Physical Properties of Epoxy Composites Filled with Micro-sized Pistachio Shell Particulates

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Abstract

The present work aims at developing a class of polymer composites consisting of thermoset polymer i.e. epoxy as a matrix material with pistachio shell in the form of micro-particulates as a filler material. A set of composites with varying filler loading has been fabricated by a simple hand lay-up technique. The effect of filler content on the physical properties of such fabricated samples is investigated and presented in this work. The various properties evaluated are density, voids content and water absorption rate. From the experimental results, it is observed that the inclusion of micro-sized pistachio shell particulates in the epoxy resin results in the reduction of its density as a function of filler loading. It is also observed that the voids generated in the composite increase with filler loading. Further, the inclusion of these bio-particulates increases the water uptake behaviour of the composite as a function of filler loading due to the hydrophilic nature of the bio-filler.

Keywords: Polymer matrix composites, epoxy, pistachio shell, density, void content, water absorption rate.

1. Introduction

Improper handling of plastic waste has given rise to ecological issues. As a result, there has been a noteworthy surge in the utilization of bio-based substances within polymer composite research. Among various bio-based additives, pistachio shells possess a unique chemical composition that holds significant promise as a reinforcing agent within polymeric resins. Incorporating pistachio shells in particulate form as fillers within polymer matrix composites not only helps in environmental conservation but also effectively lowers the production costs of the final goods. Utilization of these materials as a filler in polymeric resin results in the utilization of waste material along with that is reduces the overall consumption of the harmful polymers. Work has been performed on the utilization of this waste as a filler material in the polymeric resin.

Guru et al. [1] used pistachio shells and urea-formaldehyde to create an environmentally friendly construction material that was made non-flammable by the use of fly ash as a flame retardant. They concentrated on evaluating the mechanical, thermal, and burning properties of the composites developed by them. Karaagac [2] explored the mechanical and thermal characteristics of rubber matrices filled with micro-pistachio shell particles. In their study, they found that by increasing the pistachio shell loading, the material's tensile strength and Young's modulus were observed to decline. They also observed that the hardness also reduces as a function of filler content but the decrement is very less. The addition of a pistachio shell, on the other hand, considerably increases abrasion resistance because the loss of material due to abrasion reduces significantly. Alsaadi et al. [3] studied in detail the influence of pistachio shell particle content on the mechanical characteristics of polyester matrix composites. In their analysis, they found that the mechanical properties of the material increase with filler content when the fillers are added in limited quantity i.e. 10 wt. %. When the filler content increased beyond 10 wt. %, the mechanical properties show a decreasing trend till the maximum filler content.

Gairola et al. [4] evaluated the impact strength of a micro-sized pistachio shell with an epoxy matrix under various environmental conditions as a function of filler content. They discovered that the maximum impact energy of 22.67 kJ/m^2 was obtained for 10 wt. % filler, which thereafter dropped with increasing the filler loading. A very detailed

study was performed by Chandrakar et al. [5] recently on epoxy/pistachio shell composites where they evaluated the different physical and mechanical properties of the material. While measuring the density of the different sets of composites, they found that the density of the material increases linearly with the filler content. While measuring the mechanical properties of the material, they found that the tensile strength, flexural strength, and hardness of the material are purely a function of filler content, and these properties increase as the filler content increases.

The study by Salazar-Cruz et al. [6] focuses on evaluating the thermal properties of composites developed from chemically treated pistachio shell particles and polypropylene. In their method, pistachio shell particles were chemically treated and mixed with polypropylene to create the composites. Their work demonstrates the feasibility of using pistachio shell particles to enhance the thermal properties of polypropylene-based composites. Pradhan et al. [7] investigate the utilization of pistachio nut shell waste as a filler in polymer composites for tribological applications. The authors prepared the composites by incorporating pistachio shell particles into a polymer matrix. The tribological properties of the composites were evaluated using a pin-on-disc apparatus. The study reported improved friction and wear resistance for the composite materials compared to the pure polymer.

