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EXPERIMENTAL CHARACTERIZATION OF EPOXY-BASED COMPOSITES REINFORCED WITH NATURAL SEED FILLER AND BORON CARBIDE PARTICLES

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Abstract

Natural-fiber-reinforced polymer composites have attracted considerable attention as sustainable alternatives to conventional synthetic composites due to their low density, biodegradability, cost efficiency, and environmental friendliness. These composites are composed of reinforcement and polymer matrix phases, with reinforcement content typically ranging from 5% to 40% and matrix content from 60% to 90%. In epoxy-based composite systems, hardener content is generally maintained between 1% and 5% of the resin weight to ensure effective curing. To further enhance matrix performance, micro- and nano-sized fillers are incorporated in small proportions, usually below 10 wt.%, to improve mechanical strength, stiffness, and durability. Although extensive research has been conducted on natural-fiber-reinforced composites and their mechanical, thermal, chemical, and physical properties, limited attention has been given to bio-particulate reinforced epoxy composites, particularly those utilizing avocado seed cover powder as a sustainable filler material.

This study focuses on the fabrication and characterization of epoxy composites reinforced with avocado seed powder (ASP) and Boron carbide particles. Mechanical characterization was carried out through tensile, flexural, compressive, impact, hardness, density, void content, and water absorption tests, while morphological analysis was performed using X-ray diffraction and Scanning Electron Microscopy. The experimental results reveal that the incorporation of avocado seed powder and boron carbide significantly enhances tensile, flexural, and compressive properties, while moderate filler loading improves hardness and reduces water absorption. These findings suggest that avocado seed powder can serve as an effective eco-friendly reinforcement material for advanced epoxy composite applications.

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

Literature Review

Sakthi et al. extracted *Bauhinia racemosa* fibers and incorporated them into an epoxy matrix, while eggshell powder was used as filler to investigate its effect on composite performance. The reinforcement and filler proportions were optimized using Taguchi experimental design through Minitab. The composites were fabricated using the hand lay-up technique and tested according to standard procedures. The results showed that maximum hardness was achieved when both fiber and filler contents were at their highest levels, whereas minimum water absorption was obtained with minimum fiber content and maximum filler addition.

Muniappan et al. investigated the effect of coffee bean natural filler reinforcement at mass fractions of 5%, 10%, 15%, 20%, 25%, and 30% on the mechanical properties of epoxy LY556 composites fabricated by compression molding. Their study revealed improved interfacial bonding between filler and matrix, while the composite containing 30% filler exhibited reduced wettability with the epoxy matrix.

Obada et al. studied coir–coconut husk powder reinforced polymer composites prepared through simultaneous heat and pressure application, focusing on morphological and hardness behavior under acidic conditions. Composite samples were exposed to Sulfuric acid at pH 2.2 and room temperature (27°C) under four test conditions. The results indicated gradual material degradation and weak adhesion between reinforcement and matrix, confirmed through Scanning Electron Microscopy and EDS analysis, while prolonged acid immersion increased hardness compared with the control sample.

Theja et al. evaluated the use of recycled tea dust as an organic residue reinforcement for epoxy polymer composites intended for engineering applications. Different volume fractions of tea dust powder (10%, 20%, 30%, 40%, 50%, and 60%) were incorporated into the epoxy matrix. The results showed that 40 vol.% reinforcement produced the best mechanical performance, whereas higher filler content reduced strength because of poor interfacial bonding between the filler and matrix.

Girimurugan et al. investigated the impact strength and hardness properties of banana fiber and *Camellia sinensis* particle reinforced epoxy composites. Four specimens were prepared according to ASTM standards by maintaining matrix content at 65% and varying banana fiber content (35%, 33%, 31%, and 29%) together with *Camellia sinensis* particle content (0%, 2%, 4%, and 6%). Results from Izod impact and Rockwell hardness tests demonstrated that increasing *Camellia sinensis* particle content improved hardness but significantly reduced impact energy absorption and impact strength.

Reinforcement – Avocado Seed Cover Powder

For this study, avocado seeds were collected from local juice shops in Adama. The collected seeds were thoroughly washed with water to remove surface impurities and then sun-dried for 24 hours to reduce moisture content. After drying, the seed covers were manually separated from the seeds and further dried before grinding. The dried seed covers were initially ground using a coffee grinder; however, because the resulting particles were not sufficiently fine, additional grinding was carried out using a dry ball milling machine. Finally, the powder was sieved through a 200-mesh sieve to obtain a uniform particle size of 75 µm for composite reinforcement.

