Polyester Composites Filled with Micro-sized Pistachio Shell Particulates: Mechanical Characterization

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Abstract: The present work comprises the fabrication of polyester-based composites with pistachio shell particulates as a reinforcement. The effect of pistachio shell loading in the polyester resin was discussed in detail. In this work, mainly the mechanical properties are discussed. The properties investigated are tensile strength, tensile modulus, flexural strength, flexural modulus, compressive strength and hardness. From the investigation, it was observed that the various mechanical properties under investigation are modified with the inclusion of pistachio shell particulates. Among the different properties, tensile strength and flexural strength are the properties that increase with filler loading up to a certain loading of 20 wt. % and decreases thereafter. Other mechanical properties investigated increase with filler loading for the entire range used in the present work.

Keywords: Polymer matrix composites, epoxy, pistachio shell, Tensile properties, flexural properties, compressive strength, hardness.

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I. INTRODUCTION

Pistachios are prized for their edible nuts, which are enclosed in a rigid outer layer known as the pistachio shell. These shells primarily contain about 42% cellulose, 13.5% lignin, 0.18% extractives, 1.26% ash, and 3.11% cellulose–lignin complexes. When compared with natural fibers such as hemp, sisal, kenaf, bamboo, and coconut coir, pistachio shells possess a higher cellulose fraction, contributing to enhanced hydrophilicity. They are commonly applied in orchid cultivation, as fire igniters, livestock feed, and wood product additives. Environmentally and economically, incorporating pistachio shells into polymer composites serves as a sustainable and affordable approach. Furthermore, their inherent mechanical strength, rigidity, and hardness make them promising reinforcement materials for polymer-based systems across a variety of engineering uses.

Gairola et al. [1] analyzed epoxy composites reinforced with micro-sized pistachio shell particles to assess their impact behaviour under different environmental exposures. Results indicated the highest impact energy (22.67 kJ/m²) at 10 wt.% filler loading, after which performance declined due to particle agglomeration and poor interfacial bonding. Immersion in water, petrol, and kerosene further reduced impact strength. The 10 wt.% composite showed notable hydrophilicity, and fracture morphology revealed predominantly brittle failure characteristics across all samples. Chandrakar et al. [2] explored epoxy composites reinforced with 75 μm pistachio shell particles at filler loadings up to 30 wt.%. The study observed a steady rise in density, peaking at 1.23 g/cm³ for 30 wt.% filler. Mechanical analysis revealed proportional enhancement in tensile, flexural, and hardness properties, indicating efficient stress transfer. Conversely, compressive strength dropped until 10 wt.% filler but improved thereafter, achieving a maximum value at 30 wt.% due to better particle packing and structural stability. Salazar-Cruz et al. [3] evaluated the thermal performance of polypropylene composites reinforced with chemically treated pistachio shell particles. The study revealed that chemical surface modification enhanced filler–matrix interfacial bonding, leading to improved thermal stability and higher degradation temperatures compared to untreated counterparts. Differential scanning calorimetry showed increased crystallinity, indicating effective nucleating behaviour of the treated fillers.

Pradhan et al. [4] investigated the tribological performance of epoxy composites incorporating Pistacia vera shell particulates. The results indicated a minor drop in tensile strength, decreasing from 48.5 MPa for pure epoxy to 38.2 MPa at 30 wt.% filler content. However, hardness exhibited a consistent rise, reaching 85 Shore D. Notably, wear resistance improved markedly, showing a 32% reduction in wear loss at 20 wt.% loading, while the coefficient of friction decreased from 0.48 to 0.37, signifying superior durability. Mohammed and Salman [5] developed polymethyl methacrylate (PMMA) composites containing 5–20 wt.% pistachio shell powder (PSP). The tensile strength improved from 47.2 MPa (neat PMMA) to 55.8 MPa at 10 wt.% PSP before slightly declining at higher loadings. Compressive strength rose from 128 MPa to 142 MPa at 20 wt.%, while impact strength peaked at 6.3 kJ/m² for 15 wt.% PSP. Hardness increased from 82 to 89 Shore D with filler content, indicating improved surface resistance.