Mohammed and Salman [8] investigate the influence of pistachio shell addition on the mechanical behaviour of self-curing PMMA composites. Rautaray et al. [9] focused on the mechanical and thermal behaviour of unsaturated polyester matrix (UPM) composites filled with pistachio shell particles (PSP). An important result includes the enhancement of mechanical properties such as tensile strength and Young's modulus with the addition of pistachio shell particles. The thermal behaviour analysis indicated improved thermal stability and resistance to thermal degradation in the composite materials. In view of these, the present work is on the fabrication of epoxy/pistachio shell composites and the evaluation of their physical properties like density, voids content and water absorption rate as a function of filler loading.

2. Material considered and composite fabrication

Epoxy (LY 556) is chosen as the matrix material for the present research work. It provides a solvent-free room temperature curing system when it is combined with the hardener tri-ethylene-tetramine (TETA). The shell of pistachio in the form of micro-particulates is used as a filler material in the present investigation. The ellipsoid-shaped pistachio nutshells are initially crushed into relatively small pieces, which are then processed through a ball milling machine to obtain finer-sized particles. Later, with the help of sieves, the particles with less than 50 microns particle size are used as a filler material. The composites are fabricated using the hand lay-up method. In total four sets of composites are prepared with filler loading varying from 5 wt. % to 20 wt. %.

3. Experimental details

The experimental density (ρ_{ce}) of composites under study is determined by using the Archimedes principle using distilled water as a medium (ASTM D 792-91). The theoretical density (ρ_{ct}) of composite materials in terms of weight fractions of different constituents can easily be obtained using a rule of the mixture model. The volume fraction of voids in the composites is calculated with the help of experimental and theoretical density. Water absorption tests were carried out to analyze the behaviour of the composite in the presence of water-affected environments. Mainly the test was conducted in normal water to assess the amount of water absorbed by the composite according to ASTM D 570 standard.

4. Results and Discussion

4.1 Density and voids content

The density of the composite is measured using Archimedes' principle and the evaluation of density theoretical is done by rule of the mixture model. Both the densities obtained for epoxy filled with micro-sized pistachio shell particulates are presented in Table 1. It is clearly observed from the table that the inclusion of micro-sized pistachio shell particulates decreases the density of the epoxy matrix as a function of filler loading. The density of unfilled epoxy is 1.154 gm/cm^3. When 5 wt. % of pistachio shell particulates of 50-micron size are added, and the density of the composite decreases and reaches 1.121 gm/cm^3. This is a decrement of 2.85 % as compared to the neat epoxy. Similarly, when the content of filler increases to 20 wt. %, the density decreases to 1.038 gm/cm^3. This shows an appreciable decrement of 10.05 %. The reduction in density of the composite with an increase in filler loading is mainly because of the lower density value of filler material as compared to the matrix material used in the present

investigation. The density of pistachio shell particulates is measured to be 0.88 gm/cm^3 which is much lower than the density of the epoxy matrix. It is further observed that the density obtained theoretically is more as compared to the experimentally measured density for a given filler loading. This is because of the presence of voids in the actual composites. The density of voids is less than the density of epoxy as well as pistachio shell particulates. In actual composites, the air got trapped. These air voids are not considered during with evaluation of the density using the rule of the mixture model and because of that, the theoretical density is more than the measured density.

Table 1 Effect of filler loading on the density and voids content of epoxy/pistachio shell particulate composites

S. No.	Composition	Theoretical Density (gm/cm^3)	Experimental Density (gm/cm^3)	Voids content (%)
1	Epoxy + 5 wt. Pistachio shell particulates	1.136	1.121	1.32
2	Epoxy + 10 wt. Pistachio shell particulates	1.119	1.088	2.77
3	Epoxy + 15 wt. Pistachio shell particulates	1.102	1.063	3.54
4	Epoxy + 20 wt. Pistachio shell particulates	1.086	1.038	4.42

The presence of voids in the composites is also present in Table 1. It is clear from the table that minimum voids are present in the composites prepared with minimum filler loading whereas maximum voids are present in the composites prepared with maximum filler loading. In the present work, the minimum void content of 1.32 % is registered for the composite prepared with 5 wt. % of the filler, whereas, a maximum void content of 4.42 % is present for the composite prepared with 20 wt. % of the filler material. Clearly, composites fabricated with fewer particles result in the low generation of voids mainly due to proper wetting of the surface of lesser fillers with matrix material as compared to large content fillers.

