Experimental Study on the Effect of vol% of Avocado Seed Particulate with 5 vol% Boron Carbide Reinforced Epoxy Composites on Mechanical & Physical Properties

By:

Rediet Belihu Kibkabe

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of

Master's in Manufacturing Engineering

Office of Graduate Studies

Adama Science and Technology University

Jun, 2024 G.C.

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DECLARATION

I hereby declare that this Master Thesis entitled "Experimental Study on the Effect of vol% of Avocado Seed Particulate with 5 vol% Boron Carbide Reinforced Epoxy Composites on Mechanical & Physical Properties" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Rediet Belihu	________________	________________
Name of the student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Experimental Study on the Effect of vol% of Avocado Seed Particulate with 5 vol% Boron Carbide Reinforced Epoxy Composites on Mechanical & Physical Properties" prepared under my guidance by Rediet Belihu Kibkabe submitted in partial fulfillment of the requirements for the degree of Masters of Science in Manufacturing Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Kiran Shahapurkar	____________________	______________
Advisor	Signature	Date

APPROVAL

I, the advisor of this thesis entitled “Experimental Study on the Effect of vol% of Avocado Seed Particulate with 5 vol% Boron Carbide Reinforced Epoxy Composites on Mechanical & Physical Properties” developed by Rediet Belihu Kibkabe, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Kiran Shahapurkar	________________	____________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Rediet Belihu Kibkabe have read and evaluated the thesis entitled “Experimental Study on the Effect of vol% of Avocado Seed Particulate with 5 vol% Boron Carbide Reinforced Epoxy Composites on Mechanical & Physical Properties” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

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ACKNOWLEDGMENT

First and foremost, I would like to express my profound gratitude and admiration to the All-Powerful God and the Holy Virgin Mary for their constant blessing and grace, which have been instrumental in the successful completion of my thesis work. I am sincerely thankful to my advisor, Dr. Kiran Shahapurkar, whose guidance, encouragement, understanding and support have been invaluable throughout this journey. It has been a tremendous honor to have the opportunity to study under his wise counsel.

I would also like to extend my heartfelt appreciation to Dr. Venkatesh Chenrayan, my colleagues, and fellow students for their unwavering encouragement and valuable suggestions. Their insights have greatly enriched my research and contributed to its overall quality. I am grateful to Mr. Sintayehu Legesse, the head of the Mechanical Engineering Department, and the lab assistants of the Material Engineering Department for their assistance in facilitating and providing the necessary equipment during the experimental procedures.

Moreover, I am deeply indebted to my family for their unwavering support, prayers, and sacrifices. Their constant presence and belief in me have been a source of strength and motivation, enabling me to overcome challenges and prepare for the future.

Lastly, I extend my sincere thanks to all those who have contributed to the completion of this thesis work. Your contributions, whether big or small, have played a crucial role in the successful culmination of this endeavor. I am truly grateful for your support and collaboration throughout this research journey.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASP	Avocado Seed Powder
ASTM	America Society for Testing and Material
AVS	Avocado Seed Starch
CCHPRC	Coir-Coconut Husk Powder Reinforced Composite
CDA	Cow Dung Ash
CM	Composite Material
CMC	Ceramic Matrix Composite
CSP	Coconut Shell Particulate
EDS	Energy Dispersive X-ray Spectrometer
ER	Epoxy Resin
ESA	Egg Shell Ash
ESP	Egg Shell Powder
FRC	Fiber Reinforced Composite
FTIR	Fourier Transform Infrared Spectroscopy
HV	Vickers Hardness Number
JF	Jute Fiber
MFC	Micro-Fibrillated Cellulose
MMCs	Metal Matrix Composite
NFRPC	Natural Fiber Reinforced Polymer Composite
PMCs	Polymer Matrix Composite
PRPCs	Particle Reinforced Polymer Composite
PVA	Poly Vinyl Alcohol
RPC	Reinforced Polymer Matrix
RTM	Resin Transfer Molding

SCBA	Sugar Cane Bagasse Ash
SEM	Scanning Electron Microscope
SSA	Sub-Saharan Africa
UTM	Universal Testing Machine
WSP	Walnut Shell Particulate
XRD	X-Ray Diffraction

NOMENCLATURE

E_{fm}	Flexural modulus
E_t	Tensile Modulus
M_{ASP}	Mass of Avocado Seed Powder
M_{B4C}	Mass of Boron Carbide Powder
M_{Epoxy}	Mass of Epoxy Resin
M_c	Mass of Composite
V_{ASP}	Volume of Avocado Seed Powder
V_{B4C}	Volume of Boron Carbide
V_C	Volume of Composite
V_{Epoxy}	Volume of Epoxy Resin
V_{asp}	Volume of pumice powder
V_m	Volume of matrix
V_v	Void Content
W_a	Weight of the sample after soaking in water
W_b	Weight of the sample before soaking in water
m_a	Mass of sample in air
m_w	Mass of sample in water
ρ_{ASP}	Density of Avocado Seed Powder
ρ_{B4C}	Density of Boron Carbide Powder
ρ_{Epoxy}	Density of Epoxy Resin
ρ_a	Actual density
ρ_a	Actual density of composites
ρ_{asp}	Density of avocado seed powder

ρ_c	Density of Composite
ρ_m	Density of matrix
ρ_t	Theoretical and
ρ_t	Theoretical density
ρ_w	Density of water
σ_I	Impact strength,
σ_c	Compression Stress
σ_f	Flexural stress
σ_t	Tensile Strength
σ_t	Tensile Stress
HV	Vickers Hardness
A	Cross-sectional Area
E	Energy absorbed
F	Applied Force
S	Support span
$W\%$	Percentage of Water Absorption,
d	Arithmetic Mean
m	The slope of the load
ε	Tensile strain

ABSTRACT

The increasing demand for environmentally friendly, lightweight, stiff, and durable products in today's world has spurred the development of natural filler reinforced polymer composites. In this study the composites were fabricated using open mold casting method to determine effect of vol% of avocado seed powder and B_4C on the characteristics of bio-composite. Epoxy resin was used as the matrix, while boron carbide powder (particle size=75micron) and avocado seed powder were employed as reinforcing materials. Five samples were created by varying the volume percentage of avocado seed powder (0, 5, 10, and 15 vol.%) while keeping the boron carbide (B_4C) powder constant at 5 vol.%. The highest recorded tensile strength, flexural strength and compressive strength were 50.22 MPa, 74.74 MPa, and 99.56 MPa, respectively, achieved with 15 vol.% avocado seed powder and 5 vol.% B_4C . The maximum impact strength observed at 34.5 kJ/m2 with neat epoxy composite. The largest hardness of 34.26 HV was obtained with 15 vol.% avocado seed powder and 5 vol.% B_4C . The minimum water absorption rate (0.17%) was achieved with 10 vol.% avocado seed powder and 5 vol.% B_4C. Additionally, a smaller void content was observed at 5 vol.% avocado seed powder and 5 vol.% B_4C .

Keywords: *Composite, Natural fibers, Hardness, Avocado seed powder, Boron Carbide*

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Materials play a crucial role in various applications, including structural and nonstructural, electrical, electrochemical, biological, biomedical, thermal, and more. Their purpose is to enhance human productivity and improve living conditions. However, the growing awareness of environmental issues such as global warming, waste management, diminishing fossil fuel reserves, and escalating oil prices has spurred a need for novel materials that are environmentally friendly, lightweight, strong, and economically viable. As a result, there is a rising emphasis on promoting green products to support sustainable development (Bakri *et al*., 2017).

Throughout human history, composite materials have held important significance, serving as essential components in early civilizations' housing and paving the way for future innovations. The advantages offered by composites are numerous, with notable characteristics including corrosion resistance, design flexibility, durability, lightweight nature, and strength. These composites have become deeply ingrained in our daily lives, finding applications in diverse sectors such as construction, medical fields, oil and gas industries, transportation, sports, aerospace, and numerous others (Abramovich, 2017).

The scientific community is increasingly focusing on agricultural waste and forestry-derived natural fiber-reinforced polymer composites, surpassing the interest in synthetic fiber-reinforced composites (Faruk *et al*., 2012). These materials, commonly known as bio-composites or green composites are eco-friendly materials that utilize natural fibers or fillers as reinforcement within a matrix. Depending on the type of fiber reinforcement and matrix used, they can be either fully or partially composed of bio-based materials. Natural fibers and fillers offer several advantages, including affordability, degradability, manageability, recyclability, and renewability (Bakri *et al*., 2017).

The avocado (Persea Americana) is a member of the Lauraceae family, known for its tropical and Mediterranean trees and shrubs. It has been cultivated in Mexico, Central America, and South America for thousands of years and continues to be popular today. The avocado is not only valued as a food source but has also been used for medicinal purposes and treating skin conditions due to its high nutritional content and therapeutic properties (Punia *et al*., 2022). This fruit is a rich source of carbohydrates, proteins, fibers, essential micronutrients, polyphenols, fats, oils, vitamins, and minerals, making it highly sought after for human consumption. Its consumption is particularly beneficial for heart health and maintaining a healthy circulation system due to the presence of unsaturation lipids (Djonny *et al*., 2020). Avocado fruits have an olive-green peel and thick, pale-yellow pulp that contains various fatty acids such as linoleic, oleic, palmitic, stearic, linolenic, capric, and myristic acids. While primarily used for human consumption, avocados have also been employed as a medical plant in Mexico and other parts of the world (Saad-aldeen, 2022).

The seed of the avocado constitutes approximately 13-18% of the fruit and is typically considered a byproduct that is often discarded during pulp processing. However, it holds potential value to the industry as a source of bioactive compounds (Tesfaye *et al*., 2022). According to (Faris, 2016) the total cultivated area for avocado in Ethiopia is 8938.24 hectares and production of 256331.64 quintals, more area coverage is expected in the south-western and other parts of the country due to more conducive climatic and edaphic factors.

1.2 Composite Materials

Composite materials are composed of two or more components, with the interface between them playing a crucial role. The components typically consist of a reinforcement phase and a matrix phase, often referred to as the reinforcing phase and the matrix phase, respectively. Additionally, the interface formed between the reinforcing phase and the matrix phase is recognized as the interface of composite materials due to its unique structure and composition

1.2.1 Classification of Composite Materials

Composite materials can be classified into many categories depending upon the matrix phase and reinforcing phase.

