International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Mechanical Properties of Epoxy Composites Filled with Micro-Sized Pistachio Shell Particulates

Satyam Vishwakarma, Virendra Rajput and Syed Faisal Ahmed

Department of Mechanical Engineering, Sagar Institute of Research and Technology-Excellence, Bhopal-463041, Madhya Pradesh, India

ABSTRACT

In the present work, the effect of bio-particulate as a filler material in the polymer matrix is investigated on the different mechanical properties of the material. The polymer selected is epoxy resin and the bio-filler selected is the pistachio shell in the form of micro-particulates. The size of the particulates used is 50 microns. The composites are fabricated by varying the content of the filler ranging from 5 wt. % to 20 wt. % using the hand lay-up method. The effect of varying filler content on properties like tensile properties, flexural properties, compressive strength and hardness are evaluated and reported. From the investigation, it was found that the tensile strength of the material increases with filler loading till the content of the filler increases to 10 wt. % and decreases after that. Against that, the tensile modulus of the material increases with filler loading for the entire range of filler content. Similar behaviour is obtained for the flexural properties of the composite as well. While studying the compressive strength of the material, it is noticed that it increases as a function of filler content. Also, the incorporation of pistachio shell particulates in the epoxy matrix increases the hardness of the material as a function of filler content.

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

1. Introduction

Inadequate management of plastic waste has led to ecological challenges, prompting a substantial increase in the adoption of bio-based components in polymer composite studies. Among diverse bio-based additives, pistachio shells exhibit a distinctive chemical composition that shows great potential as a strengthening agent within polymeric resins. The incorporation of pistachio shells in particulate form as fillers within polymer matrix composites offers dual benefits: it contributes to environmental preservation and effectively reduces the manufacturing expenses of end products. The application of these materials as fillers in polymeric resins not only repurposes waste but also diminishes the consumption of harmful polymers. Research has been conducted on repurposing this waste as a filler material in polymeric resins.

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 mechanical properties 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 tensile strength of the composites is measured with a computerized Instron 1195 universal testing machine in accordance with the ASTM D638 procedure by applying uni-axial load through both ends. Static uniaxial compression tests on specimens are carried out using the same computerized universal testing machine. The method by which the compression test is conducted is in accordance with ASTM D695. The three-point bend test was carried out in accordance with ASTM D790 to measure the flexural strength of the composites. The hardness test was carried out in accordance with ASTM D-2240 using a PosiTector SHD Shore hardness Durometer.

4. Results and Discussion

4.1 Tensile properties

Figure 4.4 shows the ultimate tensile strength of the unfilled epoxy and the composite prepared with epoxy filled with micro-sized pistachio shell particulates. The figure shows the variation of the properties as a function of filler loading of the particulates. It is clearly observed from the figure that the inclusion of the pistachio shell micro-particulates in the epoxy resin enhances the tensile strength of the material. However, the increment in tensile strength with filler loading is limited to 10 wt. % of the filler loading only. In the present case, it is observed that once the filler loading increases above 10 wt. %, the tensile strength of the material starts reducing. The reduction in the tensile strength is due to the large amount of filler particles which originates the problem of agglomeration. The tensile strength of the neat epoxy is 34.4 MPa. The maximum tensile strength obtained is 41.1 MPa for a filler loading of 10 wt. % which is 19.5 % higher than the tensile strength of the unfilled epoxy. At a filler loading of 20 wt. %, the tensile strength is 33.8 MPa showing a reduction in the value of the tensile strength.

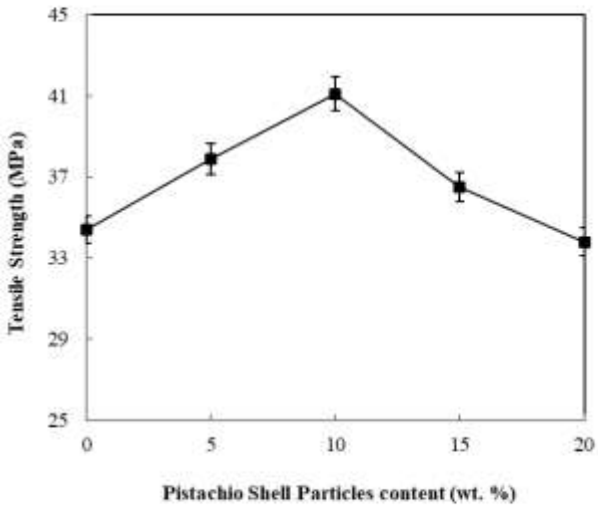

Figure 1 Effect of filler loading on ultimate tensile strength of the epoxy/pistachio shell particulate composites

