



EXPERIMENTAL INVESTIGATION ON EPOXY COMPOSITES REINFORCED WITH NATURAL SEED FILLER AND BORON CARBIDE ADDITIVES

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Abstract:

Natural-fiber-reinforced polymer composites have emerged as promising alternatives to conventional synthetic composites because of their low density, biodegradability, cost-effectiveness, and environmental sustainability. These materials consist of reinforcement and polymer matrix phases, where the reinforcement content generally varies from 5% to 40%, while the matrix content ranges between 60% and 90%. In epoxy-based systems, hardener content is usually maintained between 1% and 5% of resin weight for effective curing. To further improve matrix performance, nano- or micro-sized fillers are incorporated in small proportions, usually below 10 wt.%, to enhance mechanical strength, stiffness, and durability. Although extensive research has been carried out on natural fiber reinforced composites and their mechanical, thermal, chemical, and physical characteristics, limited work has focused on bio-particulate reinforced epoxy composites. In particular, avocado seed cover powder has received very little attention as an alternative filler material.

This study investigates the fabrication and characterization of epoxy composites reinforced with avocado seed powder (ASP) and boron carbide (B₄C) particles. Mechanical tests including tensile, flexural, compressive, impact, hardness, density, void content, and water absorption were conducted, along with morphological analysis using XRD and SEM. Results indicate that the incorporation of avocado seed powder and boron carbide significantly improves tensile, flexural, and compressive properties, while moderate filler addition reduces water absorption and improves hardness.

Keywords: Epoxy composites, avocado seed powder, boron carbide, natural filler, mechanical properties, polymer composites.

Literature:

(Sakthi et al., 2020) extracted the bahunia racemosa fibers and reinforced into the epoxy matrix and the composite is filled with the egg shell powder to study the effect of the egg shell inclusion. The reinforcement and filler addition levels are proposed by Taguchi's experimental design through MINITAB software. The composites were produced through hand layup process and tested as per the standards. The optimum results show that, for maximum hardness, the inclusion of fibers and the fillers must be maximum and to obtain the minimum water absorption, the addition of the fibers must be minimum and the addition of the fillers must be maximum.

(Muniappan et al., 2019) analyzed the influence of coffee bean natural filler reinforcement (5, 10, 15, 20, 25 and 30% mass fraction) on the mechanical properties of Epoxy LY556 composite and fabricated using compression molding. It also indicates that bonding between filler and matrix is better and 30% mass fraction filler reveals reduced wettability with the epoxy matrix in composite.

(Obada et al., 2019) studied coir-coconut husk powder reinforced polymer composite (CCHPRC) prepared by the simultaneous application of heat and pressure, and investigated an acidic environment and its morphological and hardness properties. Four test conditions were selected to elucidate the short-term effect of the exposure of the composites to Sulfuric Acid (H₂SO₄) solution with a pH of 2.2 at room temperature (27 °C). As a result, the gradual material degradation and poor adhesion between reinforcement and matrix was observed which was confirmed by SEM/EDS analysis. Prolonged acid immersion time seemed to promote an increase in terms of the composites' hardness in comparison with the control sample.

(Theja et al., 2021) studied, effect of organic residue, tea dust is effectively recycled/utilized for fabricating polymer composite to find its suitability in engineering applications. Epoxy polymer is considered as matrix material and different volume fractions of used tea dust powders (10, 20, 30, 40, 50, and 60 vol%) are used as reinforcement. Based on the mechanical strength the best combination is found to be 40% vol. in epoxy matrix; higher addition than 40% reduces the strength due to lower bonding between the powders and matrix.

(Girimurugan et al., 2020) investigated impact strength and hardness properties of banana fiber and camellia sinensis particle reinforced epoxy composite. Four composite specimens for Izod impact test and Rockwell hardness test were prepared as per the ASTM standards by keeping weight percentage of the matrix material as constant (65%) and varying the weight percentage of banana fiber (35, 33, 31, 29%)/Camellia Sinensis particles (0, 2, 4, 6%) respectively. Izod impact test and Rockwell hardness tests were performed on the four composites specimens. Experimental results revealed that the addition of Camellia Sinensis particles enhanced the hardness and diminishes the impact of energy and impact strength of the composites considerably.