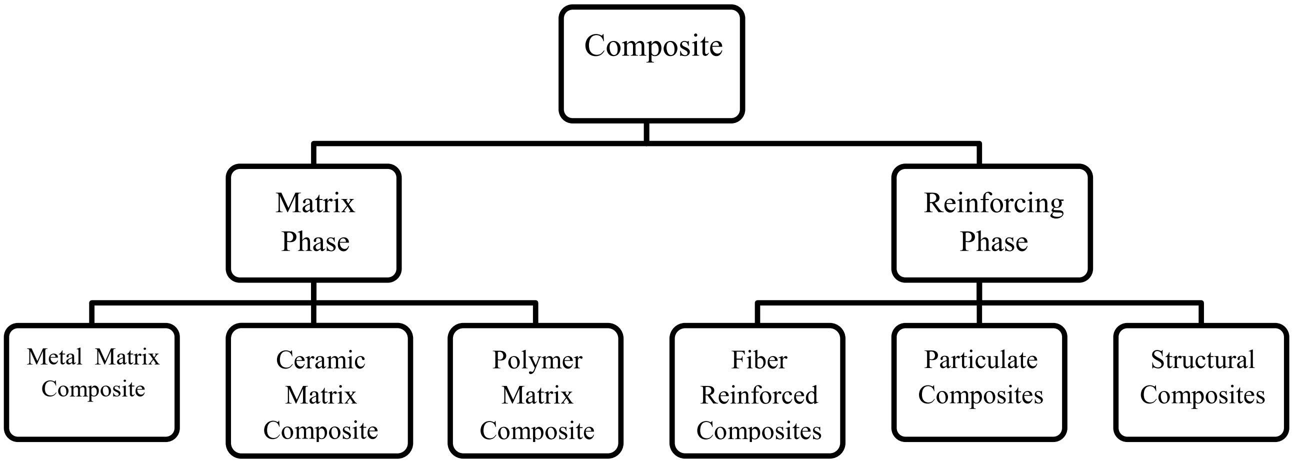


Figure 1.1: Classification of composites (Saleh, 2018)

A. Matrix Phase

The matrix phase, also known as continuous phase, is a cohesive material that envelops the reinforcing phase and exhibits relatively soft and tough characteristics. One of the primary roles of the matrix phase is to provide support and protection to the reinforcing phase. When composite materials are subjected to external loads, the matrix phase primarily undergoes shear deformation, enhancing the distribution of phases and facilitating load transfer (Hihara & Bakkar, 2016).

I. Metal Matrix Composites

Metal–matrix composites (MMCs) are a type of material where metals are reinforced with fibers or particles, aiming to enhance or customize specific properties such as stiffness, strength, thermal conductivity, thermal expansion, friction, and wear resistance. These composites are renowned for their lightweight nature and high-specific strength, making them highly valuable in various industrial sectors, particularly automotive, aerospace, and thermal management. The characteristics of MMCs are determined by the reinforcement material, the matrix material, and the interface between them, playing a critical role in shaping the overall properties of these composites (Hihara, 2016).

II. Ceramic Matrix Composites

Ceramic matrix composites (CMCs) are composed of a ceramic matrix with dispersed ceramic phases such as carbides or oxides. CMCs hold great promise for applications that involve high temperatures due to their remarkable resistance to corrosion, exceptional compressive strength, enhanced resistance to thermal shocks, higher melting points, improved capability for bearing dynamic loads, and stability at elevated temperatures (exceeding 1500°C) (Hihara, 2016).

III. Polymer Matrix Composites

A polymer matrix composite (PMC) is a type of composite material that consists of a combination of short or continuous fibers embedded in an organic polymer matrix. PMCs are specifically engineered to effectively transfer loads between the fibers and the matrix. These composites offer several advantages, including their lightweight nature, high stiffness, and better strength along the direction of the reinforcements. Additionally, PMCs demonstrate good abrasion resistance and corrosion resistance, further enhancing their overall performance.

Composites commonly utilize polymers, which can be classified as thermoplastics polymers, thermosetting polymers, or elastomers. Polymers, derived from a diverse range of cost-effective raw materials, offer numerous advantages. These include a low specific weight, enhance resistance to corrosion, improved electrical and thermal insulation properties, ease of shaping, efficient mass production, and attractive optical properties such as fiber optics and glazing applications. However, polymers also have some significant drawbacks. These include poor mechanical stiffness and strength, limited heat resistance, susceptibility to aging, and combustibility (Abramovich, 2017).

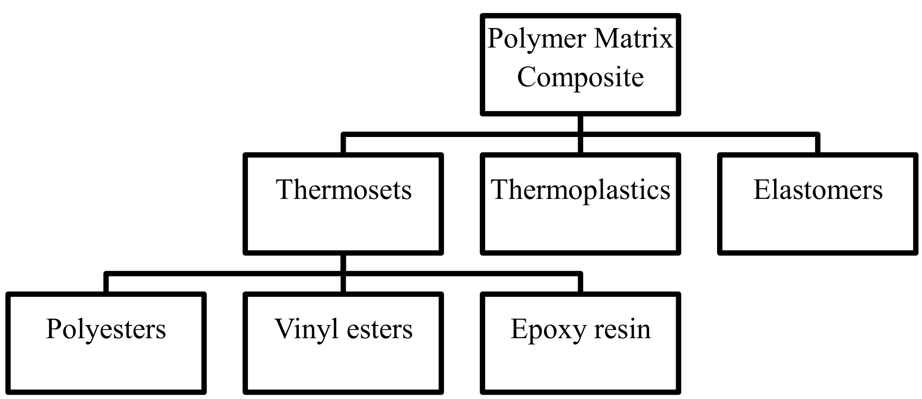


Figure 1.2: Classification of polymer matrix composites (Shalwan & Yousif, 2012)

a) Thermosets

The most common matrix for PMCs; is cheaper than thermoplastics. Higher stiffness is advantageous. In order of increasing performance, and cost (Ngo, 2020):

Polyesters: Unsaturated polyesters have the ability to undergo cross-linking in the presence of accelerators, resulting in the formation of a rigid structure. However, the use of unsaturated polyesters may have certain limitations, as the curing process can release styrene (Ngo, 2020).

Vinyl esters: Polyamides exhibits significantly superior mechanical properties and environmental resistance compared to polyesters. However, it is important to note that polyamides are generally more expensive than polyesters (Ngo, 2020).

Epoxy resin: Typically, these materials are created by blending two liquid components, a resin and a hardener. The polymer undergoes curing through the formation of chemical cross-links between its chains. This curing process imparts desirable mechanical properties such as strength, toughness, and high modulus, along with excellent environmental resistance. However, it is worth noting that these materials tend to be more expensive compared to other options (Ngo, 2020).

b) Thermoplastics

Conventional thermoplastic processing techniques can be employed to manufacture short-fiber composites. These composites offer a greater potential for high-grade recycling and feature a tougher matrix. Moreover, parts made from short-fiber composites can be joined together through welding, utilizing heat and pressure. Example of short-fiber composites include PEEK (poly-ether-ether ketone) and PES (poly-ether-sulphone), which are known for their high cost and high-performance characteristics when combined with carbon fiber or aramid. Another example is polypropylene with chopped glass fiber, which is commonly used in low-load automotive applications. Additionally, nylon with chopped glass fibers is utilized in electrical and automotive parts (Bîrca *et al*., 2019).

Applications of Polymer Matrix Composite

- Automotive industry
- Aircraft and aerospace industry
- Marine
- Sports goods
- Biomedical applications

B. Reinforcing Phase

The reinforcing phase in composite materials refers to the filament (continuous or chopped), flake, or granular material with exceptional strength, modulus, hardness, and brittleness. It serves as the primary load-bearing phase when the composite materials are subjected to external forces. These reinforcing materials are dispersed within the composite and are surrounded by the matrix, earning them the name of dispersed phases (A. K. Sharma *et al*., 2020).

i. Fiber Reinforced Composite (FRC)

Fiber –reinforced composites (FRC) comprise of fibers embedded within matrix materials. These composites can be categorized as either discontinuous fiber composites or short fiber composites if the composite properties are influenced by the length of the fibers. On the other hand, when the length of the fibers reaches a point where further increases do not yield additional improvements in the composite's elastic modulus, it is classified as a "continuous fiber reinforced" composite. The fibers used in FRC are typically characterized by their small diameter and exhibit excellent tensile properties. However, they are prone to twisting when subjected to axial pressure, necessitating reinforcement to prevent bending and bucking of individual fibers (Saleh, 2018).

ii. Particulate Composite

Particulate composite are composite materials where particles are dispersed or embedded within a matrix material. These particles can take the form of flakes or powders. Concrete and wood particles boards are widely recognized and familiar examples of particulate composites (Saleh, 2018).

iii. Structural Composite

Structural composites are multi-layered composites with typically low density, designed for applications that demand structural integrity and high tensile, compressive, and torsional strengths and stiffness. The properties of these composites are influenced not only by the characteristics of the constituent materials but also by the geometrical design of the structural elements. Laminar composites and sandwich panels are among the most prevalent types of structural composites (Saleh, 2018).

1.3 Statement of Problem

The processing of avocados results in byproducts, particularly the avocado seeds, as most industrial applications primarily utilized the pulp. With an annual production of 5 million tons, avocados are ranked as the fourth most important tropical fruit globally. In Ethiopia, the annual avocado production is approximately 25,633 tons (Mokria *et al.*, 2022). However, the non-edible parts pose a challenge for juice shops and contribute to a significant biomass waste issue throughout the country. The increasing demand for avocados leads to higher production due to their numerous benefits. Nevertheless, this trend presents a potential problem as the waste generated can result in ecological issues by decomposing and releasing methane which is a potent greenhouse gas that contributes to climate changes. Additionally, if not properly disposed of, avocado waste can attract pests and rodents, and pollute soil and water sources through leaching. It also cause economic losses due to the high costs associated with transporting and disposing of the waste materials.

Therefore, incorporating avocado seeds as an alternative for composite materials in aesthetic parts of automotive can have a significant impact on the manufacturing sector by reducing costs and biomass waste. Furthermore, this approach brings economic benefits to juice producers. As a result, the objective of this thesis is to investigate the use of avocado seed power as a reinforcing material, combined with B_4C (boron carbide) and a polymer matrix, to enhance its organic nature, abundance, biodegradability, and desirable properties

1.4 Objectives

1.4.1 General Objective

The general objective of this thesis is to evaluate avocado seed powder and B_4C reinforced with epoxy matrix composite by using open mold casting process for automobile brake pad application.

1.4.2 Specific Objective

- ❖ Fabricate avocado seed powder and B_4C reinforced epoxy composite through open mold casting method.
- ❖ Determine the effect of volume percentage of avocado seed powder and B_4C on the characteristics of bio-composites.
- ❖ Investigate the physical properties in-terms of density and void content.

- Investigate mechanical properties in-terms of impact, tensile, compression, flexural and water absorption properties.
- Characterize the structure property correlations using scanning electron microscopy.

1.5 Scope of the Study

This thesis paper is delimited to:

- Synthesis of composite material with varying volume percentage of avocado seed powder and B_4C particle.
- Focus on testing of mechanical property of composite for aesthetic parts of automobiles.
- Testing of the composite with available equipment/machines as per ASTM D-638-14, ASTM D90-17, ASTM D695-15, ASTM D-256, ASTM D-792, standards.
- Non availability of nano-particles and epoxy resin supply in Ethiopia can be mentioned as limitation.