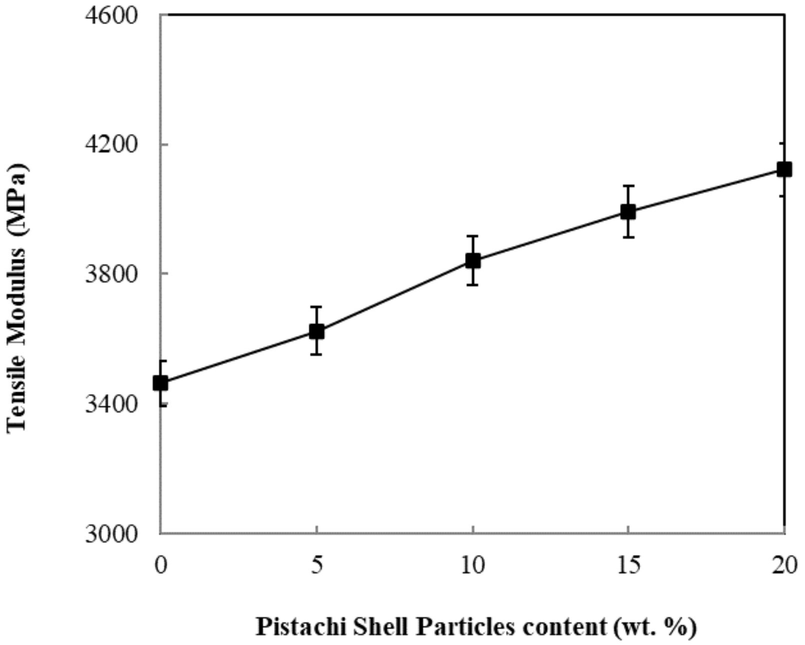

Figure 2 Effect of filler loading on tensile modulus of the epoxy/pistachio shell particulate composites

The tensile modulus of the epoxy/pistachio shell composites as a function of filler loading is presented in Figure 2. It is clear from the figure that the tensile modulus of the filled epoxy is higher than the unfilled one. The increase in tensile modulus is proportional to the filler content. The maximum tensile modulus is obtained when the filler loading is 20 wt. %. The tensile modulus of unfilled epoxy is 3463 MPa and it increases to 4121 MPa which is an increment of 19 % over the tensile modulus of neat epoxy. With the increase in filler content, tensile modulus increases because the addition of filler provides stiffness to the material.

4.2 Flexural properties

The flexural strength of the epoxy/pistachio shell particulate composites as a function of filler loading is presented in Figure 3. 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 epoxy/pistachio shell particulate composite increases with filler content when the fillers are added in a limited quantity i.e. 10 wt. %. Once the filler content increases above 10 wt. %, the flexural strength starts dropping. The flexural strength of neat epoxy is measured to be 42.4 MPa which increases for 10 wt. % filler to 51.13 MPa. When the filler content increases beyond 10 wt. %, the flexural strength of the material reduces for all sets of the composites prepared. The measured value of flexural strength is 45.86 MPa for epoxy composite filled with 20 wt. % of the filler material.

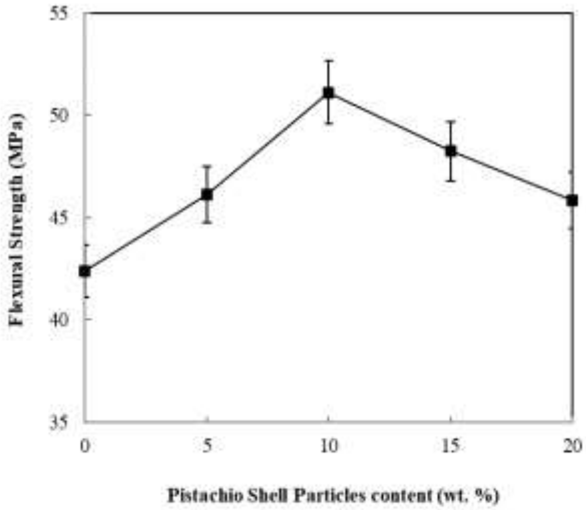

Figure 4 Effect of filler loading on flexural strength of the epoxy/pistachio shell particulate composites

Similar to the tensile modulus, flexural modulus also increases with filler content as shown in figure 4. The reason for the increment in the value flexural modulus is the increment in the rigidity of the polymer matrix with the inclusion of the filler material. Maximum flexural modulus is obtained for the combination of epoxy filler with 20 wt. % pistachio shell particulates. The value obtained in this case is 4025 MPa against 3140 MPa for unfilled epoxy. An increment of 28.18 % is obtained against the value for neat epoxy.