Reinforcement -Avocado Seed Cover Powder

To conduct this study, avocado seeds were collected from local juice shop in Adama Oromia region, Ethiopia. The avocado seeds were washed with water to remove impurities then allowed to open dry under sunlight for 24 hours to remove the moisture content. Then the seeds were separated from its cover. After that the dried seed cover was grinded with coffee grinder machine. Since the result was not fine powder, using a dry ball milling machine is required for further grinding process. The powder was then sieved using a 200-mesh sieve with a mesh size of 75 μm .



Figure 3.1: ASP preparation: (a): washed avocado seed, (b): drying the seed, (c): avocado cover peeled from the seed, (d): coffee grinder, (e): grinded ASP with coffee grinder, (f): Ball milling Machine, (g): milled ASP

Preparation of Avocado Seed Powder (ASP)

The avocado seed was grinded by ball milling after it was cleaned and dried. Then the powder was sieved with size of 75 microns.



Figure 3.7: (a): Dried avocado seed cover, (b): Grinded ASP, (c): milled ASP

Physical Characterization

3.7.1. XRD Analysis

X-Ray diffraction analysis (XRD) is a nondestructive technique that provides detailed information about the crystallographic structure, chemical composition, and physical properties of a material. It is based on the constructive interference of monochromatic X-rays and a crystalline sample. For this investigation XRD-7000 X-RAY DIFFRACTOMETER, SHIMADZU Corporation (Japan) which is found in ASTU Materials Science Engineering laboratory is used.

3.7.2. SEM

Scanning electron microscopy (SEM) is widely used to study and provide information on size and morphology. SEM is based on a focused beam of electrons that scan the sample, which interacts with the atoms in the sample to provide three-dimensional surface topography (Pallares-Rusiñol et al., 2023). This process was conducted in Biology department of ASTU.

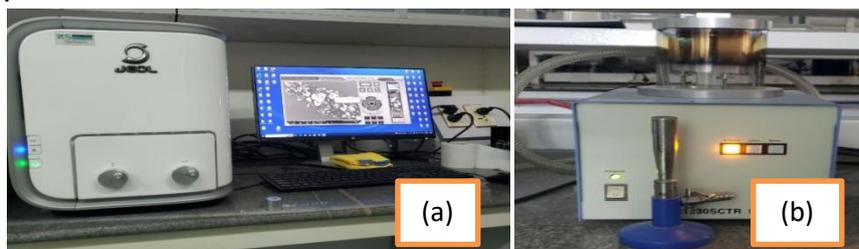


Figure 3.24: (a): Scanning Electron Microscope, (b): Smart Coater

RESULT AND DISCUSSION

In this section, the results of all the experimental work are discussed in detail. The tests performed in this paper are flexural, tensile, hardness, impact, compression, water absorption, density, void content, and morphological analysis of the fabricated composite material, which is epoxy resin reinforced with avocado seed particulate and boron carbide.

4.1 Density Test

The quality of production, the fiber and filler dispersion, and the amount of voids caused by air trapped all have an impact on the mechanical characteristics of fabricated samples. Composites become lighter as their fiber content rises. As the amount of fiber in a composite material grows, so does the void content.

4.2 Tensile Test

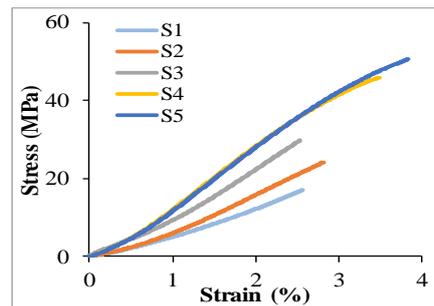


Figure 4.1: Representative Tensile stress-strain curves of composites

Figure 4.1 represents the tensile stress-strain curves for neat epoxy and epoxy composites with avocado fiber and B_4C particle reinforcement. S3, S4 and S5 have a 2.54, 3.50 and 3.89% strain corresponding to 29.85, 46.02 and 50.22 MPa tensile stress, respectively. From the specimens, S1, S2, and S3 showed more brittle behavior while S4 and S5 specimens showed less brittle behavior.

