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Effects of the Addition of Pistachio Shell Particles on the Properties of Polyurethane Matrix Composite

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Abstract— In this research, a composite material-based polyurethane matrix with natural resources is prepared via the casting method and the effects of the weight fractions (2.5-12.5) wt% of pistachio shell particles on the properties of the prepared composite are investigated. Mechanical and physical tests are also conducted to evaluate the prepared composites and the maximum tensile strength at 5% wt., compression strength at 7.5wt%, impact strength at 2.5 wt%, Shore D hardness at 12.5%, and no reduction in water absorption.
Keywords— Polyurethane matrix, composite, particles, natural resources, natural filler, pistachio shell, mechanical properties, water absorption

I. INTRODUCTION

Composite materials from natural materials and polymeric matrices have been extensively investigated in composite research. Natural materials have also been used because of the economic and ecological benefits of the prepared composites [1]. The properties of several materials, such as jute, hemp, and flax, have also been explored by using a thermosetting matrix [1,2]. Natural materials have been applied to different industrial sectors because of their price-to-performance ratio, biodegradability, and lightness [3]. With advancements in automotive industries, natural materials have been remarkably developed [3,4]. For instance, polyurethane resins have been widely used because of their structural adaptability as rigid and flexible foams, elastomers, thermosetting, and thermoplastics; these resins have also been commonly utilized because they can be obtained from vegetable oils or petroleum [5]. Natural resources have been used to produce fillers and fibers, including wood flour, groundnut, husk ash, rice straw, rice husk, cotton, jute, and cellulose [6–8]. These materials help improve the mechanical properties of composites, entail low costs, increase impact strength, and enhance other mechanical properties, such as tensile strength, percentage elongation, tear strength, and hardness [6,9]. They are also used as reinforcing agents in plastic materials and provide significant advantages over synthetic fibers and fillers [6,10]. Composites can be prepared by including fillers into a polymer matrix to obtain the desired properties with different applications [6,7]. Elastomeric composites can also be formed by incorporating fibers and achieve the combined behavior of a soft and elastic rubber matrix and a firmly strong fibrous reinforcement [6,11]. Coconut shell, wood fiber, groundnut husk, rice straw, and rice husk have been commonly used in literature to fill and reinforce various polymer matrices. Thus, composites with enhanced dimensional stability, mechanical properties, and thermal responses have been synthesized [12–16]. This research aimed to prepare a composite material based polyurethane matrix via the casting method and investigate the effects of the weight fractions of pistachio shell particles on the properties of the prepared composite. Mechanical tests tensile, compression, impact, and hardness and a physical test (water absorption, %) were conducted to evaluate the prepared composite.

II. EXPERIMENTAL WORK

A. Materials

A two-part polyurethane resin system with a solvent-free low-viscosity polyurethane resin system (Fosroc Nitofill UR63) was prepared. When mixed in the desired amounts, it reacted to form a tough, slightly flexible resin with good adhesion, viscosity of 1.0 poise at 35 °C, and specific gravity of 1.067 at 25 °C. Pistachio shells obtained from a local market were used as filler materials, soaked in water for 2 hr, dried in an electric oven for 24 hr at 50 °C, powdered in a ball mill, and sifted through a 1.2 µm sieve.

B. Composite preparation

The mass of polyurethane resin was obtained on the basis of the required volume of a cast, a hardener, and polyurethane resin added in wt.% at a 3:1 ratio. The reinforcement material of the pistachio shell particles was weighed (2.5,5,7.5,10,12.5) on the basis of the

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required weight fractions of the total resin and hardener. The reinforcement filler of the pistachio shell particles and the matrix were mixed continuously and slowly to prevent bubbling during mixing. The mixture was placed in a KAWH 9050 ultrasonic vibrator at 60 W for 5 min to remove any bubbles, such as captured gas generated during mixing, and to ensure that the pistachio shell particles were uniformly distributed inside the mixture. The hardener was then added to the mixture by gently mixing. The mixture of polyurethane resin and pistachio shell particles was uniformly poured into a glass mold until the mold was filled up to the required level. The mixture was left in the glass mold for 1 day at 25 °C to solidify. The cast was aged for 3 days to dry. This step was essential to promote complete polymerization, achieve good coherency and eliminate residual stress. The cast was cut on the basis of the standard dimensions of each specimen test.