4.2 Water absorption behaviour

The water absorption rate of unfilled epoxy is very low and it absorbs negligible water over a duration of seven days. When the water absorption of neat epoxy is evaluated after seven days of immersion, it is found that it is 0.67 % only. With the help of the weight of the sample before the immersion and after the immersion, the water absorption percentage is calculated. The water absorption rate of the epoxy/pistachio shell particulate composites as a function of filler loading is presented in Figure 1. From the figure, it is clear that the water absorption rate of the composite increases with filler loading. The water absorption rate increases with the inclusion of pistachio shells mainly because of the hydrophilic nature of the pistachio shell particulates against the hydrophobic behaviour of the polymeric resin. As the content of the filler increases, the number of particles available for making a hydrogen bond with water molecules also increases and hence the water absorption rate increases. The minimum water absorption of 1.88 % is reported for a maximum filler loading of 5 wt. % and immersion time of seven days. When the filler loading is 20 wt. %, the maximum water absorption rate is 2.75 %.

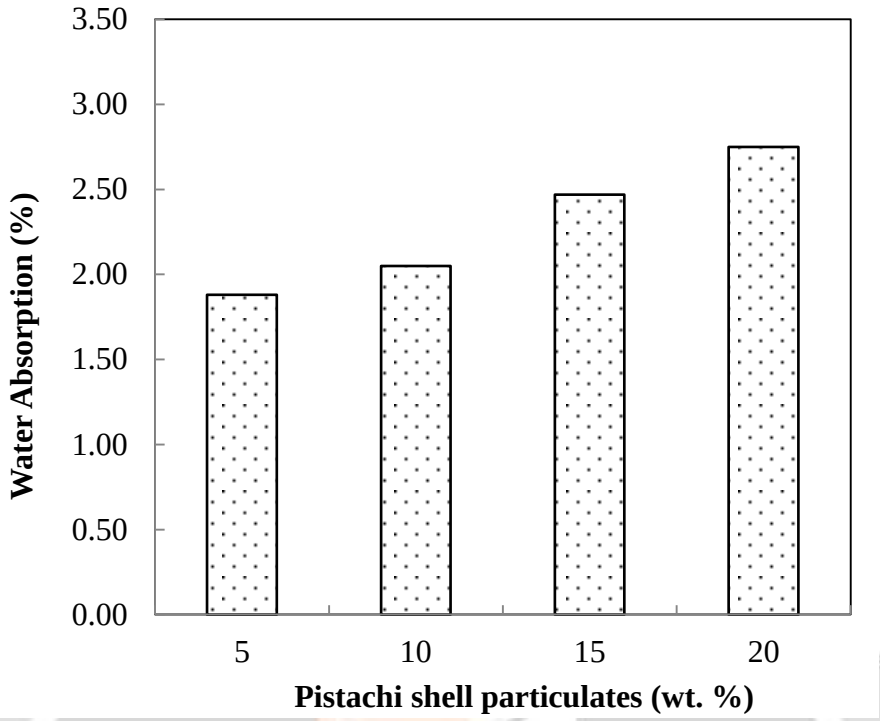

Figure 1: Effect of filler loading on the water absorption rate of the epoxy/pistachio shell particulate composites

5. Conclusions

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

1. Micro-sized pistachio shell particulates possess ample reinforcing potential to be used as a filler material in the epoxy matrix.

2. The density of the composite decreases with an increase in filler content, whereas voids content increases with an increase in the filler content. The minimum density and maximum voids are obtained for epoxy filled with 20 wt. % of the 50-micron particle size pistachio shell particulate.

3. A water absorption rate of the epoxy/pistachio shell particulate composites is evaluated as a function of filler content. The water absorption rate of the composite increases with filler loading. The minimum water absorption rate is obtained when the filler loading is minimum and the maximum water absorption rate is obtained when the filler loading is maximum.

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