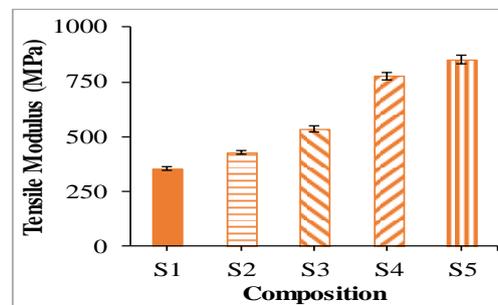


Figure 4.2: Young's modulus measured experimentally

Figure 4.2 shows the experimentally determined young's modulus. S3 had a tensile modulus of 535.92 MPa which was fabricated from 5 vol.% of B_4C and 5 vol.% of avocado fiber. S4 had a tensile modulus of 775.92 MPa which was fabricated from 5 vol.% of B_4C and 10 vol.% of avocado seed particulate while S5 had a tensile modulus of 850.66 MPa fabricated from 5 vol.% of B_4C and 15 vol.% of avocado seed particulate. All composites' tensile moduli rise with increasing fiber content and are between 20.8 and 119.1% higher than in S1.

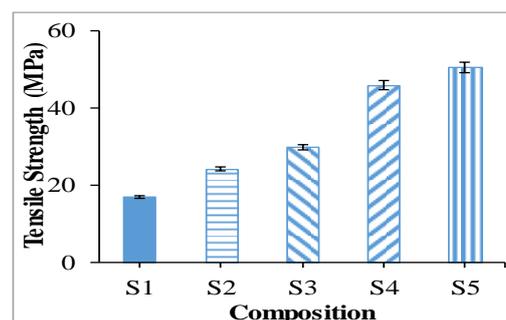


Figure 4.3: Tensile strength measured experimentally

Figure 4.3 shows the experimentally determined tensile strength of the specimens in response to fiber volume fraction. When compared to neat epoxy samples, all avocado/epoxy composites have superior strength. Strength increases ranged from 42.5 to 170.6%, with S5 showing the greatest improvement. The combination of B_4C particles with avocado in a load-carrying matrix increases the fiber-filler-matrix bonding and thus strength. When avocado concentration rises to 15 vol.%, the tensile strength of B_4C filled avocado/epoxy composites rises.

4.3 Flexural Test

Figure 4.4 shows the flexural stress-strain characteristics of the samples that were put through a flexural test. Every one of the specimens exhibits nearly linear stress-strain profiles up to failure, suggesting that both neat epoxy and avocado fiber reinforced epoxy composites fail in brittle mode.

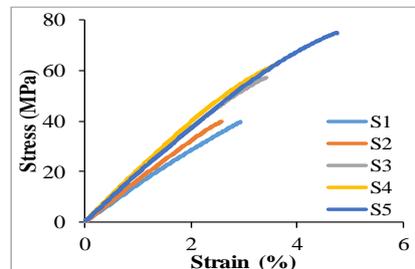


Figure 4.4 Representative Flexural stress-strain curve of the composite specimens.

Figure 4.4 shows that flexural stress increases with an increase in avocado filler content. S1 has 2.94% strain at 39.90 MPa flexural stress while S2 has a 2.58% strain at 39.84 MPa flexural stresses. S3 has 3.41% strain at 57.20 MPa flexural stresses whereas S4 has a 3.65% strain at 67.95 MPa flexural stresses. S5 specimen reveals the highest strain of 4.74% and 74.74 MPa of stress.