1.6 Significance of the Study

- Avocado seeds are biodegradable, easily available, and low cost and this gives an advantage of utilizing in several types of composites for various applications.
- Introducing new alternative material for aesthetic parts of automobiles.
- Economic benefits for the community.
- Waste utilization.

1.7 Organization of the Thesis

The organization of the thesis had been done as follows. Chapter one includes introduction in which the background, statement of problem, objectives, scope of the study, significance of the study and limitations were described. Chapter two includes the literature survey, a summary of the literature, and the research gaps. Chapter three covers the material and methods, which include the fabrication and characterization of mechanical and physical properties whereas chapter four deals with the results and discussion. Chapter five comprises the conclusion and recommendation. The interpretations of the obtained results were analyzed and recommendation and future work was directed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive literature analysis of particle-reinforced epoxy/polymer matrix composites. A review of the literature is provided, which includes information about particulate polymer-based composites. The chapter offers a critical review of previous research conducted on this topic, providing valuable guidance for the current study. Additionally, this chapter covers the examination of previous research papers.

- Natural particulate and mechanical properties of natural particulate polymer composites
- Avocado seed particulate and mechanical properties of avocado seed particulate reinforced polymer composites
- Mechanical and physical properties of B_4C filled reinforced polymer composites
- Behavior of natural particulate reinforced polymer composites for application of brake pad
- Manufacturing techniques of polymer composites

2.2 Natural Particulate and Mechanical Properties of NPPC

In the earlier times, only synthetic fiber/particulate based reinforced composites were used due to low cost and good mechanical properties. These composites use the glass fiber or carbon fiber as reinforcement for composite materials. In the modern time, sustainability is the major concern of all the research. For sustainable development, there is a great need as well as challenge for every industry to replace the non-sustainable products with the sustain able ones. Also, because of the limited amount of conventional energy resources and rising environmental concerns, we have got to shift towards the renewable raw materials for the development of new components. Owing to the above reasons, it leads to the replacement of synthetic fibers/particulates with natural fibers/particulates as reinforcement in fiber/particulate reinforced composites. Other than this, natural fibers/particulates also have many benefits such as low relative density, low cost, high impact resistance, and high flexibility, low specific gravity, less abrasiveness to equipment, less health hazards, process-friendly, lower greenhouse emissions, recyclability and CO2 neutral. Hence natural fiber/particulate reinforced composite is safe for environment. Natural fiber/particulate-based composite is extensively used in automotive applications. This is due to their light weight which leads to lesser fuel consumption and reduced emissions of harmful gases (Kerni *et al*., 2020).

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. From the results of the experiments addition of the fillers such as egg shell powder has maximum impact on the hardness and the moisture absorption characteristics of the fiber reinforced polymer composites. 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. The maximum mechanical properties were observed for 25% mass fraction of coffee bean natural filler composite. The fracture toughness increases with incorporation of coffee bean filler, due to uniform distribution of coffee bean in epoxy matrix and stress was disseminated equally. 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. Exposure periods of 3, 6 and 9 days (3PA, 6PA, 9PA) were considered, while samples not exposed to the acid solution were used as control (NP). In order to measure the surface degradation and hardness variation due to immersion in the acid solution, scanning electron microscopy, energy dispersive spectroscopy (SEM/EDS), and hardness tests were carried out. 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. Hand-layup approach is adopted for fabricating the polymer composite and the samples are tested for their mechanical properties viz., impact, flexural and tensile strength. 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.

Pramod Kumar *et al*., (2023) studied, effect of mechanical properties of composites of teak wood and tamarind kernel as reinforced particulates with polyester resin. This work analyzed the mechanical behavior of different type of combination of composite material, with different tests such as tensile test and flexural bend test. Finally, it is reported that more value in the combination of tamarind dust on flexural bend test.

Ajithram *et al*., (2023) investigated the absorption properties of a polymer composite material made from water hyacinth (Eichhornia crassipes) natural plant powder materials, especially for false ceiling applications. In order to create composite samples, it is combined with an epoxy polymer matrix, and the powder particles are used as a part of the compression molding process. A composite sample with high hardness strength was obtained in which 30% of hyacinth fiber and 5% of moringa filler powder were used. This combination achieved a Shore D hardness value of 98 in the composite sample. Based on the results of the water and chemical absorption studies, filler material can increase the level of absorption resistance of composite samples (15% for water and 25% for chemical) by a significant amount.

Ashok Kumar *et al*., (2022) investigated the mechanical characteristics of raw jute fiber-based epoxy composites and hybridized epoxy composites incorporating jute fiber (JF) and powdered egg shell (PES) based bio-filler. The ESP was used in different compositions such as, 3%, 6%, 9%, and 12% with the JF reinforced epoxy composite. The findings indicate the viability of hybridizing the epoxy composites with this new composition of materials. The addition of 9% PES bio-filler increased tensile characteristics, flexural strength, and Shore D hardness by 73.83, 50.17, and 21.43 percent, respectively. The inclusion of PES above 9% in JF epoxy composite was not impressive and hence, it is recommended to use 9% ESP in JF/ESP Epoxy hybrid composites.

R. Sharma & Sharma, (2023) focused on the selection of argo waste Coconut shell particulate (CSP)/Walnut shell particulate (WSP) fillers due to their light weight, biodegradability, low density, abundant availability, and easy process-ability. In a controlled laboratory environment, the impact of different weight percentages of CSP/WSP (argo waste) particles (2.5, 5.0, 7.5, 10.0, 12.5, and 15.0 wt%) loaded into epoxy resin (LY 556) using a molding process was investigated. It is observed from experimental work that the dimensional stability of CSP/WSP (1:1) reinforced epoxy-based composites is better at 2.5 wt% of particulates.

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.

2.3 Avocado Seed Particulate and Mechanical Properties of Avocado seed Particulate RPC

The processing industry discards avocado seeds, which increases production and ultimately pollutes the environment. It would be advantageous to handle these waste by-products both economically and environmentally. Avocado (Persea americana Mill.) crop is cultivated and highly demanded internationally because of the growing demand for fruit and food products. It is a dicotyledonous plant that belongs to the flowering plant family Lauraceae, a native of Central America and Mexico. Generally, avocado seeds are discarded, considering them a waste by-products of avocado processing industries. This by-product has not been used significantly, causing serious environmental pollution. Effective waste by-product management would benefit from an economic and environmental perspectives. Seeds of avocados represent a substantial percentage (13 %–17 %) of the avocado fruit and are rich in various functional and bioactive components, namely polysaccharides, proteins, lipids, minerals, and vitamins. Avocadoes have four basic parts.

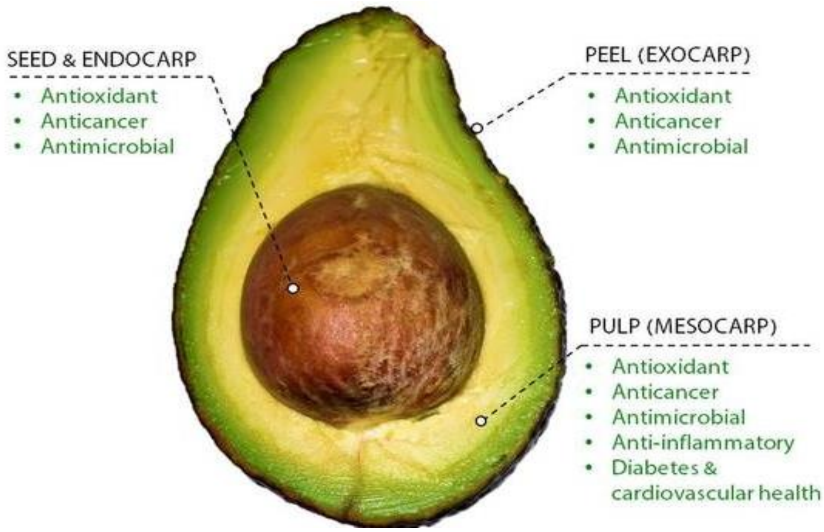


Figure 2.1: Basic parts of avocado (Punia *et al*., 2022)

I. The Exocarp

The exocarp of an avocado is commonly referred to as the skin. Depending on the type of avocado, the skin color and thickness will vary. For example, Gwen avocados have green skin that is thick with a pebbled apperance while Zutano avocados have thin skin that is yellow-green and shiny. The exocarp of certain avocados may also chane in apperance as the fruit ripens. Hass avocados start with green skin that darkens to a purple-black color when ripe. The Fuerte avocado, which has thin green skin does not change in apperance when ripe (Punia *et al*., 2022).

II. The Mesocarp

The mesocarp is also known as the flesh of the avocado, and this is the edible and most abundant part of the fruit. The flesh of the fruit also varies in apperance depending on the variety of avocado. The Bacon variety of avocado has flesh that is a greenish-yelow, while the Pinkerton variety has pale, creamy green flesh. The Zutano avocado has flesh that is light in texture with pale green color (Punia *et al*., 2022).

III. The Endocarp

The endocarp is the thin inner layer of the avocado and its seed. It is often difficult to differentiate the endocarp from the flesh of the avocado fruit. When the seed is ripe, the endocarp may appear to be a film over it, giving it a frosty or whitish appearance (Punia *et al*., 2022).

IV. The Seed

At the center of the avocado is its seed. It is the seed that makes the avocado fruit as opposed to a vegetable and it can vary in size from small to large. The variation in seed size are dependent on the type of avocado. The Pinkerton, which is a winter variety avocado, has a small seed at its core. Reed avocados, a summer variety, and Lamb Hass, which is a California summer variety, both have medium seeds. The mid-winter variety Bacon avocado has a medium to large seed (Punia *et al.*, 2022).

Avocados are good source of Vitamin K, dietary fiber, Vitamin B6, Vitamin C, Folate and copper. It is also a good source of potassium: they are higher in potassium than a medium banana. avocado also contains essential nutrients such as carbohydrates, sugar, soluble and insoluble fiber, avocado is also good source of oil containing monounsaturated fat its oil contents vary depending on its varieties and the period of extraction of oil by cold-press process. avocado is a rich source of mineral. When ripe the color of the skin is purplish black, the edible flesh of the fruit constitutes 65%, seed is 20% and the skin is 15% which makes up the total weight of the fruits. Although they are fruits, avocados have a high fat content of between 71 to 88% of their total calories about 20 times the average for other fruits. High avocado intake has been shown to have a beneficial effect on blood serum cholesterol levels. About 75% of an avocado's calories come from fat, most of which is monounsaturated fat. They are rich in B Vitamins, as well as Vitamin E and Vitamin K. They have high fiber content among other fruits - including 75% insoluble and 25% soluble fiber. A fatty triol (fatty alcohol) with one double bond, avocadene (16-heptadecene-1-2-4-triol), is found in avocado (Orhevba *et al*., 2011).