Rautaray et al. [6] studied unsaturated polyester matrix (UPM) composites reinforced with 5–25 wt.% pistachio shell particles. Tensile strength rose from 32.6 MPa to 39.8 MPa at 15 wt.% filler, while flexural strength peaked at 68.5 MPa. Impact strength reached 4.9 kJ/m² at 20 wt.%, and hardness climbed to 86 Shore D at 25 wt.%. Thermal analysis revealed improved stability, with degradation onset shifting from 312 °C to 327 °C. Pączkowski and Gawdzik [7] synthesized epoxy and polyester composites reinforced with 10–40 wt.% pistachio shell waste. Flexural strength improved from 62.3 MPa (neat) to 71.5 MPa at 20 wt.%, while hardness rose to 88 Shore D at 40 wt.%. Enhanced thermal stability and biodegradability were observed, with mass loss increasing from 4.5% to 12.8% after 90 days. Romero-Ceron et al. [8] reinforced thermoplastic starch with chemically modified pistachio shell waste (5–25 wt.%). At 15 wt.%, tensile strength and storage modulus improved to 15.7 MPa and 178 MPa, respectively, while elongation decreased, indicating stiffness gain. Deo et al. [9] and Singh et al. [10] reported similar reinforcement effects in polyester and EPDM composites, showing increased tensile, flexural, hardness, and thermal stability, confirming pistachio shell particles as sustainable and effective bio-fillers. In view of the past research work, the present investigation deals with the development of polyester/pistachio shell particulate composites at varied loading of filler and evaluation of the different mechanical properties like tensile strength, flexural strength, compressive strength and hardness.

II. MATERIAL CONSIDERED AND COMPOSITE FABRICATION

In the present study, unsaturated isophthalic polyester resin is employed as the matrix material. The matrix phase, procured from Carbon Black Composites, Mumbai, serves as the base for composite fabrication. Pistachio shells, selected as the bio-filler, are utilized in the form of micro-sized particulates. These naturally ellipsoidal shells are initially crushed into smaller fragments before being refined using a ball milling machine to achieve a uniform fine powder. The ground material is then sieved, and particles smaller than 50 microns are collected for use as reinforcement within the polyester matrix. Composite samples are fabricated through the conventional hand lay-up technique. A total of six composite formulations is prepared, each containing a different proportion of pistachio shell filler. The filler content is systematically varied from 5 wt. % to 30 wt. %.

III. EXPERIMENTAL DETAILS

The tensile behavior of the composites was evaluated using a computerized Instron 1195

Universal Testing Machine following the ASTM D638 standard, applying a uniaxial load at both ends of the specimen. Compressive strength was determined through static uniaxial compression tests on the same equipment, conducted as per ASTM D695 guidelines. Flexural strength was measured via a three-point bending test in accordance with ASTM D790. Hardness measurements were performed using a PosiTector SHD Shore Durometer, following the ASTM D2240 procedure.

IV. RESULTS AND DISCUSSION

Tensile Properties

Figure 1 shows the ultimate tensile strength of the unfilled polyester and the composite prepared with polyester filled with micro-sized pistachio shell particulates. The figure shows the variation of the properties as a function of filler loading. It is clearly observed from the figure that the inclusion of the pistachio shell micro-particulates in the polyester resin enhances the tensile strength of the material. However, the increment in tensile strength with filler loading is limited to 20 wt. % of the filler loading only, and when the filler content increases above 20 wt. %, the tensile strength starts to show a declining trend. The tensile strength of unfilled polyester is 25.6 MPa. With the inclusion of 20 wt. % pistachio shell particulates, the ultimate tensile strength shows a value of 36.8 MPa. This is an appreciable increment of 43.75 % against the value of neat polyester.