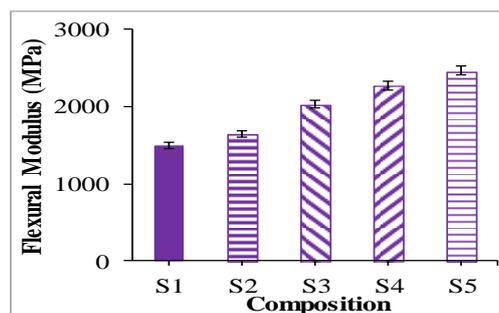


Figure 4.5: Flexural modulus measured experimentally

Figure 4.5 shows the influence of filler composition on epoxy composites' flexural modulus with avocado and B₄C particle reinforcement. The flexural modulus of all composites shows an increasing trend as the avocado filler volume fraction increases. Out of all the composite materials, S5 has the greatest modulus, showing a 52.1% improvement in modulus above neat epoxy. The robust interaction between the avocado and B₄C filler within the epoxy matrix is confirmed by the elevated flexural modulus.

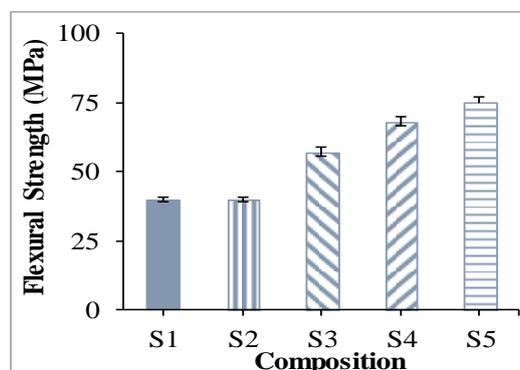


Figure 4.6: Flexural strength measured experimentally

Figure 4.6 shows the influence of filler composition on epoxy composites' flexural strength with avocado and B₄C particle reinforcement. The flexural strength of all composites shows an increasing trend as the avocado filler volume fraction increases. The strength of S2, S3, S4 and S5 rises almost uniformly and is determined to be greater than that of neat epoxy (S1). Out of all the composite materials, S5 had the greatest flexural strength, showing a 71.1% improvement in strength over neat epoxy.

4.4 Compression Test

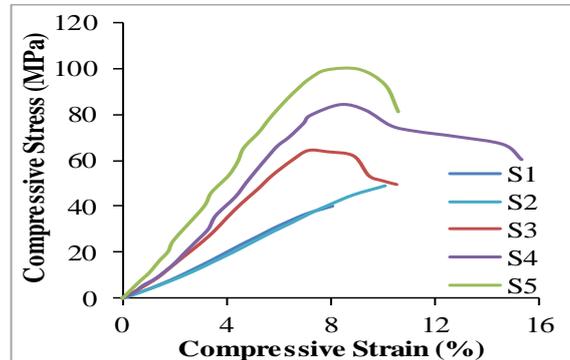


Figure 4.7: Representative compressive stress-strain curves of composite samples

The compressive stress-strain curves for avocado filler reinforced epoxy composites, including samples of neat epoxy (S1), are shown in Figure 4.7. The percentage volume of reinforcements has a major impact on the composite's failure mechanism. When compared to epoxy samples without filler reinforcement, stress-strain curves of composites reinforced with avocado reveal similar patterns.

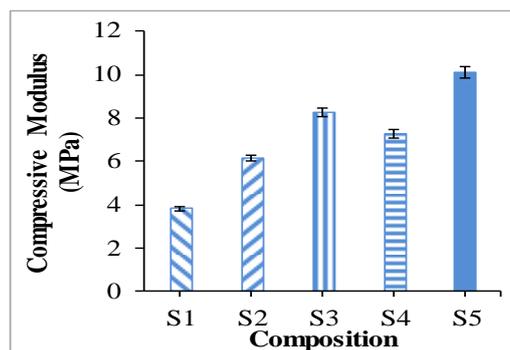


Figure 4.8: Experimentally measured compressive modulus

By measuring the gradient of the linear range on the compression stress-strain curve, the compressive modulus of the avocado filler-reinforced epoxy composites, including epoxy with no reinforcement samples, was determined. The compressive modulus of B₄C particles and avocado filler reinforced epoxy composites are improved in comparison to neat epoxy (S1) samples with 0% filler content. When compared to neat epoxy samples (S1), the improvement in compressive modulus is 60.10943, 114.9557, 89.0568 and 162.8973% for S2, S3, S4 and S5 respectively.

