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Effect Of Palm Frond Particle Size on The Mechanical Properties of Composites Made from Natural Fibers and Polyester

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تأثير حجم جزيئات سعف النخيل على الخواص الميكانيكية للمركبات المصنوعة من الألياف الطبيعية والبوليستر

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Abstract:
The widespread use of composite materials has been observed due to their inherent strength, making them an ideal alternative to many other materials. However, the high cost of synthetic fibers presents a barrier to the use of composites in most applications. Therefore, research has focused on testing natural fibers, which offer an optimal solution for using composites in various industries, such as furniture, flooring, decoration, thermal insulation, and building materials. This research paper investigates natural composite materials made from Libyan palm fronds. Three different sizes of ground palm fronds were studied: large (granular), medium, and small (powdered). These ground palm fronds were mixed with polyester resin in four ratios: 85:15, 65:35, 35:65, 15:85. Three basic tests were conducted to study the mechanical properties of the samples: impact testing, tensile testing, and bending testing. The results showed that samples made from palm fronds in powder form showed the best results among all other sample types in the three tests mentioned for mechanical properties.

Keywords: Composite materials, natural fibers, palm fronds, mechanical properties

الملخص
لوحظ انتشار استخدام المواد المركبة نظرًا لقوتها المتأصلة، مما يجعلها بديلاً مثاليًا للعديد من المواد الأخرى. مع ذلك، تُشكل التكلفة العالية للألياف الاصطناعية عائقًا أمام استخدام المواد المركبة في معظم التطبيقات. لذا، ركزت الأبحاث على اختبار الألياف الطبيعية، التي تُقدم حلاً أمثل لاستخدام المواد المركبة في مختلف الصناعات، مثل الأثاث والأرضيات والديكور والعزل الحراري ومواد البناء. تتناول هذه الورقة البحثية دراسة المواد المركبة الطبيعية المصنوعة من سعف النخيل الليبي. تم دراسة ثلاثة أحجام مختلفة من سعف النخيل المطحون: كبير (حبيبي)، متوسط، وصغير (مسحوق). خُلط سعف النخيل المطحون مع راتنج البوليستر بأربع نسب: 85:15، 65:35، 35:65، و15:85. أُجريت ثلاثة اختبارات أساسية لدراسة الخواص الميكانيكية للعينات: اختبار الصدم، واختبار الشد، واختبار الانحناء. أظهرت النتائج أن العينات المصنوعة من سعف النخيل في صورة مسحوق حققت أفضل النتائج مقارنةً بجميع أنواع العينات الأخرى في الاختبارات الثلاثة المذكورة للخواص الميكانيكية.

الكلمات المفتاحية: المواد المركبة، الألياف الطبيعية، سعف النخيل، الخواص الميكانيكية.

1. Introduction

Natural fiber composites include coconut, jute, palm, sugarcane, cotton, bamboo, and hemp fibers, extracted from plants, natural fibers contain cellulose. They are environmentally friendly, lightweight, strong, renewable, inexpensive, and biodegradable. They can be used to reinforce both thermosetting materials and thermoplastics. Epoxy, polyester, polyurethane, and phenol are examples of thermosetting resins widely used in high-performance composites. These resins provide sufficient mechanical properties, particularly stiffness and strength, at affordable prices. Genetic engineering is one of the latest developments in natural fiber development. Composite science offers promising prospects for better materials made from renewable resources, with increasing support for global sustainability. The lower density of natural fiber composites and their environmental advantages compared to conventional composites make them attractive to industry. Because these composites are biodegradable and non-carcinogenic, their importance is growing. Natural fiber composites are cost-effective materials, especially in building and construction, packaging, automotive and railway vehicle designs, and storage devices [1-7].

These composites are potential candidates for replacement of high-cost glass fiber for low load bearing applications [8-18]. Natural fibers have the advantages of low density, low cost and biodegradability. However, the main disadvantages of natural fiber composite are the relative high moisture absorption. As a result, chemical treatments are used to alter the fiber's surface characteristics.

2. Materials

The materials used to make the test samples include Saudi Arabian polyester resin and palm fronds. The polyester resin is characterized by excellent mechanical properties, such as low viscosity, high adhesion, and a low creep rate under constant stress. According to the manufacturer's specifications, the resin is added at a hardness ratio of 2:1. The Libyan palm fronds, collected from palm trees, are washed with water to remove dirt and dust before being dried in the sun. Finally, they are ground into three sizes: large, medium, and powder, as shown in Figure 1.