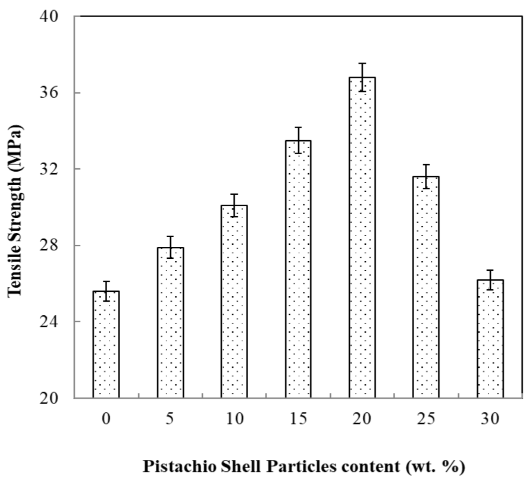

Figure 1: The ultimate tensile strength of the polyester/pistachio shell particulate composites

Flexural Properties

The flexural strength of the polyester/pistachio shell particulate composites as a function of filler loading is presented in Figure 2.

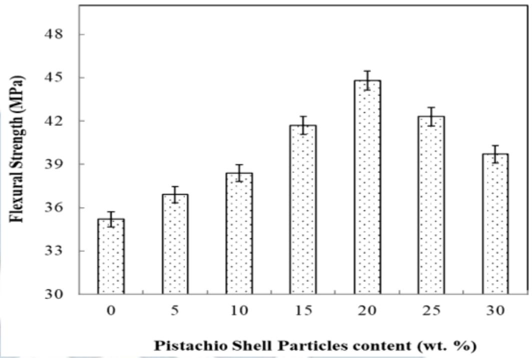

Figure 2: The flexural strength of the polyester/pistachio shell particulate composites

It is clear from the figure that the behaviour of the material under bending loading is very similar to that obtained under tensile loading. The flexural strength of the polyester/pistachio shell particulate composite increases with filler content when the fillers are added in a limited quantity, i.e. 20 wt. %. Once the filler content increases above 20 wt. At %, the flexural strength starts to drop. The flexural strength of neat polyester is measured to be 35.2 MPa, which increases to 44.8 MPa for a filler loading of 20 wt. %. The increment registered in this case is 27.3 %. When the filler content increases beyond 20 wt. %, the flexural strength of the material reduces. For a filler loading of 30 wt.%, the measured value of flexural strength is 39.7 MPa. This shows a decrease of 11.8 % from a maximum registered value of flexural strength obtained in the present investigation.

Compressive Strength

Figure 3 presents the effect of the addition of the pistachio shell particulates in the polyester matrix on the compressive strength of the material. From the figure, it is clear that the inclusion of micro-sized pistachio shell particulates helps in improving the compressive strength of the polyester resin. The increment is a function of filler loading, and the increasing trend is obtained for the entire range of filler loading used in the current investigation. The reason for the increment of the compressive strength is primarily due to the strengthening effect provided by the filler material in the matrix material.

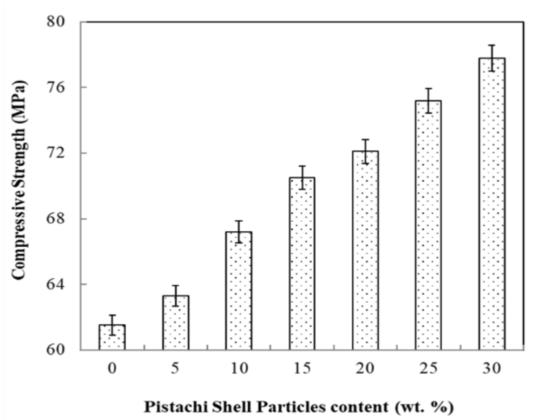

Figure 3: The compressive strength of the polyester/pistachio shell particulate composites