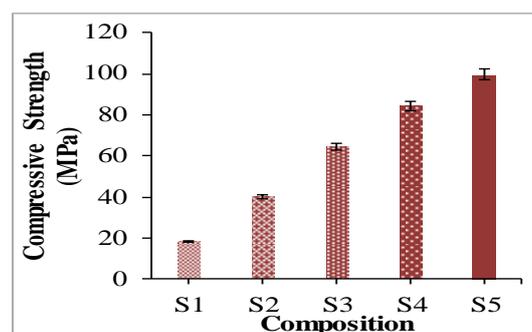


Figure 4.9: Experimentally measured compressive strength

Figure 4.9 shows the experimentally determined compressive strength of the specimens in response to avocado filler volume fraction. When compared to no filler-reinforced epoxy samples, all avocado-epoxy composites have superior strength. With the increase of filler percentage in the resin, the compressive strength of avocado-epoxy composites for S1, S2, S3, S4 and S5 is 18.23, 40.1, 64.27, 84.26, and 99.56 MPa, respectively. In the current study, it was discovered that adding 5, 10, and 15 vol.% of avocado filler reinforcements enhanced the compressive strength of the composite material. The compressive strength of the S5 composite is found to be greater (99.56 MPa). Owing to the weak hydrophilic cellulose-hydrophobic epoxy interfacial interaction, the stress-transferring capacity from the polymer matrix to the cellulose is enhanced, resulting in an increase in strength.

4.5 Impact Test

The Charpy impact test measures the energy absorbed by a standard notched specimen while breaking under an impact load. This test consists of striking a suitable specimen with a hammer on a pendulum arm while the specimen is held securely at each end. The hammer strikes opposite the notch. The energy absorbed by the specimen is determined precisely by measuring the decrease in motion of the pendulum arm. The important factors that affect the toughness of a material include low temperatures, high strain rates (by impact or pressurization), and stress concentrators such as notches, cracks, and voids (Saba et al., 2018).

For the determination of impact characteristics, experimental test have been performed for five different samples. Each samples were tested three times and their average was displayed in the following table.

The experimental results shows that the composite specimen with higher ASP contents (S3, S4 and S5) exhibits better hardness behavior than the S1 and S2 composites due to the addition of higher weight percentage of avocado seed particulate to the epoxy resin and filler material (B4C). A higher value of hardness indicates that the material is harder, offering more resistance to penetration by other materials. So, in this case sample S3 which contains 5 vol% of avocado and 5 vol% of boron carbide shows higher hardness value which is 38.43.

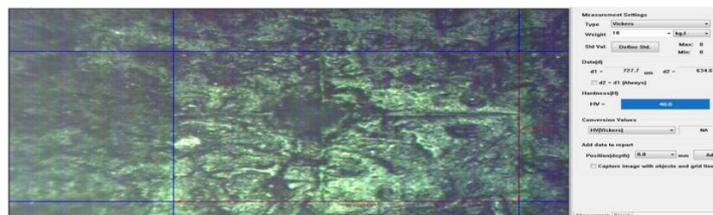


Figure 4.10: Hardness result for sample S3

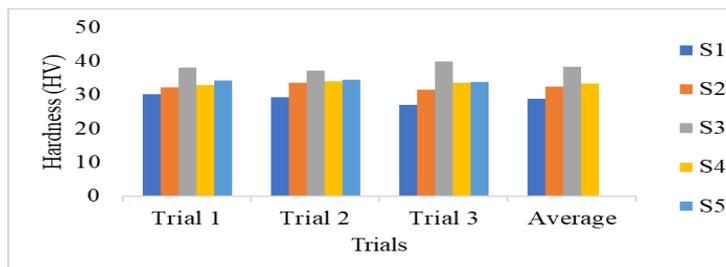


Figure 4.11: Experimentally measured hardness results

4.7 Water absorption

The specimens were taken out of each water container, cleaned to eliminate any extra water on them, and then measured. The desired accuracy of 0.1 milligrams is achieved by using a digital balance. Water absorption experiments were carried out to investigate the water uptake characteristics of avocado and boron carbide reinforced epoxy composite specimens.