Figure 1. Types of ground palm fronds

3. Experimental Work

A composite sheet of each type of ground palm frond was fabricated from a base material (polyester resin) mixed with the ground palm fronds in four different ratios, as shown in Table 1. The mixture was placed in a metal mold, covered, and left to harden at room temperature for one day (24 hours). The mold cavity was rectangular with dimensions of 283 mm × 125 mm × 15 mm. These specifications determined the shape of the composite sheet, except for its thickness of 5 mm. Four metal nuts were inserted into the corners of the mold chamber to control the thickness of the resulting composite sheet. Finally, the composite sheets were fabricated using metal molds, and these sheets served as the raw material for the tested samples Figure 2.

Table 1. Types of tested samples with their codes

Palm frond ratio%	Resin ratio %	Hardener weight g	Sample code for large Palm frond	Sample code for medium Palm frond	Sample code for Palm frond powder
85%	15%	1.03	A1	B1	C1
65%	35%	2.41	A2	B2	C2
35%	65%	4.48	A3	B3	C3
15%	85%	5.85	A4	B4	C4

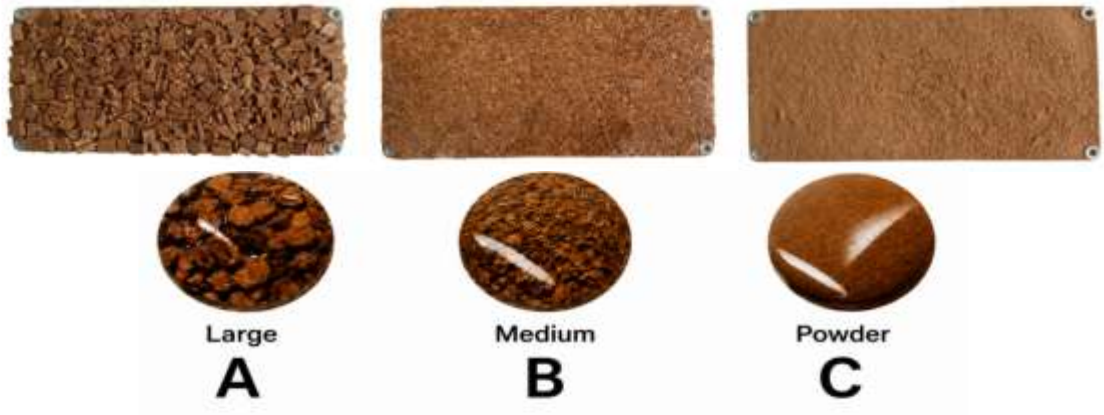

Figure 2. Types produced composite plate with three different sizes of palm fronds

4. Testing Of Mechanical Properties

Composite materials differ from metals due to their non-homogeneous nature. Testing their mechanical properties is crucial. Factors like the reinforcing and base materials, fiber type, and orientation affect composites. In this study, tensile, impact, and bending tests were performed**.** Tensile tests were performed according to ISO 527-4 [19]. Natural composite samples made from palm fronds of varying sizes were prepared and analysed under identical conditions. The test samples were 200 mm long, 20 mm wide, and 5 mm thick. The tensile test was performed using universal tensile testing machines with a maximum load capacity of 50 kN. Each test was performed four times, using equal samples of each material type. The results were recorded, and the average for each test was calculated**.** Impact test samples were prepared according to ASTM A370. The samples measured 55 mm in length, 10 mm in width, and 5 mm in thickness, according to the standard Sharpie impact test**.** Bending tests are commonly used to measure the brittleness of a material. Brittle materials tend to fracture suddenly and without warning, while ductile fractures show signs of breaking before the cracking point. In this study, the test samples were designed according to ASTM D 790-03 [20], with dimensions of 200 mm in length, 20 mm in width, and 5 mm in thickness. A three-point bending test apparatus with a maximum load of 20 kN was used to perform this type of test. The maximum load measured during the composite bending test, as well as the fracture load of the tested samples, were documented.

5. Results And Discussion

5.1 Tensile Test

Composite materials are typically characterized by brittleness and low or no elasticity during testing, as evidenced by the results. Although tensile tests usually produce stress-strain or force-displacement diagrams, a malfunction in the plotter prevented this. Instead, the results were recorded as the maximum applied force and presented graphically. Tensile strength was calculated based on the force and cross-sectional area of the tested specimens. Four tests were performed for each specimen type, and the average applied force was used to calculate the tensile strength. The results obtained were summarized and presented graphically, as shown in Figures 3 and 4, for the large and medium-sized specimens, respectively, as representative results.