- Nutritional content of avocado is listed below

Composition	Values
Ash content	1.52%
Moisture content	77.72%
Protein content	0.94g
Fat (lipid) content	12.18g
Crude fibre content	6.90g
Carbohydrate content	7.4g
Protein content	0.94g

Figure 2.2: Nutritional content of Avocado (Bangar *et al*., 2022)

Hass avocado is composed mainly of hemicellulose, cellulose, and lignin, with percentages around 44, 11 and 13% for seeds, and 11.5–25.3, 12.1–27.6, and 4.4–35.3% for skin, respectively (Alvarez & Raquel, 2023). Chemical composition of natural fiber effects the properties of natural fiber reinforced composites. Cellulose content in natural fiber determines the mechanical properties of that fiber which in turn effects the properties of natural fiber reinforced composite (Jaafar *et al*., 2018). Amount of hemicellulose and lignin also effects the properties of natural fibers. Large amount of hemicellulose and lignin in natural fiber is not desirable as it leads to high moisture absorption and biodegradation of fiber (Alsubari *et al*., 2021). For developing the composite with good mechanical properties, we have to use the natural fiber having high cellulose content and low hemicellulose and lignin content. Physical properties such as length and diameter of natural fiber also influence the mechanical properties of composite (Shalwan & Yousif, 2012). Natural fibers having small diameter have more positive impact on mechanical properties than large diameter fibers. If length of fiber is less than the critical length, it leads to the decrease in the stress transfer efficiency between fiber and matrix that results in poor mechanical properties (Ku *et al*., 2011). Percentage of fibers is also an important factor for mechanical properties of composites. Increase of high strength fiber content results in enhancement of mechanical properties. But if content of high strength fiber increases beyond optimum value, it may lead to deterioration of mechanical properties. This is because of the reason that with increasing fiber content, matrices composition is reduced which leads to weaker interfacial bonding between matrix and composite (Kerni *et al*., 2020).

Acquavia *et al*., (2023) fabricated reinforced films by impregnating paper in ethyl cellulose solutions. To prepare active films, avocado by-products from guacamole industrial production were extracted in ethyl acetate. Then, the extract (optimized to be rich in phenolic compounds and flavonoids and mainly composed by lipids) was incorporated to the paper reinforced with the highest content of ethyl cellulose. As a result, the addition of the avocado by-products extract decreased the water uptake and permeability, improved the wettability, and increased the biodegradability in seawater and the antioxidant capacity.

Aguilar & Tapia-Blácido, (2023) prepared composite foam trays based on cassava starch containing different avocado seed (AS) concentrations (0, 5, 10 and 15 % w/w) by thermo pressing. Composite foam trays with AS were colorful because this residue contains phenolic compounds. The composite foam trays 10AS and 15AS were thicker (2.1–2.3 mm) and denser (0.8–0.9 g/cm3), but less porous (25.6–35.2 %) than cassava starch foam (Control). High AS concentrations yielded composite foam tray less puncture resistant (~40.4 N) and less flexible (0.7–0.9 %), but with tensile strength values (2.1 MPa) almost similar to the Control. The composite foam trays were less hydrophilic and more water resistant than control due to the presence of protein, lipid, and fibers and starch with more amylose content in AS. High AS concentration in composite foam tray decreases the temperature of thermal decomposition peak corresponding to starch. At temperatures >320 °C the foam trays with AS were more resistant to the thermal degradation due to the presence of fibers in AS. High AS concentrations delayed the degradation time of the composite foam trays by 15 days.

Eduarda *et al*., (2020) studied the evaluation of efficiency of avocado seed powder (Persea Americana) as inhibitor on the corrosion of SAE 1008 carbon steel in acidic medium (HCl 0.5 mol. L-1). The avocado seed powder was obtained from milling and sieving at 170 mesh. Different concentrations (0.44 g L-1;0.77 g L-1; 1.11 g L-1; 1.44 g L-1; 1.77 g L-1) of avocado seed powder were added in HCl solution. The efficiency of the inhibitor was measured by electrochemical impedance spectroscopy (EIS) and potecio dynamic polarization curves, as well as gravimetric tests. The chemical characterization of the inhibitor was performed by Fourier transform infrared spectroscopy (FTIR), while the morphological characterization was obtained by optical microscopy. The FTIR characterization reveals the presence of compounds formed by heteroatoms prevent the corrosion process. The results showed that the tendency of this inhibitor is to increase the corrosion resistance as the concentration of the inhibitor also increases, revealing that the inhibitor is a promising alternative when it comes to avoiding corrosive processes on the surface of the SAE 1008 carbon steel.

Fu, (2020) developed avocado seed starch (AVS) as resin for green composites by using a green cross-linker, 1,2,3,4-butane tetracarboxylic acid to prepare a rigid thermoset resin. Two cellulose fiber reinforcements, micro-fibrillated cellulose (MFC) with average diameter of 50 nm and a common weed velvet leaf stem-derived microfibers (VLF) with average diameter of 12 μm, were used by solution casting method. MFC/AVS and VLF/AVS green composites were characterized for tensile, thermal, and dynamic mechanical properties and water absorption. Results showed that mechanical properties of VLF/AVS composites were comparable to MFC/AVS composites at same volume fraction. The tensile strength, fracture strain, and Young's modulus of AVS composites with 30% VLF microfibers and 15% sorbitol (plasticizer) were 27.8 MPa, 10.2%, and 1614 MPa, respectively. Both strength (36.7 MPa) and Young's modulus (2303 MPa) increased significantly with 40% VLF fiber content. Good reinforcement by VLF microfibers was realized due to its high aspect ratio and good dispersity in AVS matrix.

Alemu *et al.*, (2022) extracted avocado seed starch to prepare a biodegradable plastic biofilm with enset pseudo-stem cellulose and glycerol plasticizer. The characterizations were made in detail. The results showed that avocado starch/cellulosic blend-based biodegradable plastic film can be an alternative for bioplastic applications.

2.4 Mechanical and Physical Properties of B_4C filled RPC

Boron Carbide is one of the hardest ceramic materials in existence. This Boron-Carbon substance ranks only after diamond and cubic Boron Nitride in the list of hardest materials. It is sometimes called the "Black Diamond" for its extreme hardness (Kuliiev, 2020).

Originally discovered in mid-19th century as a by-product in the production of metal borides, boron carbide was only studied in detail since 1930. Boron carbide powder is mainly produced by reacting carbon with B_2O_3 in an electric arc furnace, through carbothermal reduction or by gas phase reactions. For commercial use B_4C powders usually need to be milled and purified to remove metallic impurities. As an alternative, B_4C can be formed as a coating on a suitable substrate by vapor phase reaction techniques (Kuliiev, 2020).

Properties of Boron Carbide Powder

It is a black powder in its normal physical state. It is odorless and insoluble in water. Boron carbide is characterized by its:

- Extreme hardness
- Difficult to sinter to high relative densities without the use of sintering aids
- Good chemical resistance
- Good nuclear properties
- Low density

The physical and mechanical strength values of boron carbide (Kuliiev, 2020):

Table 2.1: Properties of B4C

Density (gm/cc)	2.52
Melting point	2445
Porosity (%)	<0.5
Flexural strength (MPa)	480±40
Youngs Modulus (GPa)	450-470
Poisons ratio	0.18
Electrical Conductivity (at 25°C) (S)	140
Hardness (Kg/mm^2)	2900-3580
Fracture Toughness ($MPa * m^{\frac{1}{2}}$)	2.9-3.7
Thermal Conductivity (at 25°C)($W/m * °K$)	30-42
Coefficient of Thermal Expansion ($10^{-6}/$℃)	4.8

Applications

- ✓ **Abrasives:** Due to its high hardness, boron carbide powder is used as an abrasive in polishing and lapping applications, and also as a loose abrasive in cutting applications such as water jet cutting. It can also be used for dressing diamond tools.
- ✓ **Nozzles:** The extreme hardness of boron carbide gives it excellent wear and abrasion resistance and as a consequence it finds application as nozzles for slurry pumping, grit blasting and in water jet cutters.

- ✓ **Nuclear applications**: Its ability to absorb neutrons without forming long lived radio-nuclides make the material attractive as an absorbent for neutron radiation arising in nuclear power plants. Nuclear applications of boron carbide include shielding, and control rod and shut down pellets.
- ✓ **Ballistic Armour:** Boron carbide, in conjunction with other materials also finds use as ballistic armour (including body or personal armour) where the combination of high hardness, high elastic modulus, and low density give the material an exceptionally high specific stopping power to defeat high velocity projectiles.
- ✓ **Other Applications:** Other applications include ceramic tooling dies, precision toll parts, evaporating boats for materials testing and mortars and pestles.

Vaidya & Rangaswamy, (2021) identified tensile & flexural characteristics of Boron Carbide (B_4C) filled E-Glass/Epoxy composite with and without application of low temperature. Hand lay-up technique was used for fabricating two batches of test specimens and one batch was treated to -60$°C$ temperature treatment. One batch of specimens involved E-glass/Epoxy composite without B_4C, 5% & 10% B_4C tested at ambient temperature. Additional batch were fabricated with said composition, treated to -60$°C$ for 1hour duration, later tested according to ASTM D3039 and D790. The experiment reveals the improvement in properties of composite material after the addition of B_4C. Additionally implementation of low temperature treatment improved tensile and flexural properties of test specimens.

Madhanagopal & Gopalakannan, (2018) predicted the co-efficient of friction and the wear rate of epoxy composite with B_4C as filler by using pin on disk apparatus in non-lubricated conditions. Three different samples (1%, 2%, 4%) were prepared based on the percentage of filler addition to the epoxy resin. This experimental result was obtained by varying the operating parameters of contact pressure and velocity. This tribological data was obtained for the two constant sliding distances 1198 m and 2402 m respectively. The wear behavior of the material is predicted from the plots drawn for the co-efficient of friction and the wear rate with respect to load (1kg, 2kg and 3kg) and velocity (1m/s, 2m/s) conditions. The result showed that the binding strength drops as the load increases leads to more mass loss. The specific wear rate reaches 2.1(mm3/N-m×10-6) and the corresponding coefficient of friction is 0.38 is for the 2% sample under 3kg load. But for the other samples 1% and 4% they did not prove such appreciable rise in the output magnitude. The mechanical behavior of the material was predicted to support the results.

Mishra *et al*., (2023) Fabricated a novel hybrid polymer composite of cow dung ash (CDA), B_4C micro-particles, and epoxy. Different samples of varying weight percentages of CDA and B_4C from 2% to 5% and 1% to 4% respectively were fabricated. The mechanical properties such as tensile, flexural, impact, and hardness of the fabricated hybrid composite were determined and compared to neat epoxy (0% reinforcement). SEM was used for microstructural analysis of fabricated specimen. The result showed that the mechanical properties reached maximum value when CDA and B_4C were 3% each. The maximum tensile and flexural strength of hybrid composite was 43.38% and 17.956% more than the neat epoxy composite. It was observed that the mechanical properties have increased while adding B_4C -CDA reinforcements.