The unfilled polyester resin possesses a compressive strength of 61.5 MPa. When 5 wt. % Pistachio shell particulates are added to the polyester resin, and the compressive strength slightly increases to 63.3 MPa. When the filler loading reaches a value of 20 wt. %, the compressive strength value registered is 72.1 MPa. This is an increment of 13.9 % as compared to neat polyester. It is observed that in the case of tensile and flexural strength, above this wt. %, both the values decrease. But in the case of compressive strength, the value continues to grow. For a filler loading of 30 wt. %, the compressive strength reaches 77.8 MPa, which is an increment of 22.9 %.

Hardness

The hardness characteristics of the polyester matrix and its composites reinforced with micro-sized pistachio shell particulates are illustrated in Figure 4.9.

This figure demonstrates the relationship between Shore-D hardness and varying filler loadings. It is evident that the incorporation of pistachio shell particulates significantly enhances the hardness of the composite material. The Shore D number of the unfilled polyester is measured to be 72.4 Shore D number in the present investigation. The same increase to 73.4 Shore D number for 10 wt. % pistachio shell particulates, which shows a marginal improvement of 1.3 %.

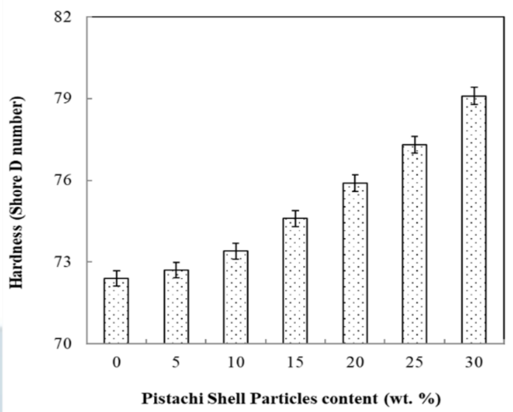

Figure 4: The hardness of the polyester/pistachio shell particulate composites

It is noticed that the improvement in the hardness is not as high as other mechanical properties for a low filler loading. For a weight fraction of 30 %, the hardness of the composite registered is 79.1 Shore D number. This is an improvement of 9.25 %. It is an appreciable improvement, as such an improvement is not observed very often when the micro-particulates are added to the polymer matrix. From the observed value, it can be said that the effect of filler loading on hardness is impactful when the content of filler is high.

V. CONCLUSIONS

This experimental investigation on pistachio shell micro-particulate filled polyester composites has led to the following specific conclusions:

Micro-sized pistachio shell particulates possess ample reinforcing potential to be used as a filler material in the polyester matrix. Successful fabrication of polyester composites filled with this bio-filler is possible by a simple hand lay-up method.

The tensile strength of the material increases with filler loading till the content of the filler increases to 20 wt. % and decreases thereafter. Against that, the tensile modulus of the material increases with filler loading for the entire range of filler content. This shows that the maximum tensile strength is obtained for a composite with 20 wt.% filler, and the maximum tensile modulus is obtained for 30 wt. % filler.

The flexural strength of the material increases with filler loading. The increment in flexural strength is limited to the filler loading of 20 wt. % and decreases thereafter. The flexural modulus of the material increases with filler loading over the entire range of filler content. This shows that the maximum flexural strength is obtained for a composite with 20 wt.% filler, and the maximum flexural modulus is obtained for 30 wt. % filler.

Incorporation of pistachio shell particulates in the polyester matrix increases the compressive strength of the material as a function of filler content. The maximum compressive strength of 77.8 MPa is obtained for a composite prepared with polyester filled with 30 wt. % of the filler.

The incorporation of pistachio shell particulates in the polyester matrix increases the hardness of the material as a function of filler content. The highest hardness of 79.1 Shore D number is reported for the composite prepared with 50-micron size filler having a loading of 30 wt.%.

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