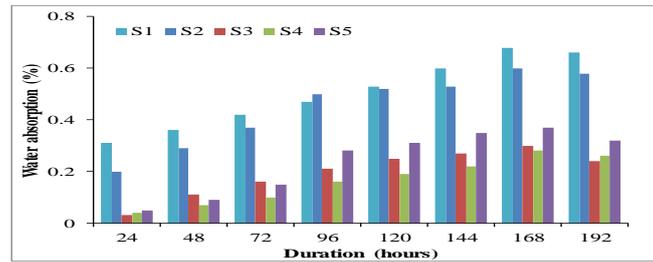


Figure 4.12: Water absorption percentage of epoxy composites with avocado filler and B_4C particles reinforced specimens after immersed in distilled water

4.8 XRD

The XRD technique is principally used for phase detection of a crystalline structure and provides valuable information on the unit cell dimensions. It is mainly based on the constructive interference of incident monochromatic X-rays and the fabricated samples; when conditions satisfy the Bragg's law that is, $n\lambda = 2d\sin\theta$. These diffracted X-rays are then detected and processed inside the equipment. XRD diffractogram signifies the plot of intensity of X-rays dispersed by the samples.

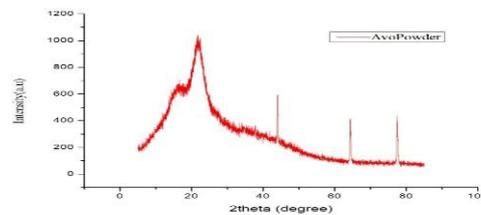


Figure 4.13 XRD graph

Conclusion

Avocado nut is a plant that has more than 100 species in the world and has not yet been studied in detail. The stinging Avocado nut shell of Ethiopian origin has a particulate fiber that can yield composite materials with comparable tribological and mechanical properties. A researcher is only trying to analyze its properties related to medicine and animal production. In other ways, Avocado nut plants grew abundantly in various countries including our country Ethiopia. Researchers are investigating the different properties of Avocado nut plants concerning food and drug applications. However, according to an investigation, there is still no study on the composition of Avocado nut plants. Because of availability of Avocado nut in our country. This study focused on the particulate fiber-reinforced polymer composite of the Avocado nut shell to waste material converts into useable.

The following results can be reached after analyzing the material properties of Avocado nut seed shell particulate reinforcement fiber reinforced composites with three different percentage compositions and with three different mixing parameters:-

1. Avocado nut seed shell, a by-product of the Avocado nut plant, can be successfully compounded with resin for a value-added product and used to manufacture composite materials with different fiber compositions and mixing methods possible by the solid casting process.
2. Avocado nut seed shell powder can greatly reduce wear loss when mixed into epoxy. At a fiber level of 30 percent by weight, the best wear resistance was achieved.
3. Because the gap between the abrasives is filled with debris, the specific wear rate of the composite reduces as the sliding distance increases and increases the weight % of Avocado nut reinforcement.
4. As the volume proportion of reinforcement Avocado capital increases, the coefficient of friction lowers.
5. Different mechanical properties of the product were determined from different weight percentage compositions and different mixing methods Sample S8 has a maximum compression strength and maximum



energy absorbed during impact test also the value of tensile strength was maximum additionally the hardness values are maximum, it is 150.8HV. This sample was a composition of 30 percent Avocado nut particle reinforcement and mixing 1 hour by a magnetic stirrer.

The mechanical strength of the composite was also affected by the percentage composition of reinforcement and mixing method. Composite 30% shows better mechanical strength than 10% and 20% of wt.% reinforced composite.

6. The maximum water-absorbed sample was sample 7. It absorbed 1.7% before 10 days due to the maximum weight present of reinforcement and inappropriate homogeneity because of being manually mixed for 10 minutes. The composite after 10 days at the equilibrium no value changes.

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