Singh *et al*., (2021) discovered the influence of eggshell ash (ESA) and boron carbide (B_4C) addition on microstructure and mechanical characteristics of ZA-27 hybrid composites. Six different composites were fabricated utilizing the stir casting technique with different weight percentages varied from 0-5 wt.%. Composites were tested for different mechanical properties. XRD and SEM were utilized for the characterization of composites. ESA particles decreased the composite density by 3.12%, and after the addition of B_4C particles, density was found to be increased but was still lower than the base ZA-27 alloy. The hardness, tensile and compressive strength of the composites increased with the addition of reinforcements. However, composite reinforced with maximum wt.% of B_4C particles showed a decreasing trend. The impact strength of the composites decreased when compared with the base alloy, but the reduction was marginal. Improved hardness, tensile and compressive strength of the composites was attributed to homogeneously dispersed ESA and B_4C particles in the matrix. Higher tensile strength resulted from strong interfacial bonding between reinforcements and metal matrix, and low impact strength was due to brittle failure and plastic deformation.

Tasyurek & Duzcukoglu, (2022) investigated effect of adding boron carbide (B_4C) particles to epoxy resin on dry sliding wear. Homogeneously dispersed 5 and 10 wt% of B_4C into epoxy resin to produce test samples. Tribological characteristics of the reinforced composite specimens were compared with the properties of pure epoxy resin. Wear tests were performed according to ASTM G-99. Taguchi L9 orthogonal array was used to obtain test pattern. The tests were conducted under three different loads of 5, 10 and 15 N, at three different velocities of 0.8, 1 and 1.2 m/s and at three different sliding distances of 750, 1000 and 1200 m. These tests were carried out under dry conditions at room temperature. Friction surfaces of the test specimens were examined by SEM. The most dominant parameter which affected the tribological properties was determined as B_4C ratio. The enhancement of wear resistance was achieved with the addition of boron carbide reinforcement to epoxy resin.

Golla & Prasanthi, (2016) examined effectiveness of the addition of 30 wt. % of boron carbide (B_4C) particle contributions regarding the longitudinal and transverse properties of the basalt fiber reinforced polymer composite at various fiber volume fractions by FEA. Assuming a uniform distribution of reinforcement and considering one unit-cell of the whole array, the properties of the composite materials were determined. The predicted elastic properties from FEA were compared with the analytical results. The results suggested that B_4C particles are a good reinforcement for the enhancement of the transverse properties of basalt fiber reinforced polypropylene.

2.5 Behavior of Natural Particulate RPC for Application of Brake Pad

The braking system is one of the crucial systems in automobiles, responsible for slowing down or stopping the automobile by converting kinetic energy to thermal energy through friction. For this reason, it is important for brake pads to have a high and stable coefficient of friction. Friction materials can be classified into three categories (Ammar *et al*., 2023):

a. **metallic brake linings: -** are made of iron or copper, commonly used in heavyweight and high-speed aircraft, as well as high-speed trains. This is mainly due to the high thermal stability of metallic brake linings. Despite their ease of fabrication and low cost, metallic brake linings have a high density, which decreases the system's energy efficiency (Ammar *et al*., 2023).
b. **carbon−carbon composites: -** are primarily utilized in aircraft applications. They are 40% lighter in weight than metallic brake linings and have a high strength at elevated temperatures, twice that of steel. This allows them to have a longer service life. However, the main limitations of carbon−carbon composite materials are their high cost and susceptibility to oxidation (Ammar *et al*., 2023).
c. **organic polymerics (resin bonded): -** are used in the production of light-duty brakes that are commonly used in normal clutches. Organic polymerics typically consist of 30–40% organic

resin, with a wide range of ingredients and formulations. There are four main categories of components used to create organic polymeric materials: binders, fillers, friction modifiers, and reinforcements (Ammar *et al*., 2023).

Sugözü & Sugözü, (2019) studied the usability of boron carbide as a reinforcement material in friction composites was investigated experimentally. Hence, composite samples containing different amounts of boron carbide (5%, 10% and 15%) were produced and compared with boron carbide-free sample. Friction and wear tests were determined by a full-scale brake friction tester according to TS 555 and TS 9076 standards. The hardness of the samples was calculated by Rockwell hardness tester and the density was calculated according to Archimedes' principle. The results showed that boron carbide could be used as a reinforcement material in friction composites.

Selvaraj *et al*., (2021) materials like banana peel powder, crab shell powder, coconut fibers, stark corn fibers, metal oxide composites, metal nitride composites, multiwalled carbon nanotubes, and hybrid nanocomposites are studied on the basis of their performance under high-frictional force applications and analyzed by considering their mechanical, chemical, thermal, and tribological properties. Carbon nanotube-based composites showed improved tribological and braking performances making them more attractive than the materials in commercially available brake pads. In addition to these, the effects of usage of such nanomaterials on the environment and health are reviewed, in order to understand the feasibility of utilization of nanomaterials in automotive brake pad applications. This work suggested that there are a variety of nanomaterials that prove to be capable of automotive brake pad applications and, with further research and technological developments, would prove to be an asset to the automotive brake pad industry.

Muzathik *et al*., (2013) examined properties of Boron mixed brake pads by comparing them with the commercial brake pads. Friction coefficient of Boron mixed brake pads and commercial brake pads were significantly different and increased with the increase in surface roughness. The abrupt reduction of friction coefficient is more significant in commercial brake pad samples than in Boron mixed brake pad formulations. Fade occurred in commercial brake pad sample at lower temperatures. Boron formulations are more stable than their commercial counterparts.

Pads *et al*., (2022) focused on analyzing the main parameters that affect brake pad performance. Brake pads made from agricultural waste need to pay attention to the type, amount, and particle size of the agricultural waste used to have better physical and mechanical properties. The small particle size of the reinforcement creates stronger structural bonds and allows the particles to withstand more force or pressure before breaking. The hardness, compressive strength, porosity, and density of the resulting sample decreased with the increasing sieve size used. Meanwhile, brake pads produced with large particle sizes will result in a higher percentage of oil and water absorption, wear, and burnt parts.

Ajibade *et al*., (2019) conducted experiments on a number of reinforcements, namely orange peels, coconut, periwinkle, palm kernel and egg shell particles to study their diffraction patterns, thermal stability and phase identification. After evaluating the results to reinforce polymer composites with agro-waste materials for automobile brake pad applications. It was accompanied by noteworthy achievement to displace asbestos-based brake pads at low cost. Diverse research has reported that composite performance could be enhanced by understanding and modifying the structural issues concerning the reinforcement. The selected agro-waste materials can be used as substitutes for asbestos in automobile brake pad manufacture.

Chandradass *et al*., (2021) fabricated brake pad material using asbestos-free agro-waste sugar cane bagasse ash (SCBA) at low cost by a compression molding technique. SCBA in varying proportions (0%, 5%, and 10% weight) was added to the composite mixture containing epoxy resin as a binder. The size of the SCBA particle was 300 mm. The fabricated brake pad was subjected to mechanical, physical, and tribological analyses. The obtained results were compared with conventional asbestos-based brake pad material. The results showed that the sample having 10% SCBA as filler content has high tensile strength, flexural strength, density, low water, and oil absorption. Also, the hardness test and impact test results revealed the suitability of SCBA in brake pad material.

2.6 Manufacturing Techniques of Natural Particulates RPC

Natural fiber reinforced polymer composites are manufactured by various methods like hand lay-up technique, injection molding, compression molding and resin transfer molding. The methods of processing include three steps i.e. removal of moisture from natural fiber, mixing of fiber and matrix and part fabrication. From different studies, it has been found out that 80°C is the optimal temperature for the removal of moisture from natural fiber (Sapuan *et al*., 2011).

2.6.1 Hand layup process

The hand lay-up process is the most common and widely used open mold composite manufacturing process. Initially, fiber preforms are placed in a mold where a thin layer of antiadhesive coat is applied for easy extraction. The resin material is poured or applied using a brush on a reinforcement material. The roller is used to force the resin into the fabrics to ensure an enhanced interaction between the successive layers of the reinforcement and the matrix materials (Jamir *et al.*, 2018).

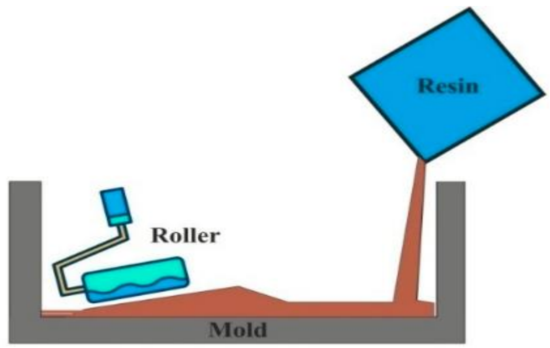


Figure 2.3: Hand layup process

2.6.2 Spray up process

Spray-up technique is no different than hand lay-up. However, it uses a handgun that sprays resin and chopped fibers on a mold. Simultaneously, a roller is used to fuse these fibers into the matrix material. The process is illustrated in Figure 2.4. It is an open mold type of technique, where chopped fibers provide good conformability and quite faster than hand lay-up (Perna *et al*., 2018).

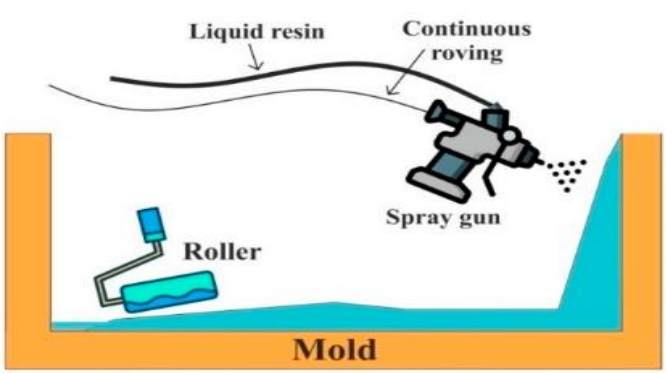


Figure 2.4: Spray up process

2.6.3 Vacuum bagging

Vacuum bag molding uses a flexible film made of a material such as nylon polyethylene or polyvinyl alcohol (PVA) to enclose and seal the part from the outside air. Many times, the vacuum bag molding technique is performed with the assistance of the hand lay-up technique. Laminate is first made by using the hand lay-up technique, and then after it is placed between the vacuum bag and the mold to ensure fair infusion of fibers into the matrix material (Putra *et al.*, 2015). The air between the mold and the vacuum bag is then drawn out by a vacuum pump while atmospheric pressure compresses the part. The process can be well understood by Figure 2.5.