Figure 3.1: ASP preparation: (a): washed avocado seed, (b): drying the seed, (c): avocado cover pealed 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.

Figure3.7: (a): Dried avocado seed cover, (b): Grinded ASP, (c): milled ASP

Physical Characterization

3.7.1 XRD Analysis

X-ray diffraction is a non-destructive analytical technique used to determine the crystallographic structure, chemical composition, and physical properties of materials. The method operates on the principle of constructive interference between monochromatic X-rays and the crystal lattice of a material, producing diffraction patterns that reveal structural information. For this investigation, an XRD-7000 X-ray Diffractometer manufactured by Shimadzu Corporation was employed. The analysis was carried out in the Materials Science and Engineering Laboratory of Adama Science and Technology University.

3.7.2 SEM

Scanning Electron Microscopy is widely used to examine the surface morphology, particle size, and microstructural features of materials. The technique operates by directing a focused beam of electrons onto the sample surface, where interactions between the electrons and atoms generate signals that provide detailed three-dimensional topographical information. As reported by Pallares-Rusiñol et al., SEM enables precise observation of surface characteristics and structural features at high magnification. In this study, the SEM analysis was carried out in the Biology Department laboratory of Adama Science and Technology University.

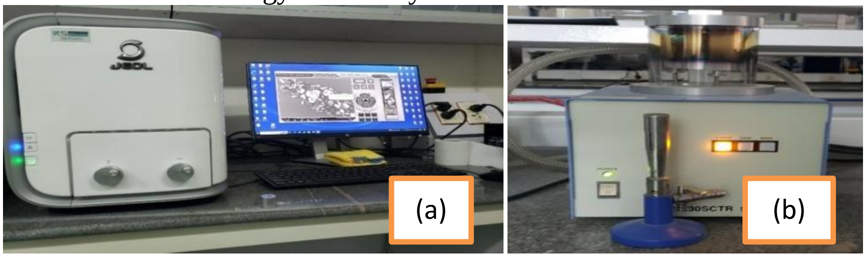


Figure 3.24: (a): Scanning Electron Microscope, (b): Smart Coater

Results and Discussion

This section presents and discusses in detail the results obtained from all experimental investigations carried out on the fabricated composite materials. The composite specimens, consisting of epoxy resin reinforced with avocado seed particulate and Boron carbide, were evaluated through mechanical, physical, and morphological characterization. The experimental tests performed included tensile, flexural, hardness, impact, compression, water absorption, density, and void content measurements, together with morphological analysis using Scanning Electron Microscopy and X-ray diffraction. The obtained results are analyzed to assess the influence of reinforcement and filler content on the overall performance of the composite material.

4.1 Density Test

The density of fabricated composite samples is an important parameter for evaluating material quality, reinforcement distribution, and internal structural integrity. Mechanical properties are strongly influenced by production quality, uniform dispersion of fiber and filler within the matrix, and the presence of voids formed due to trapped air during fabrication. In general, the density of composite materials decreases as the fiber content increases because natural fibers possess lower density than the polymer matrix. At the same time, increasing fiber content tends to increase void formation, which contributes to higher void content within the composite and may adversely affect mechanical performance.

4.2 Tensile Test

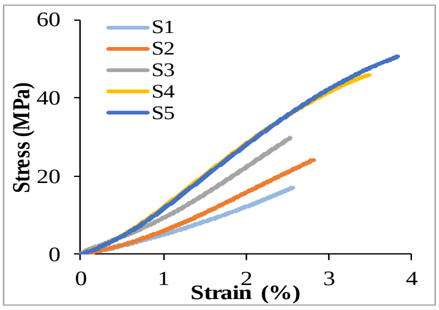


Figure 4.1: Representative Tensile stress-strain curves of composites

Figure 4.1 presents the tensile stress–strain curves of neat epoxy and epoxy composites reinforced with avocado fiber and Boron carbide particles. The composite specimens S3, S4, and S5 exhibited strain values of 2.54%, 3.50%, and 3.89%, corresponding to tensile stresses of 29.85 MPa, 46.02 MPa, and 50.22 MPa, respectively. Among all specimens, S1, S2, and S3 demonstrated comparatively brittle behavior, whereas S4 and S5 showed reduced brittleness with improved deformation before failure.