Composites containing palm frond powder exhibited higher tensile strength values compared to those containing medium and large-sized palm fronds. The highest tensile strength value among all tested specimens was recorded in C2 (65%), reaching 13610 N/m^2. Conversely, the lowest tensile strength was recorded in the large-volume sample with 85% fiber content (A1), at 2100 N/m^2. These results are expected and logical, as a decrease in fiber volume (in the case of powder) leads to an increase in surface area, resulting in better adhesion and stronger bonding between the matrix material (resin) and the fibers (palm fronds). This results in a highly cohesive mixture and, consequently, increased composite strength. On the other hand, composites containing large palm frond particles have a lower chance of complete adhesion, leading to weaker bonding. Furthermore, gaps may form between the large particles, negatively impacting the composite strength.

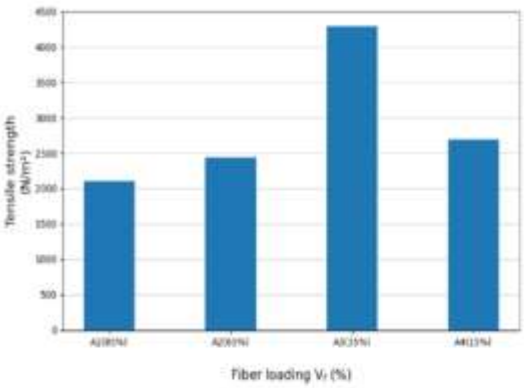

Figure 3. Tensile strength for A-type specimen

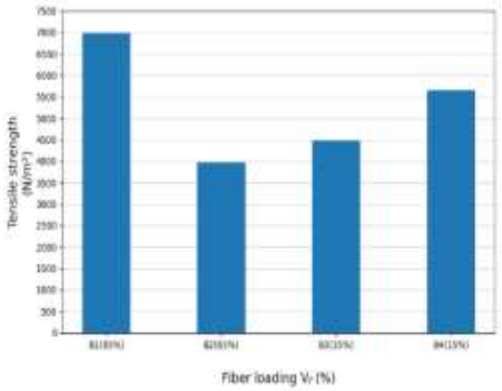

Figure 4. Tensile strength for B-type specimen

5.2 Impact Test

As mentioned previously, the impact test adhered to established standards. The impact strength (I.S) was determined using the equation I.S = UC/A, where UC represents the breaking energy and A is the cross-sectional area. Four samples of each type were tested. The average of the recorded breaking energy measurements was used to calculate the impact strength. The cross-sectional area of the tested sample was 0.00050 m² or 50 mm². The average impact force for all tested sample types was recorded, for example. Figure 5 shows a graphical comparison between samples A, B, and C at 65% and 35% of their actual volume. It was observed that samples C (containing palm frond powder) exhibited higher impact strength than samples containing large or medium-sized palm fronds (samples A or B). The highest impact resistance was recorded in sample C3 at 2.9 kJ/m², followed by sample C2 at 3.480 kJ/m². The lowest impact resistance was recorded in samples B2 and B3 (samples containing medium-sized palm fronds) at 1.540 kJ/m², followed by sample A4 (samples containing large-sized palm fronds) at 1.580 kJ/m².

5.3 Flexural Test

As clearly shown in Figure 6, the bending strength values fluctuated across almost all tested samples. Samples in Group B recorded both the highest and lowest bending strength values simultaneously. Sample B2 had a bending strength of 0.3625 N/mm², the highest among all tested samples. Additionally, sample C4 recorded the lowest impact strength value of 0.0565 N/mm². This indicates that the palm frond size had no significant effect on bending strength. Furthermore, the fiber volumetric fracture (Vf) did not show any significant effect on bending strength.