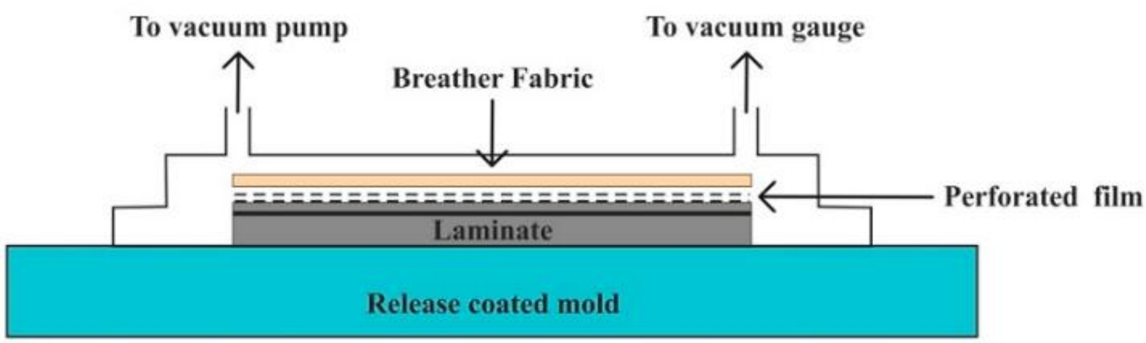


Figure 2.5: Vacuum bagging

2.6.4 Resin transfer molding

The preform fiber reinforcement mat or woven roving arranged at the bottom half of the mold and preheated resin is pumped under pressure through an injector. The mechanism of the resin transfer molding (RTM) process can be understood with Figure 2.6. A variety of combinations of fiber material with its orientation, including 3D reinforcements, can be achieved by RTM. It produces high-quality, high-strength composite structural parts with surface quality matching to the surface of the mold (Jamir *et al.*, 2018).

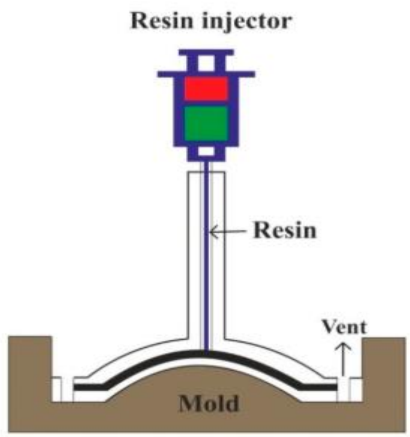


Figure 2.6: Resin transfer mold

2.6.5 Compression molding process

It uses preheated molds mounted on a hydraulic or mechanical press. A prepared reinforcement package from prepreg is placed in between the two halves of the mold, which are then pressed against each other to get a desired shape of the mold. Figure 8 represents the stepwise processing of compression molding. It offers short cycle time, a high degree of productivity, and automation with dimensional stability (Rajak *et al*., n.d.).

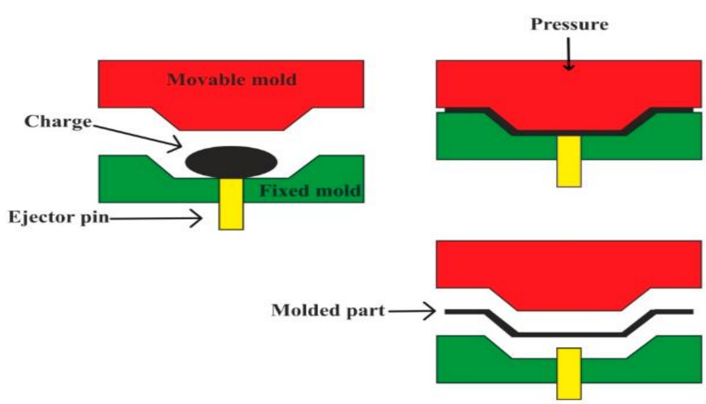


Figure 2.7: Compression molding

2.6.6 Pultrusion process

The pultrusion process can be explained (Figure 2.8) as strands of continuous fibers are pulled through a resin bath, which are further consolidated in a heated die. It is a continuous process, useful for fabrication of composites with a constant cross-section with a relatively longer length;

it enables production with a high degree of automation and lower production cost (Paola & Structural, 2019).

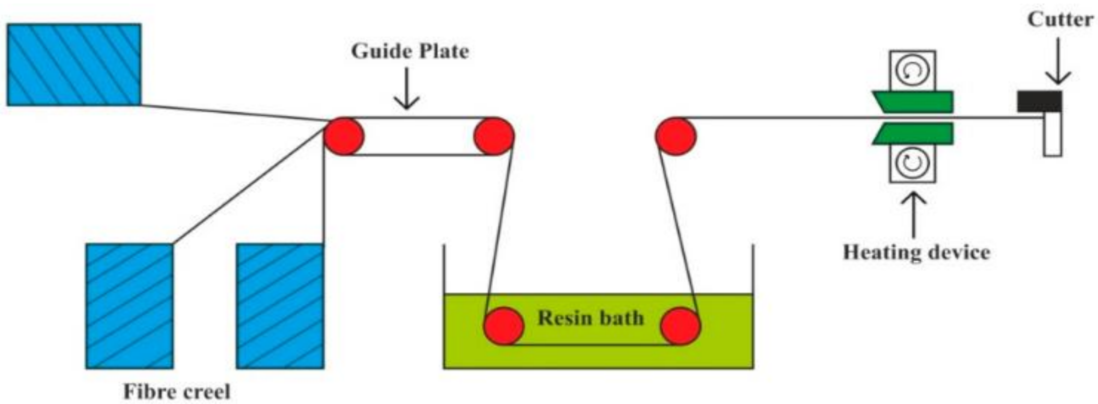


Figure 2.8: Pultrusion molding

2.6.7 Injection molding

Injection molding has the ability to fabricate composite parts with high precision and at very low cycle times. In a typical injection molding process, fiber composites in the form of pellets are fed through a hopper, and then they are conveyed by a screw with a heated barrel, as shown in Figure 2.9. Once the required amount of material is melted in a barrel, the screw injects the material through a nozzle into the mold. where it is cooled and acquires the desired shape (Rajak *et al.*, n.d.).

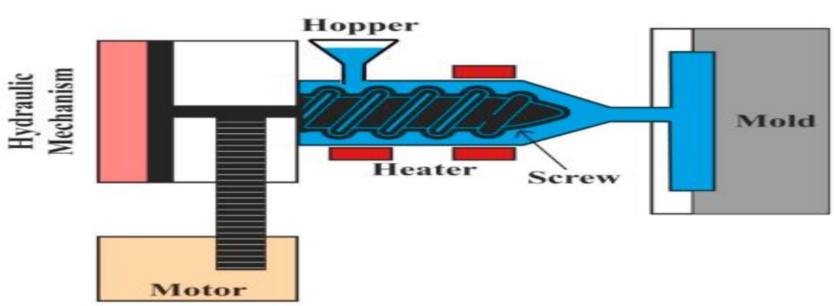


Figure 2.9: Injection molding

2.7 Summary of Literatures

Upon literature review, it has been noted that natural fiber reinforced polymer matrix composites are emerging as promising alternatives to synthetic fibers in various applications. These composites employ a combination of fibers and a matrix, with different weight percentages for the fibers (ranging from 5% to 40%) and the matrix (ranging from 60% to 90%). Additionally, the mixing ratio of the hardener varies from 1% to 5% of epoxy resin, based on weight ratios.

To enhance the mechanical properties of the matrix Nano-sized fillers are introduced. These fillers are incorporated into the matrix phase at levels below 10% to achieve improvements in mechanical performance.

2.8 Research Gap

Most of the researchers have carried out investigations on natural fiber reinforced composites and analysis of their mechanical, physical thermal and chemical properties. However limited research is conducted in bio particulate reinforced polymer composite. Avocado seed as alternative filler material in composite industry is not assessed yet.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

In this chapter the materials and methods used for the preparation of the composite material were described. Also, the equipment's and machines used to characterize the mechanical and physical properties, machinability and morphological analysis were also presented.

3.2 Materials

The materials that are utilized for the preparation of the composite sample are listed in the table below.

Table 3.1: Utilized materials

Material	Quantity
Avocado seed cover (endocarp) powder	60 gm
Boron Carbide (B_4C)	40 gm
Epoxy Resin	2L
Hardener	0.5L
Petroleum gel	1
Distilled water	1L

3.2.1 Reinforcement -avocado seed cover powder

Due to high local and global market demand, avocado plantation and production is considerably increasing in many parts of Ethiopia. avocado was introduced around 1938 in the eastern and southern regions of Ethiopia and has been widely planted throughout the country, particularly around the homestead (Faris, 2016). A report showed that Ethiopia is one of the top five avocado producing countries in sub-Saharan Africa (SSA) and the 20th in the world, where about 2 million smallholder farmers are currently involved in avocado production (Mokria *et al*., 2022).

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

3.2.2 Epoxy resin

Among the different thermoset matrix, epoxy, polyesters and vinyl esters are commonly used in automotive, infrastructure, aircraft, marine, chemical, and electrical applications. Epoxy shows superior mechanical properties when compared to polyester. Epoxy is used very effectively as an adhesive and as a laminating resin for most of the engineering applications. It offers excellent moisture barrier qualities when used in polymer composites. It binds extremely well to fibers for making fiber reinforced polymer composites (Jeyapragash *et al*., 2019). The thermosetting matrix used in this study was a medium viscosity epoxy resin (LAPOX L-12) from World Glass Fiber Plc, Addis Ababa, Ethiopia.

Figure 3.2: Epoxy resin

3.2.3 Hardener

The polymerization reaction to transform the liquid resin to the solid is induced by adding small amounts of a reactive curing agent just before incorporating fibers into the liquid mix (Jeyapragash *et al*., 2019). One such curing agent is polyamine-based hardener (K-6) which is purchased from World Glass Fiber Plc, Addis Ababa, Ethiopia and used for the preparation of composites with a mixing ratio of 9:1.

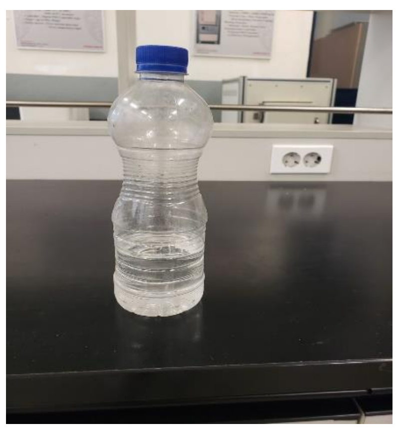


Figure 3.3: Hardener

3.2.4 Boron carbide

Boron Carbide is ceramic material used as the filler in the present investigation were purchased from Mumbai, India. These B_4C powder with size of 150 mesh was chosen over other ceramics because of its high wear resistance and good thermal shock resistance property. It was used 5 volume % and added to resin and hardener based on reviewed literature.