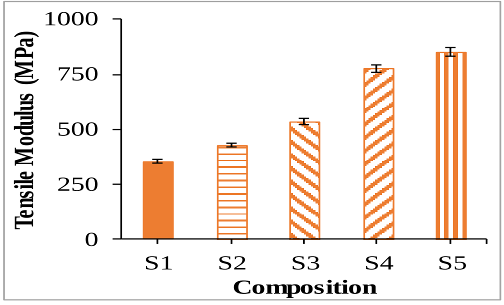


Figure 4.2: Young's modulus measured experimentally

Figure 4.2 illustrates the experimentally determined Young's modulus of the fabricated composite specimens. Specimen S3, produced with 5 vol.% Boron carbide and 5 vol.% avocado fiber, exhibited a tensile modulus of 535.92 MPa. Specimen S4, containing 5 vol.% boron carbide and 10 vol.% avocado seed particulate, showed an increased tensile modulus of 775.92 MPa, while specimen S5, fabricated with 5 vol.% boron carbide and 15 vol.% avocado seed particulate, achieved the highest tensile modulus of 850.66 MPa. The results indicate that the tensile modulus of all composite samples increased with increasing reinforcement content, showing improvements ranging from 20.8% to 119.1% compared with specimen S1.

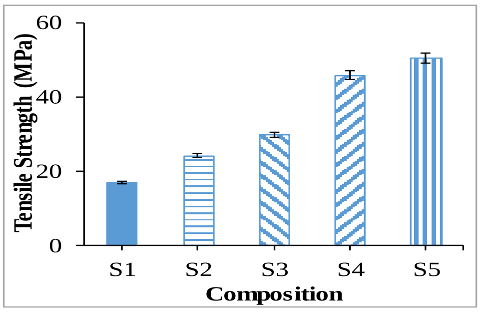


Figure 4.3: Tensile strength measured experimentally

Figure 4.3 illustrates the experimentally determined tensile strength of the composite specimens with varying fiber volume fractions. All avocado-reinforced epoxy composites demonstrated higher tensile strength than neat epoxy, indicating the positive contribution of reinforcement to load-bearing capacity. The tensile strength improvement ranged from 42.5% to 170.6%, with specimen S5 exhibiting the highest enhancement. The combined addition of avocado reinforcement and Boron carbide particles enhanced interfacial adhesion between the fiber, filler, and matrix, leading to improved stress transfer and overall tensile performance. Moreover, increasing the avocado content up to 15 vol.% produced a progressive increase in the tensile strength of the boron carbide-filled avocado/epoxy composites.

4.4 Flexural Test

Figure 4.4 presents the flexural stress–strain behavior of the specimens subjected to flexural loading. All specimens exhibited nearly linear stress–strain responses up to the point of failure, indicating predominantly elastic behavior before fracture. This response suggests that both neat epoxy and avocado fiber reinforced epoxy composites failed in a brittle manner under flexural loading.

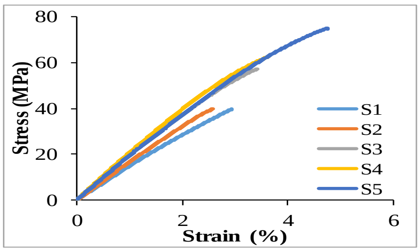


Figure 4.4 Representative Flexural stress-strain curve of the composite specimens.

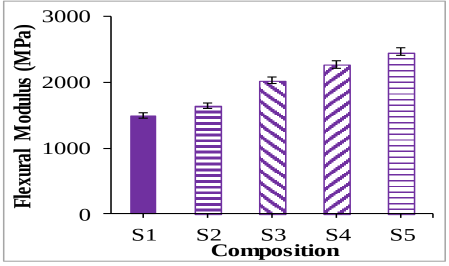


Figure 4.5: Flexural modulus measured experimentally

Figure 4.5 shows the influence of filler composition on epoxy composites' flexural modulus with avocado and B_4C 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 B_4C filler within the epoxy matrix is confirmed by the elevated flexural modulus.

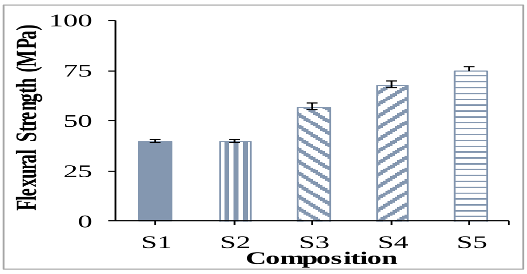


Figure 4.6: Flexural strength measured experimentally

Figure 4.6 shows the influence of filler composition on epoxy composites' flexural strength with avocado and B_4C 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

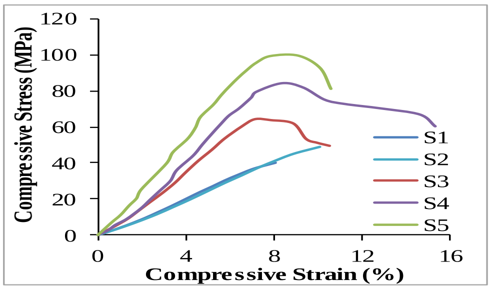


Figure 4.7: Representative compressive stress-strain curves of composite samples

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.