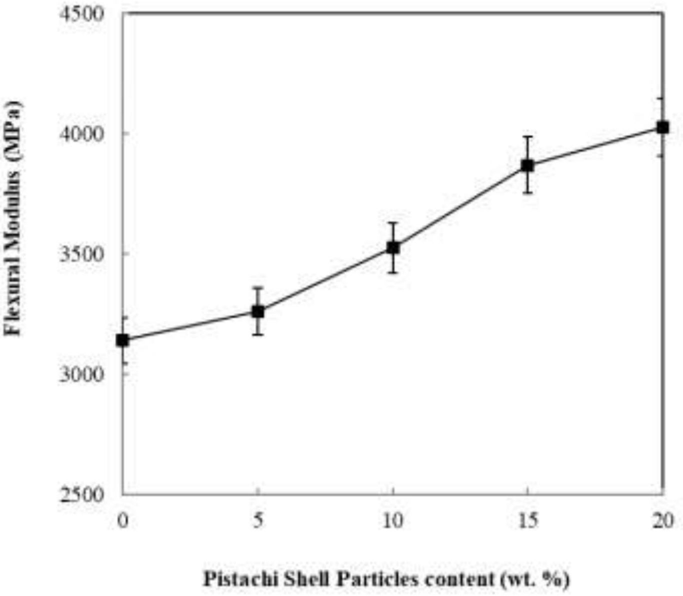

Figure 4 Effect of filler loading and the size of particles on flexural modulus of the epoxy/pistachio shell particulate composites

4.3 Compressive strength

Figure 5 presents the effect of the addition of the pistachio shell particulates in the epoxy matrix on the compressive strength of the material. The compressive strength as a function of filler loading is presented in the figure. From the figure, it is clear that the inclusion of micro-sized pistachio shell particulates helps in improving the compressive strength of the epoxy resin. The increment is a function of filler loading. The reason for the increment of the compressive strength is primarily due to the strengthening effect provided by the filler material into the matrix material. The unfilled epoxy resin possesses a compressive strength of 74.3 MPa. Inclusion of 20 wt. % of the filler material enhances the compressive strength of the material to 91.1 MPa showing an appreciable improvement of 22.61 %.

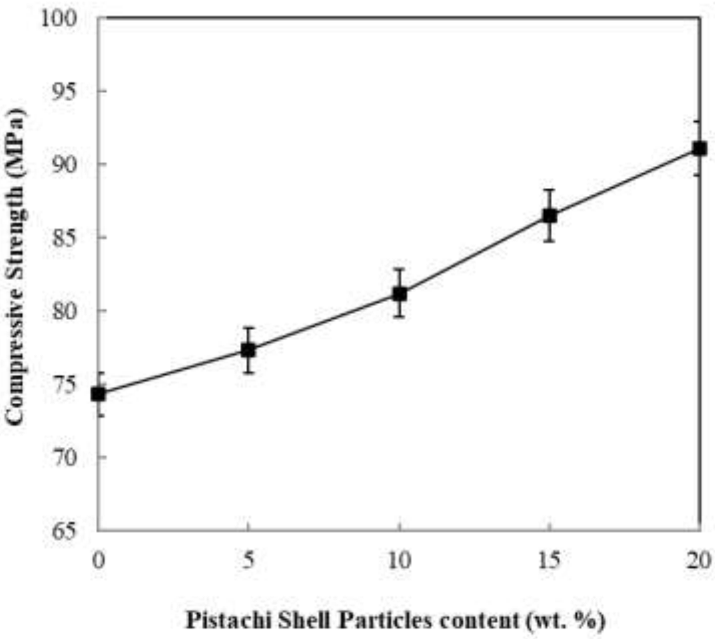

Figure 5 Effect of filler loading on compressive strength of the epoxy/pistachio shell particulate composites

4.4 Hardness

The hardness of the epoxy matrix and the composite prepared with epoxy as base matrix material and micro-sized pistachio shell particulates as a filler material is presented in Figure 6.