Figure 3.4: Boron carbide powder

3.2.5 Distilled water

This study uses distilled water PH level of 7 for the purpose of cleansing the avocado seed and for water absorption test.

3.2.6 Pure petroleum releasing agent

This releasing agent ensures safe removal of the composite sample from the mold and it enhances smooth surface finish.

Figure 3.5: Pure petroleum jel

3.3 Process Parameter

The process parameters are the factors that were varying in this process and selected based on literature reviews. Avocado seed cover powder size of 75µm volume percentage is the factors that affect the strength of composite materials. Boron carbide size of 75µm volume percentage was expected to increase the mechanical property of the composite material. The samples were made from two different sized molds: mold 1 that is 100mm*100mm and mold 2 which is 200mm*200mm with equivalent volume percentages. Both molds are used at room temperature. The mixing process is done first by hand using glass rod and stirring slowly. Then magnetic stirrer bar is used on hot plate device and mixed with 200rpm for 40 minutes. Slow and controlled pouring process is done to prevent air entrapment. The curing process takes 75 minutes at room temperature. In this experimental investigation all the parameters were utilized to investigate the effect of each parameter on the composite and obtain the optimum process parameter from the selected factors.

3.3.1 Avocado seed cover powder volume percentage

Particulate weight percentage has major influence on mechanical properties of composite material. In this research avocado seed cover powder was selected in four levels 0, 5, 10 and 15 vol.% as per literature reviews.

3.3.2 Boron Carbide volume percentage

In several researches nano-particulate filled composite materials were reinforced below 10 vol.%. The weight percentage of B_4C was designed at constant level which is 5 vol.% in order to enhance the mechanical properties.

Table 3.2: Sample composition in vol%

Codes	Composition (vol.%)			
	Avocado powder	Boron carbide	Epoxy	Hardener
S1	0	0	100	10
S2	0	5	95	10
S3	5	5	90	10
S4	10	5	85	10
S5	15	5	80	10

3.4 Sample Preparation Method

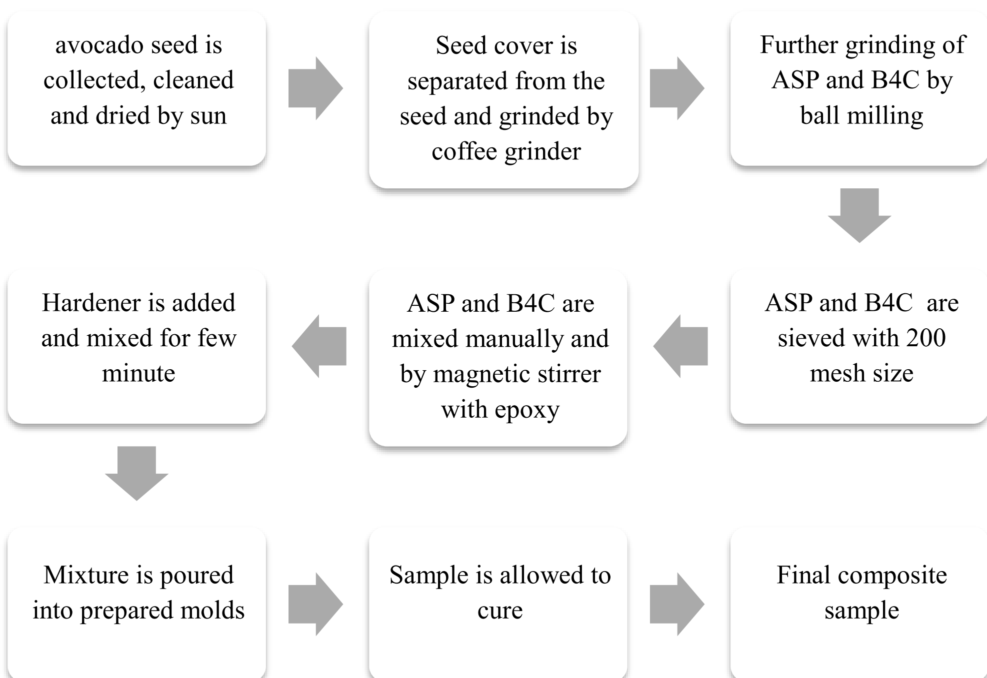


Figure 3.6: Sample preparation flow chart

3.4.1Preparation 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

3.4.2 Preparation of B_4C powder

To make the purchased B_4C powder proportional to the size of ASP, it was grinded by ball milling and sieved with size of 75 microns.

3.4.3 Calculation of Mass of ASP, B_4C and Matrix for each sample

The volume of the composite was calculated by multiplying the length, width and breadth of the mold prepared for molding the composite material.

$$Volume\ of\ mold = L * W * t \ \ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where, L is length, W is width and t are thickness of mold.

Density of avocado seed powder, boron carbide powder and epoxy resin:

Avocado seed powder = 0.86 g/cm^3

B_4C = 2.52 g/cm^3

Epoxy resin = 1.192 g/cm^3

$$Volume\ of\ Composite(V_C) = V_{ASP} + V_{B4C} + V_{Epoxy} \ \ldots\ldots\ldots\ldots \quad (3.2)$$

Where, V_{ASP} is volume of avocado seed powder, V_{Epoxy} is volume of epoxy resin, and V_{B4C} is volume of boron carbide powder.

For sample 3

Epoxy resin = 90 vol.%

ASP = 5 vol.%

B_4C = 5 vol.%

The density of the composite is calculated by using the rule of law of mixture method and obtained first by adding the volume fraction of the resin, avocado seed powder, and boron carbide powder for each sample. Then the mass of epoxy, avocado seed powder, and B_4C was calculated.

$$\frac{M_c}{\rho_c} = \frac{M_{Epoxy}}{\rho_{Epoxy}} + \frac{M_{ASP}}{\rho_{ASP}} + \frac{M_{B4C}}{\rho_{B4C}} \ldots\ldots \quad (3.3)$$

Where, M_c is mass of composite, ρ_c is density of composite, M_{Epoxy} is mass of epoxy resin, ρ_{Epoxy} is density of epoxy resin, M_{ASP} is mass of avocado seed powder, ρ_{ASP} is density of avocado seed powder, M_{B4C} is mass of boron carbide powder and ρ_{B4C} is density of boron carbide powder.

From equation 3.3 density of composite material can be calculated as follows:

$$\frac{1}{\rho_c} = \frac{0.9}{1.192} + \frac{0.05}{0.86} + \frac{0.05}{2.52}$$

$$\rho_c = 1.2\ g/cm^3$$

$$M_c = \rho_c * V_c \ldots\ldots \quad (3.4)$$

Where, M_c is mass of composite, ρ_c is density of composite and V_c is volume of composite.

$$Volume\ of\ mold = l * w * t$$

$$V_c = 100mm * 100mm * 12mm$$

$$V_c = 120cm^3$$

After calculating the density and volume of the composite, the mass can be obtained by substituting equation 3.4 in volume fraction equation.

$$M_c = \rho_c * V_c$$

$$M_c = \frac{1.2g}{cm^3} * 120cm^3$$

$$M_c = 144.06g$$

The mass of composite can be multiplied by each weight percentage to obtain the mass of ASP, epoxy resin and B_4C.

Mass of epoxy resin:

$$Mass\ of\ Epoxy = M_c * 0.9$$

$$Mass\ of\ Epoxy = 144.06 * 0.9$$

$$= 129.65g$$

Mass of ASP:

$$Mass\ of\ ASP = M_c * 0.05$$

$$Mass\ of\ ASP = 144.06 * 0.05$$

$$= 7.203g$$

Mass of B_4C:

$$Mass\ of\ B4C = M_c * 0.05$$

$$Mass\ of\ B4C = 144.06 * 0.05$$

$$= 7.203g$$

Table 3.3: Tabulated composition of avocado powder, boron carbide and epoxy resin in gram

Codes	Mass Composition (gm)		
	Avocado Powder	Boron Carbide	Epoxy
S1	0	0	144.06
S2	0	7.20	136.86
S3	7.20	7.20	129.65
S4	14.41	7.20	122.45
S5	21.61	7.20	115.25

3.4.4 Open mold casting

Open cast molding is a process whereby a liquid resin and a powder reinforcement added together in one container or beaker. These are then mixed by hand as a chemical reaction begins to transform the liquid mixture into a solid. While the mixture is still in liquid form, it is poured into the molds. Once the mixture solidifies, the finished part is ready to be removed from the mold.

This process is the simplest way to manufacture thermoset-based composites and offers several advantages, including lower mold costs, readily available production tools, and easy mold maintenance. To apply this process, first the mold should be prepared by using wood, metal, plastics and so on. For this investigation 200mm*200mm*3mm and 100mm*100mm*12mm metal is used to prepare the mold. Then mold release was used for preventing the epoxy resin from sticking to the mold. 100% pure petroleum jell was chosen because of its excellent release properties, easy availability and application.

The avocado seed powder and boron carbide were mixed with the epoxy resin and before the pouring process 10% hardener was added to facilitate the curing process. Finally, the solution was left to cure and harden in the mold. This process was repeated for each different wt.% composition.

The following steps were used to fabricate the samples:

i. Avocado seed powder, boron carbide and the epoxy resin were measured based on the weight fraction as show below

Figure 3.8: Measuring: (a): ASP, (b): B4C powder, (c): Epoxy

ii. ASP, B_4C and epoxy were mixed in beaker slowly by using glass rod.

Figure 3.9: Mixing the solution

iii. The mixture was further mixed by using magnetic stirrer bar to avoid agglomeration and to produce smooth solution. Hot plate device was used to apply the stirrer bar and it was used on 200 rpm for 40 minutes. The hardener was added and mixed with the solution by using glass rod for 2-3 minutes.

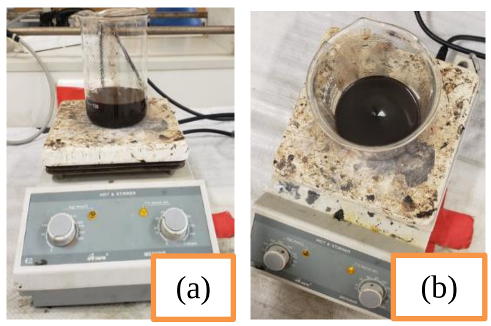


Figure 3.10: (a) and (b): Mixing by stirrer bar

iv. The mold is prepared by using RHS, steel plate and bolts. The mold was made in to two different sizes which are 100mm*100mm*12mm and 200mm*200mm*3mm. before the solution is poured, the molds were cleaned by using cotton and sanitizer. Then pure petroleum jell was smeared on the molds. Finally, the solution was poured in to the prepared mold.