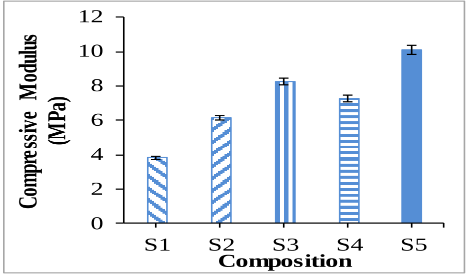


Figure 4.8: Experimentally measured compressive modulus

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 B_4C 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.

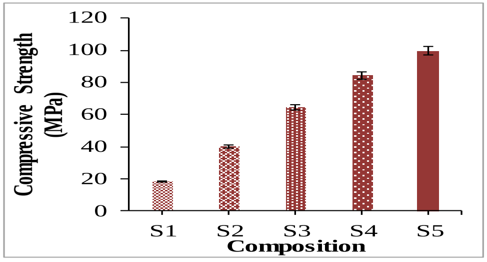
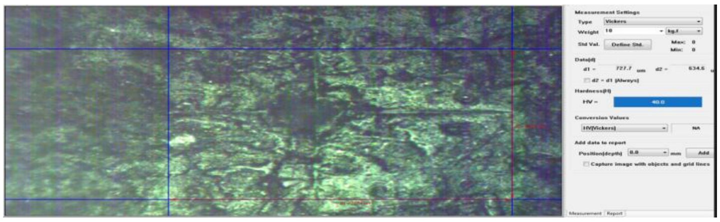


Figure 4.9: Experimentally measured compressive strength

Figure 4.9 presents the experimentally determined compressive strength of the composite specimens as a function of avocado filler volume fraction. Compared with unreinforced epoxy, all avocado-filled epoxy composites exhibited improved compressive strength. As the filler content increased, the compressive strength values for specimens S1, S2, S3, S4, and S5 were recorded as 18.23, 40.1, 64.27, 84.26, and 99.56 MPa, respectively. The results indicate that the addition of 5, 10, and 15 vol.% avocado filler progressively enhanced the compressive performance of the composite material, with specimen S5 achieving the highest compressive strength of 99.56 MPa. This improvement can be attributed to enhanced stress transfer between the epoxy matrix and reinforcement, where the incorporation of avocado filler improves interfacial interaction and contributes to greater resistance under compressive loading.

4.5 Impact Test

The Charpy impact test is used to measure the amount of energy absorbed by a standard notched specimen during fracture under impact loading. In this test, a specimen is securely supported at both ends and struck by a pendulum-mounted hammer on the side opposite the notch. The absorbed energy is determined from the reduction in pendulum motion after fracture, which reflects the material's impact toughness. According to Saba et al., factors such as low temperature, high strain rate, and stress concentrators including notches, cracks, and voids significantly influence the toughness of composite materials. For impact characterization, experimental tests were carried out on five different composite specimens. Each specimen was tested three times, and the average values were recorded for analysis.The experimental results indicate that composite specimens with higher avocado seed particulate (ASP) content, particularly S3, S4, and S5, exhibited improved hardness compared with S1 and S2 due to the increased proportion of avocado seed particulate and Boron carbide in the epoxy matrix. Higher hardness values indicate greater resistance to surface indentation and penetration by external materials. Among the tested specimens, S3, containing 5 vol.% avocado seed particulate and 5 vol.% boron carbide, exhibited the highest hardness value of 38.43.


Measurement Settings
Type: Vickers
Weight: 10 kg.f
Max: 0
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Data(d)
d1 = 727.7 um d2 = 634.6
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Hardness(H)
HV = 40.0
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HV(Vickers) NA
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Figure 4.10: Hardness result for sample S3

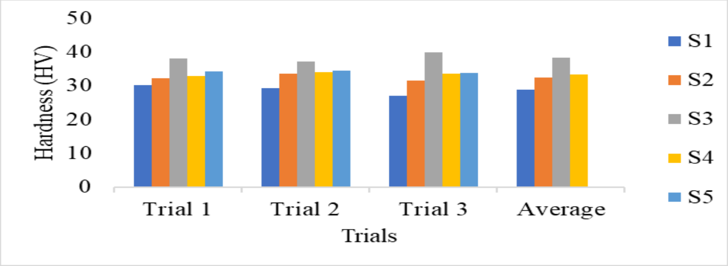

Figure 4.11: Experimentally measured hardness results

4.7 Water Absorption

For the water absorption test, the composite specimens were removed from each water container at the specified intervals, carefully wiped to remove surface moisture, and then weighed using a digital balance with an accuracy of 0.1 mg. Water absorption experiments were conducted to evaluate the moisture uptake behavior of epoxy composites reinforced with avocado particulate and Boron carbide particles. The test was performed to assess the influence of reinforcement on the water absorption characteristics of the fabricated composite specimens.