C. Composite Tests

Tensile and compression were applied using a Tinius Olsen universal testing machine H100KU model. A tensile test and a compression test were then performed in accordance with ASTM D638M-87b [17] and ASTM D695-85 [18], respectively. An unnotch impact test was carried out in accordance with ISO-179 by using an HSM41 Charpy impact tester [19]. A hardness test was conducted on the basis of Shore hardness (D) by using QualiTest HPE in accordance with ASTM D 2240 [20]. A water absorption test was accomplished in accordance with ASTM D 570-98 [21]. These tests were completed at 25 °C. At least three samples were obtained for each test.

III. RESULTS AND DISCUSSION

A. Tensile Test

Figure (1) shows the relationship between the tensile strength and weight fraction of a polyurethane composite material filled with pistachio shell particles. The tensile strength of the prepared composite material increases as the weight fraction increases to 6 wt% because of the high linkage between the matrix material and the reinforcement particle material. As a result, the slip during tension is reduced. This increase also occurs because particulates easily penetrate the matrix, especially when the weight fraction of the particulates is low; likewise, these particulates easily reach the glades located within the matrix material . This penetration subsequently enhances the wettability of the polyurethane matrix, especially in a liquid matrix material. The polyurethane composite material also hardens in early stages. The increase in wettability between the matrix and the reinforced materials is attributed to the interface surface area between the matrix material and the reinforced materials and between the reinforced materials. Composite materials reinforced by particulates depend not only on the properties of components but also on the interface nature between components and weight fraction; particulate-reinforced composite materials also rely on the geometry of particulates. The tensile strength of neat polyurethane is 16.65 MPa, and this value is improved when pistachio shell particles are added as fillers. As a result, a maximum strength of 24.6 MPa is obtained at a weight fraction of 5 wt%. At more than 5 wt%, tensile strength decreases possibly because of bond weakness,where pistachio shell particles experience difficulty in penetrating and diffusing in a matrix material because of an increase in their weight fraction, especially when weight fraction is more than 5 wt%. The amount of fillers increases when pistachio shell particles are added. As a consequence, the bonding between the matrix material surface and the particulate filler is reduced. The bond between the polyurethane matrix material and the filler materials weakens when the surface of particulates is incompletely wetted by a liquid polyurethane matrix material. This phenomenon decreases the efficiency of load transfer by the matrix from the composite material to the particulate. Therefore, the composite material exposed to weak stress breaks. In addition to the difficulty in matrix penetration that may weaken adhesion forces, numerous defects are created in the composite material; defects then generate stress in regions and accelerate because of sample failure and composite brittleness.

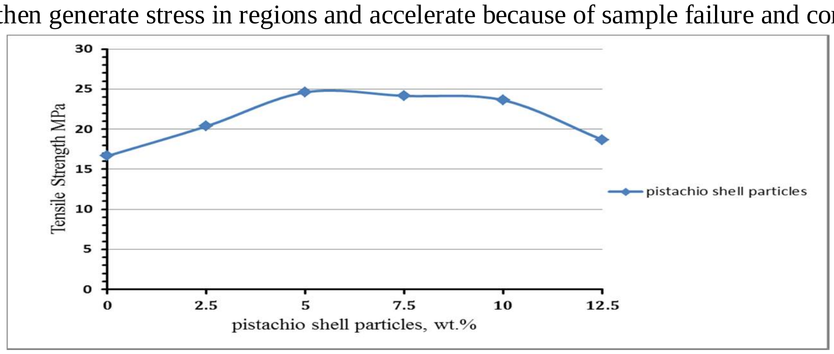

Fig. 1 Relationship between the tensile strength and weight fraction of the polyurethane resin filled with pistachio shell particles at a range of 2.5–12.5 wt%.

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B. Compression Test

Figure (2) illustrates the compression strength of the polyurethane matrix composite filled with pistachio shell particles. The compression strength increased after the pistachio shell particles were added as fillers to the polyurethane up to a weight fraction of 7.5 wt%. with maximum compression strength 49.25 MPa, which is higher than that of neat polyurethane 44.75 MPa. The compression strength of the composite with the fillers increased possibly because particulates hindered crack movement. By contrast, compression strength decreases when the weight fraction of pistachio shell particles exceeds 7.5 wt%. This phenomenon may be attributed to an increase in the viscosity of the liquid matrix at high amounts of particulates. As a consequence, the matrix experiences difficulty in penetrating the fillers. The wettability of the filler is reduced before the matrix hardens. Thus, the adhesion between the matrix and the filler decreases, and flaws and gaps are formed within the prepared composite material. Compression strength decreases at high filler rates. Adhesion force also significantly decreases as the weight fraction of fillers increases.