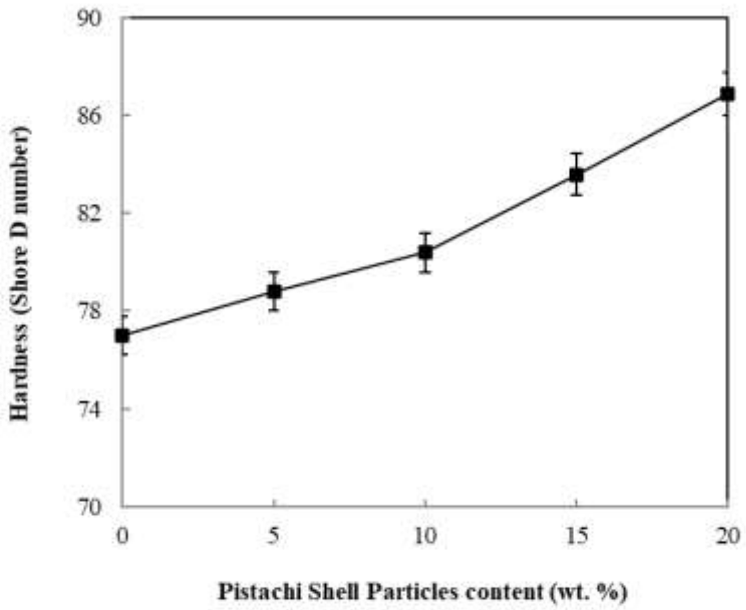

Figure 6 Effect of filler loading on the hardness of the epoxy/pistachio shell particulate composites

The figure shows the variation in the Shore-D hardness of the composite as a function of filler loading. From the figure, it can be observed that the inclusion of micro-sized pistachio shell particulates gainfully improves the hardness of the material. The improvement in hardness is mainly because of the hard nature of the pistachio shell particulates. The inclusion of hard micro-particulates enhances the ability of matrix material to deform plastically. The shore D number of the unfilled epoxy is measured to be 77 in the present investigation. The same increase to 86.9 for 20 wt. % of pistachio shell particulates. This is an improvement of 12.85 %. It is an appreciable improvement as such improvement is not observed very often when the micro-particulates are added to the polymer matrix.

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 tensile strength of the material increases with filler loading till the content of the filler increases to 10 wt. % and decreases after that. 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 composite with 10 wt.% filler and maximum tensile modulus is obtained for 20 wt. % filler.
3. The flexural strength of the material increases with filler loading irrespective of the size of the filler. The increment in flexural strength is limited to the filler loading of 10 wt. % and decreases after that. The flexural modulus of the material increases with filler loading over the entire range of filler content.
4. Incorporation of pistachio shell particulates in the epoxy matrix increases the compressive strength and hardness of the material as a function of filler content. The maximum compressive strength of 91.1 MPa is obtained for a composite prepared with epoxy filled 20 wt. % of the filler. The highest hardness of 86.9 Shore D number is reported for a similar content of the filler.

Reference

1. Guru, M., Şahin, M., Tekeli, S., &Tokgöz, H. (2009). Production of polymer matrix composite particleboard from pistachio shells and improvement of its fire resistance by fly ash. High-Temperature Materials and Processes, 28(3), 191-195.
2. Karaagac, B. (2014). Use of ground pistachio shell as alternative filler in natural rubber/styrene–butadiene rubber-based rubber compounds. Polymer composites, 35(2), 245-252.

3. Gairola, S., Gairola, S., & Sharma, H. (2020). Environment Effect on Impact Strength of Pistachio Shell Filler-Based Epoxy Composites. In Advances in Applied Mechanical Engineering (pp. 801-808). Springer, Singapore.
4. Alsaadi, M., Erkliğ, A., &Albu-khaleefah, K. (2018). Effect of Pistachio Shell Particle Content on the Mechanical Properties of Polymer Composite. Arabian Journal for Science & Engineering (Springer Science & Business Media BV), 43(9).
5. Chandrakar, S., Agrawal, A., Prakash, P., Khan, I. A., & Sharma, A. (2021, May). Physical and mechanical properties of epoxy reinforced with pistachio shell particulates. In AIP Conference Proceedings (Vol. 2341, No. 1, p. 040012). AIP Publishing LLC.
6. Salazar-Cruz, B. A., Chávez-Cinco, M. Y., Morales-Cepeda, A. B., Ramos-Galván, C. E., & Rivera-Armenta, J. L. (2022). Evaluation of thermal properties of composites prepared from pistachio shell particles treated chemically and polypropylene. Molecules, 27(2), 426.
7. Pradhan, S., Prakash, V., & Acharya, S. K. (2022). Bio waste (Pistacia vera nut shell) filled polymer composites for tribological applications. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 236(2), 334-344.
8. Mohammed, Z. H., & Salman, S. D. (2023). The influence of pistachio shell addition on the mechanical behavior of self-curing PMMA composites. Innovative Infrastructure Solutions, 8(6), 1-15.
9. Rautaray, S., Senapati, P., Sutar, H., & Murmu, R. (2023). The mechanical and thermal behaviour of unsaturated polyester matrix (UPM) composite filled with pistachio shell particles (PSP). Materials Today: Proceedings, 74, 581-586.