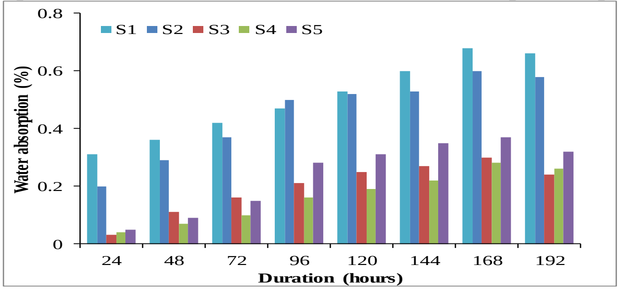

Figure 4.12: Water absorption percentage of epoxy composites with avocado filler and B_4C particles reinforced specimens after immersed in distilled water

4.8 XRD

X-ray diffraction is primarily used for phase identification in crystalline materials and provides important information about crystal structure and unit cell dimensions. The technique operates on the principle of constructive interference between incident monochromatic X-rays and the fabricated composite samples. Diffraction occurs when the interaction satisfies Bragg's law, expressed as:nλ=2dsinθn\lambda = 2d\sin\thetanλ=2dsinθ.The diffracted X-rays are detected and processed by the instrument to generate an XRD diffractogram, which represents the variation of X-ray intensity with diffraction angle and provides information about the structural characteristics of the samples.

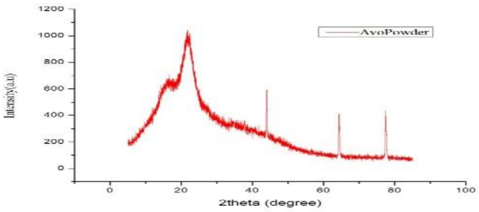

Figure 4.13 XRD graph

Conclusion

Avocado is a widely available plant with more than one hundred species distributed globally, yet several of its by-products remain insufficiently explored for engineering applications. In particular, avocado seed shell of Ethiopian origin has received limited attention despite its potential as a particulate reinforcement material capable of producing composite materials with promising tribological and mechanical properties. Most previous studies have mainly focused on avocado-related applications in food, medicine, and animal production, while very limited research has examined its suitability for composite material development. Owing to the abundant availability of avocado waste in Ethiopia, this study focused on converting avocado seed shell waste into a useful reinforcement material for polymer composite fabrication.

Based on the analysis of avocado seed shell particulate reinforced polymer composites prepared with different composition levels and mixing conditions, the following conclusions were drawn:

1. Avocado seed shell powder, a by-product of avocado processing, was successfully combined with epoxy resin to produce value-added composite materials using the solid casting method with different reinforcement compositions and mixing parameters.
2. The incorporation of avocado seed shell powder significantly improved wear resistance when added to epoxy resin, with the best wear performance observed at 30 wt.% reinforcement.
3. The specific wear rate of the composite decreased with increasing sliding distance and higher avocado reinforcement content, mainly because wear debris filled the gaps between abrasive surfaces during sliding.
4. An increase in avocado reinforcement volume fraction led to a reduction in the coefficient of friction, indicating improved tribological behavior.
5. Mechanical characterization showed that reinforcement percentage and mixing method strongly influenced composite performance. Sample S8, containing 30% avocado particle reinforcement and mixed for one hour using a magnetic stirrer, exhibited the highest compressive strength, maximum impact energy absorption, highest tensile strength, and maximum hardness value of 150.8 HV.
6. Overall, the composite containing 30 wt.% reinforcement showed better mechanical performance than the 10 wt.% and 20 wt.% reinforced composites.
7. Water absorption analysis indicated that Sample 7 exhibited the highest moisture uptake, reaching 1.7% before 10 days of immersion. This was attributed to higher reinforcement content and poor homogeneity caused by manual mixing for only 10 minutes. After 10 days, the specimen reached equilibrium and no further change in water absorption was observed.

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