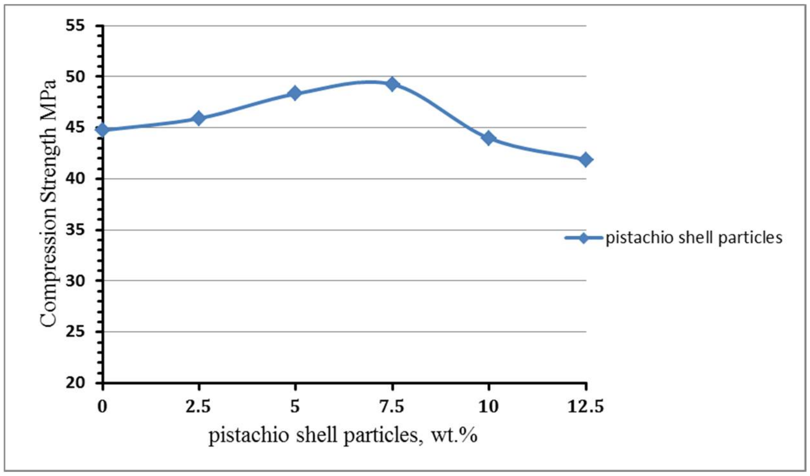

Fig. 2 Relationship between the compression strength and weight fraction of the polyurethane resin filled with pistachio shell particles at a range of 2.5–12.5 wt%.

C. Impact Test

Figure (3) illustrates the behavior of the prepared composite materials in terms of the change in impact strength as the weight fraction varies. The impact test is different from the other mechanical tests because the former is rapid; in particular, a sample is subjected to rapid stress and thus alters the behavior of materials. As the weight fraction of pistachio shell particles increases to 2.5 wt%, the impact strength increases and reaches the maximum value of 3.97 kJ/m^2 Figure (3). This finding is higher than the impact strength of neat polyurethane 3.72 kJ/m^2. This increase in impact strength may be related to particulate fillers that may prevent crack growth in the prepared polyurethane composite; this phenomenon possibly causes the crack to change in shape and direction, that is, crack tip energy decreases, and impact strength increases. The decrease in the impact strength at a weight fraction higher than 2.5 wt% can be related to the weakness in the bond between the polyurethane matrix and the pistachio shell particulates as fillers.

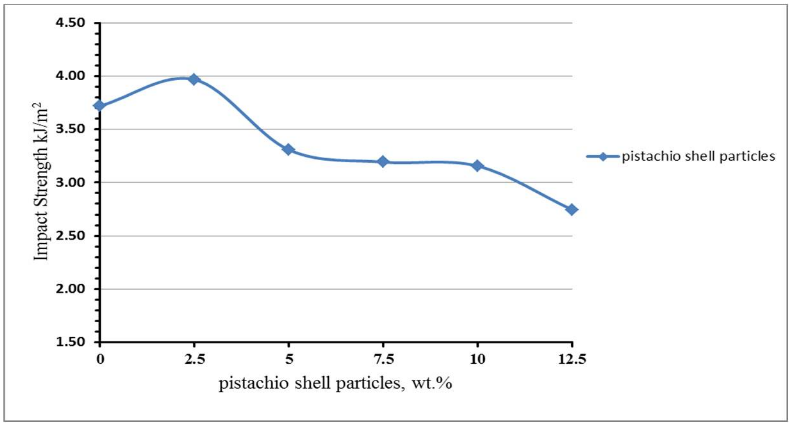

Fig. 3 Relationship between the impact strength and weight fraction of the polyurethane resin filled with pistachio shell particles at a range of 2.5–12.5 wt%.

