	Force (N)	Flexural strength (N/mm ²)
B1 (80%)	0.11	0.0412
B2 (60%)	0.83	0.3112
B3 (40%)	0.2	0.075
B4 (20%)	0.546	0.2047

6.4 WORKABILITY

Through the operations conducted on natural fibers and comparing them with compressed wood, it was shown through observations that natural fibers have the ability to work, and the results were similar to those conducted on compressed wood. It has been observed that composite boards made from almond chuck in powder form have much better workability than similar boards made from natural fibers with medium or large grain size of almond chuck as shown in Figure 6.

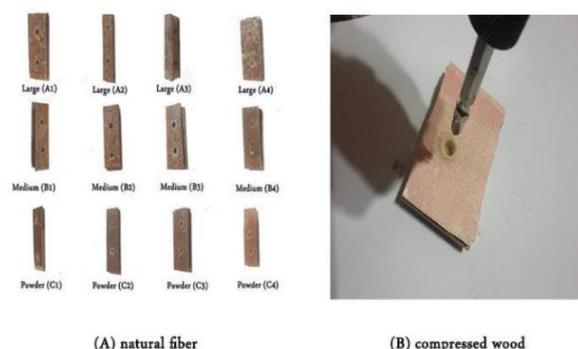


FIGURE 6. Samples made of almond fibers bonded together using a binder of different sizes (large, medium, powder) and compressed wood

7. CONCLUSION

The primary goal of the study has been met; it can be inferred that the mechanical characteristics, tensile strength, and impact

strength of the almond peel fiber reinforced composite material are heavily impacted by grain size. Among three different diameters of almond fiber, composite plates reinforced with almond grains in powder form produce the best mechanical qualities, particularly tensile strength and impact strength.

Fiber volume fraction (Vf) has a significant impact on tensile strength and impact strength; the highest tensile strength was obtained for powdered almond peels at Vf 60%. While the maximum impact strength was recorded at Vf of 40% for powdered almond peels. Flexural strength is unaffected by changes in fiber volume fraction (Vf) or the size of almond grains. Its results vary depending on the settings used, indicating the need for more exploration. Finally, almond fiber reinforced composites are an excellent choice for substituting other materials in various applications because they are categorized as green composites and have no negative environmental impact.

Results demonstrated that composite material formed of natural fiber, in the shape of almond chunks, offers satisfactory results in terms of mechanical characteristics and workability when compared to wood plate. This encourages the use of such composite material in many applications such as furniture.

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