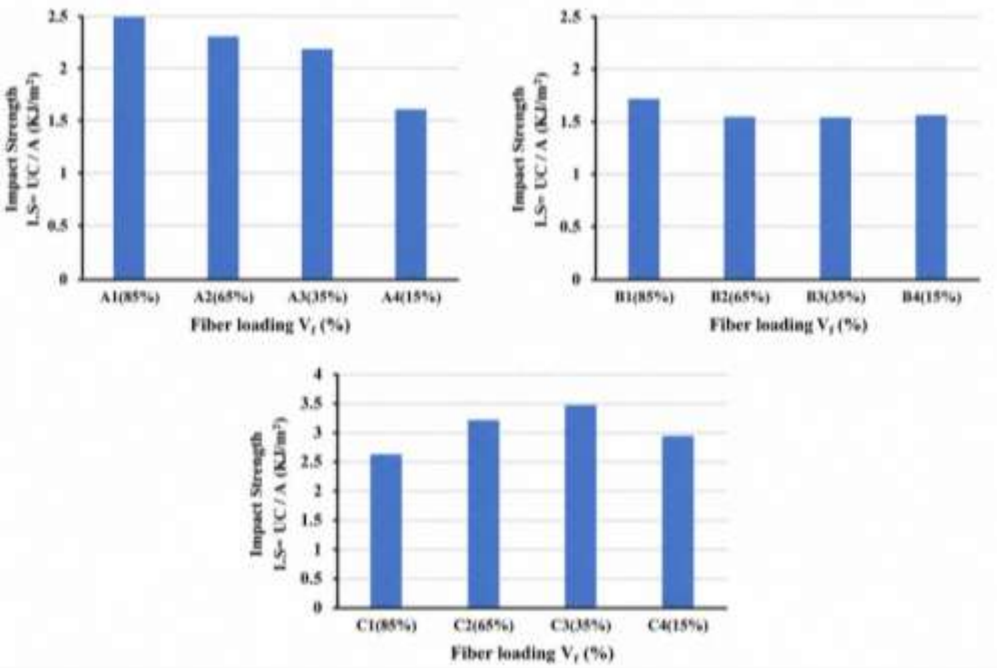

Figure 5. shows a graphical comparison between samples A, B, and C.

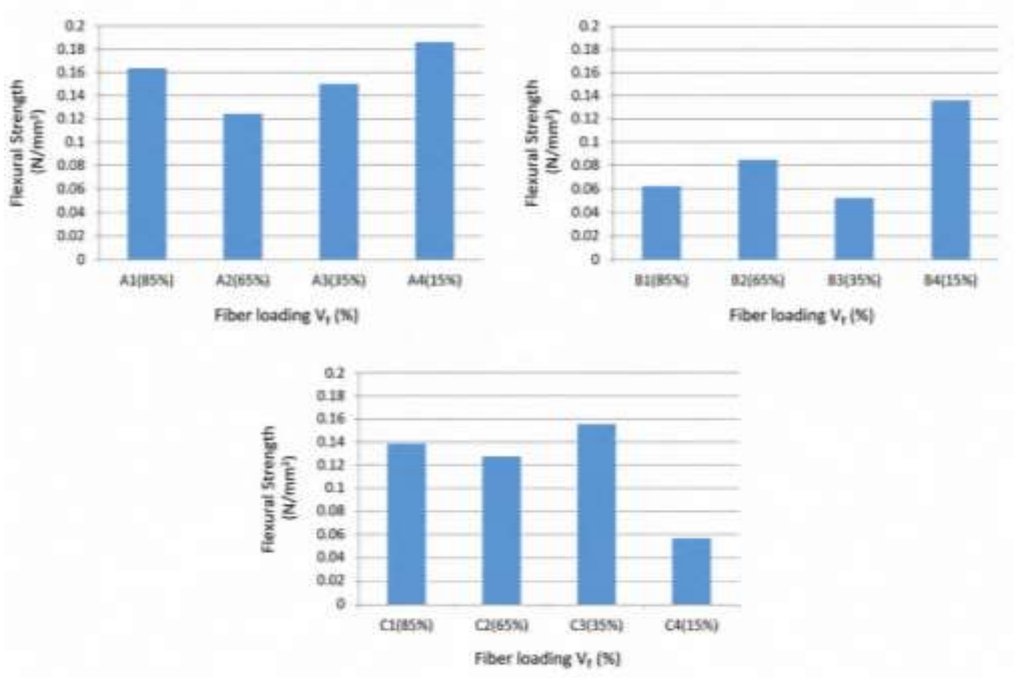

Figure 6. The values of bending strength fluctuated across all the tested samples.

6. Conclusion

The main objective of the research was achieved; it can be concluded that the mechanical properties, tensile strength, and impact strength of a palm frond fiber-reinforced composite material are significantly affected by particle size. Among three different palm frond fiber sizes, composite panels reinforced with palm frond particles in powder form showed the best results in terms of mechanical properties, especially tensile and impact strength. Tensile and impact strength are significantly affected by the fiber size ratio (Vf), with the highest tensile strength value recorded at a Vf of 65% for palm fronds in powder form. The highest impact strength value was also recorded at a Vf of 35% for palm fronds in powder form. Flexural strength showed no effect with changes in fiber size ratio (Vf) or palm frond particle size. Its results fluctuated with different parameters, encouraging further detailed research. Finally, palm frond fiber-reinforced composite materials are an ideal option for replacing other materials in various applications, given their classification as environmentally friendly composite materials with no harmful impact on the environment.

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