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D. Hardness test

Figure (4) reveals that the hardness of polyurethane increases when pistachio shell particles are added as fillers. The hardness continuously increases when weight fraction increases. The concept of hardness can be considered a measure of plastic deformation. In this phenomenon, a material is influenced by external stress, and particulate pistachio shells added as fillers likely increase hardness as a result of increased resistance to plastic deformation. Hardness reaches the maximum value at 12.5 wt% of pistachio shell particles, with a Shore D hardness of 80.23. By comparison, the hardness of neat polyurethane is lower at 69.85 Shore (D) hardness. Therefore, the hardness of polyurethane increases after pistachio shell particles are added because the chemical composition of pistachio shells includes hemicellulose, cellulose, and lignin [22,23]. This composition is accounted for high hardness.

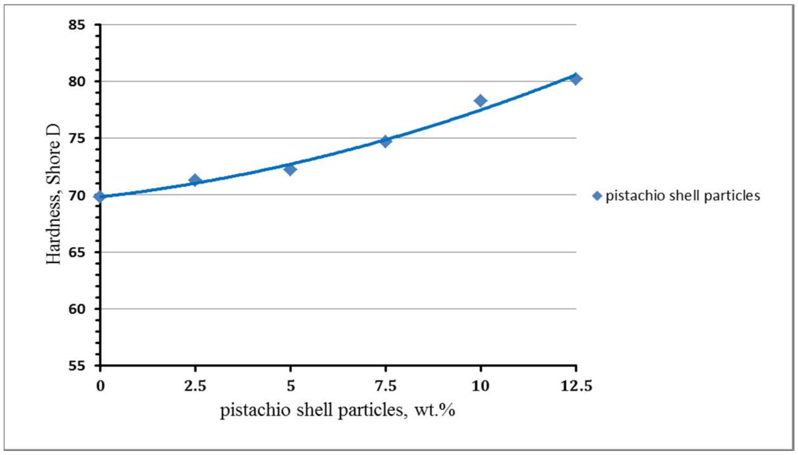

Fig. 4 Relationship between the shore D hardness and weight fraction of the polyurethane resin filled with pistachio shell particles at a range of 2.5–12.5 wt%.

E. Water Absorption

Figure (5) reveals the effects of the weight fraction of pistachio shell particles as fillers on the percentage of water absorption. The absorption value significantly increases when pistachio shell particles are added to polyurethane. This phenomenon occurs because these matrix materials exhibit low absorption. Thus, the moisture plays a role in deteriorating the interface between the matrix and the reinforced material. The reinforced material may absorb small amounts of water. As a consequence, the adhesion between the matrix material and the reinforced material decreases. In general, no improvement is observed in decreasing water absorption when fillers are within the scope of the added pistachio shell particles as compared with the %water absorption of the neat polyurethane polymer matrix 0.1562. The absorption value increases as the weight fraction of pistachio shells increases with maximum value of 0.3134% at 12.5% wt.

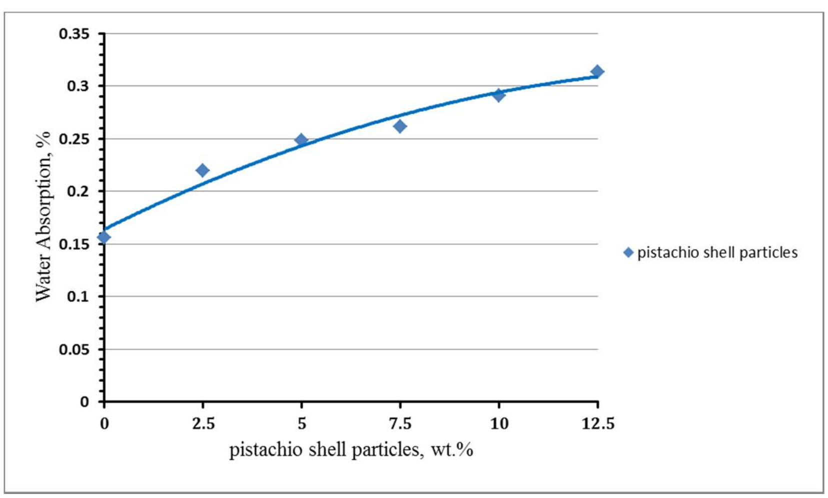

Fig. 5 Relationship between the water absorption and weight fraction of the polyurethane resin filled with pistachio shell particles at a range of 2.5–12.5 wt%.

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IV. CONCLUSIONS

Tensile strength was improved when the weight fraction of pistachio shell particles increased and reached the maximum value at 5 wt%. As weight fraction increased, the properties of the prepared composite decreased. Also, Compression strength and impact strength increased as the weight fraction of pistachio shell particles increased to 7.5 and 2.5 wt%., respectively the properties of the prepared composite decreased. Hardness increased as the weight fraction of pistachio shell particles increased and reached the maximum value at 12.5 wt%. The water absorption percentage, which is a physical property of the prepared composite material, increased as the weight fraction of pistachio shell particles increased. High mechanical properties could be obtained by adding 2.5 wt% of pistachio shell particles.

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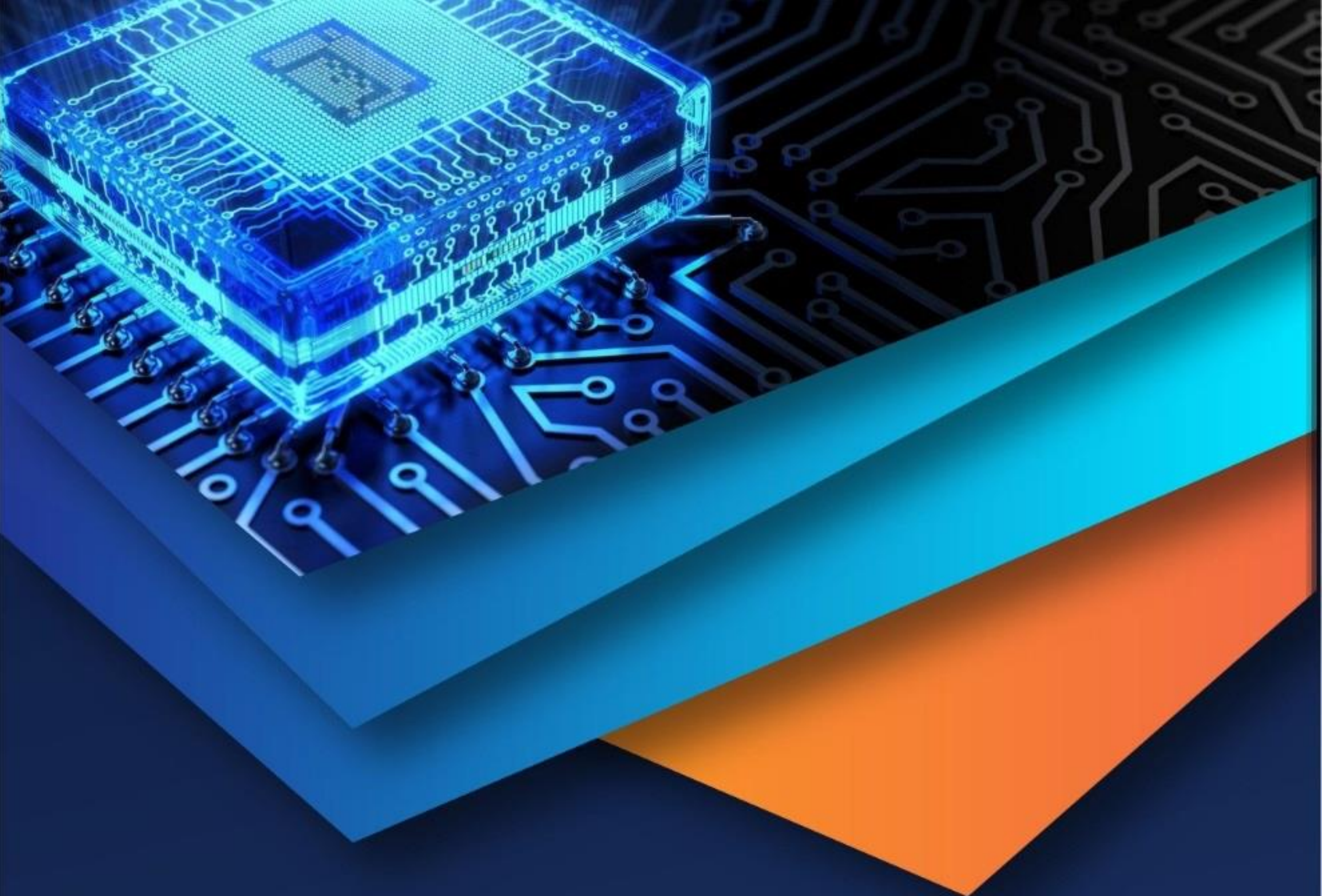

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