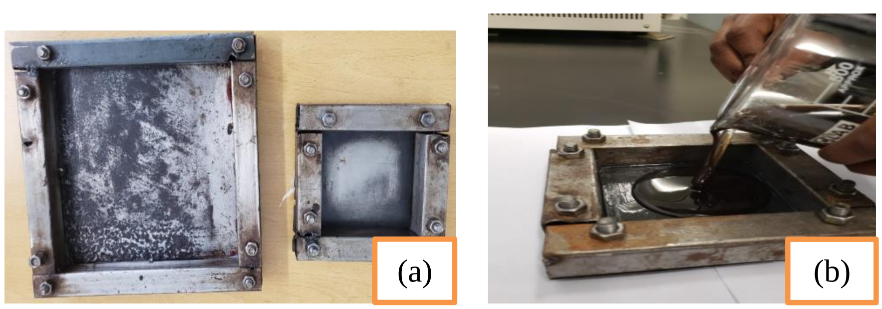


Figure 3.11: a):Prepared mold, (b): Pouring mixture to the mold

v. The sample was cured and released from the mold.

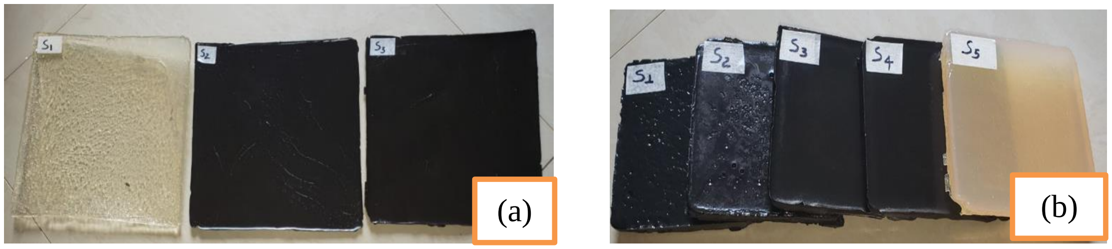


Figure 3.12: (a): Larger samples, (b): Smaller samples

vi. At last the samples were cut by using grinder as per the ISO and ASTM standards for each test.

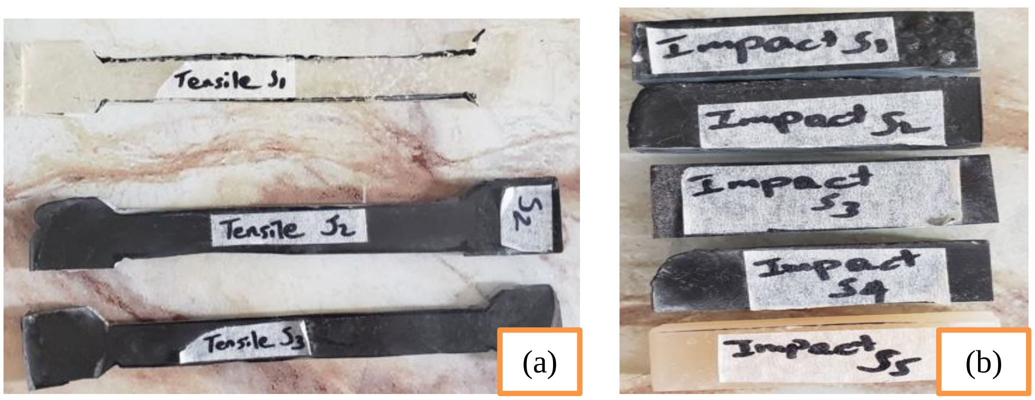


Figure 3.13: (a) and (b): Samples as per the standard

3.5 Machines and Equipment Used

The machines and instruments that are used to prepare and characterize the sample are listed below:

3.5.1 Mass balance

1) Analytical precision balance

This device is an extremely accurate laboratory balance created to precisely measure the mass of an object. Offering a readability up to 0.00001 grams (0.01 mg). This analytical balance is found in ASTU, Material Science Engineering laboratories. It provides accurate measurement because the balance is highly sensitive. It is therefore designed with draft shields that slides to provide protection from external environments such as air flows and dust which might affect the precision.

Figure 3.14: Analytical mass balance

2) Digital balance

Digital mass balance is also available at the Material Department of ASTU. It is also used to measure the mass of an object.

Figure 3.15: Digital mass balance

3.5.2 High energy mixer (Mill)

This device grinds samples in to fine powder by using zirconia balls. It has timer that can be adjusted up to 6000 seconds. After the timer is set, the balls started to collide and mill the sample. It is found in ASTU Materials Engineering department laboratory.

Figure 3.16: (a),(b)&(c): High energy mixer

3.5.3 75 Microns size testing sieve

This device is used to sieve the fine powder as well as to give same size for the powder. It is made up of stainless-steel wire mesh and brass frame. It was available in department of Materials Engineering in ASTU.

Figure 3.17: 75 microns size sieve

3.5.4 Vacuum oven system

This machine is used in this investigation for the purpose of evaporating and drying water from the cleaned material. This machine was accessed in ASTU Materials Engineering laboratory.

Figure 3.18: Vacuum oven

3.5.5 Hot plate MS300HS and magnetic stirrer

This device is used to make a stir bar, immerse in a liquid, quickly spin, or stirring a solution with maximum speed of 1500rpm and temperature of 380°C. It is found in Materials Engineering Department in ASTU.

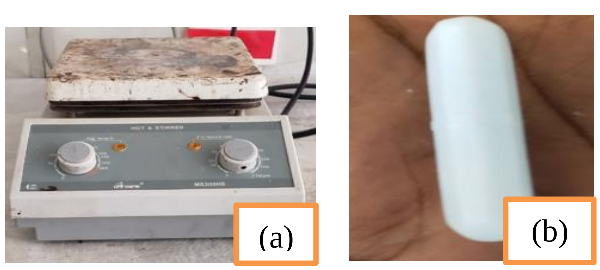


Figure 3.19:(a): Hot plate, (b): Magnetic stirrer bar

3.5.6 Vickers hardness testing machine HVS-50

The Vickers hardness test uses square-based pyramid diamond indenter with an angle of 136º between the opposite faces at the vertex, which is pressed into the surface of the test piece using a prescribed force, F. The HVS-50 machine used for this thesis was shown in Figure 3.19 which has measuring rage: 5 to 2900 HV, Test Force: 9.807, 49.03, 98.07, 196.1, 294.2, 490.3N, maximum height of test piece: 180mm, depth of throat: 125mm, magnifications of the measuring system: 125X, 250X and minimum scale value of the optical micrometer: 0.5µm.

Figure 3.20: Vickers hardness testing machine

$$HV = \frac{Constant*Testforce}{Surface\ area\ indentation} \quad (3.5)$$

$$HV = \frac{0.102 * 2F\left(\sin\frac{136°}{2}\right)}{d^2}$$

Where: - HV is Vickers hardness value,

F is load in kgf,

d is arithmetic mean of the two diagonals $\left(\frac{d_1+d_2}{2}\right)$, d1 and d2 in mm.

The above equation was taken from manual of HVS-50 machine in ASTU.

3.5.7 Pendulum impact testing machine

A pendulum impact testing machine is used to determine the impact strength or toughness of a material under impact loading by measuring the amount of energy the material is able to absorb.

The Charpy impact test is also known as the Charpy V notch test. It is a standardized high strain stress test that determines the amount of energy absorbed by a material during fracture.

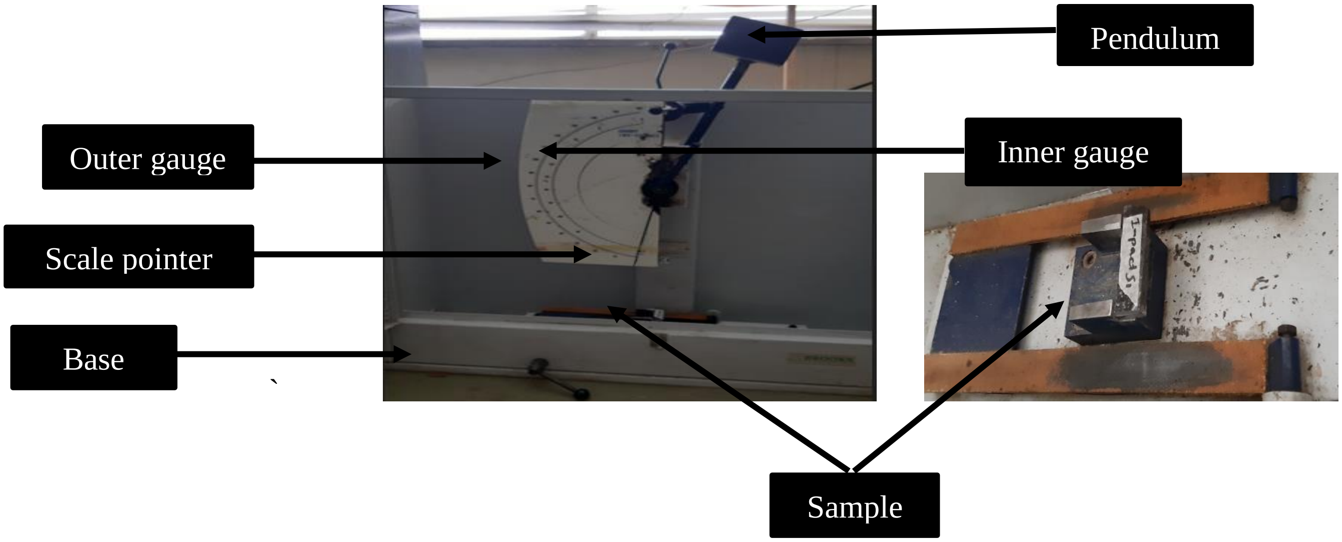


Figure 3.21: Pendulum impact testing machine

3.5.8 Universal testing machine

A universal testing machine (UTM), also known as a universal tester is used to test the tensile strength, flexural (bending), shear and compressive strength of materials. The "universal" part of the name reflects that it can perform many standard tensile and compression tests on materials, components, and structures (in other words, that it is versatile). The specimen is placed in the machine between the grips and an extensometer if required can automatically record the change in gauge length during the test. If an extensometer is not fitted, the machine itself can record the displacement between its cross heads on which the specimen is held. However, this method not only records the change in length of the specimen but also all other extending / elastic components of the testing machine and its drive systems including any slipping of the specimen in the grips. Once the machine is started it begins to apply an increasing load on specimen. Throughout the tests the control system and its associated software record the load and extension or compression of the specimen.

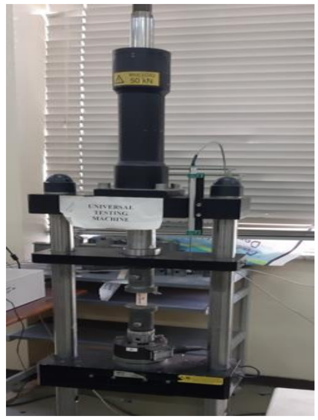


Figure 3.22: Universal testing machine

3.6 Mechanical Characterization

Tensile, flexural, compression, impact, and water absorption tests that are categorized under mechanical characterization were performed based on the ASTM standards. Each sample was conducted three times to make sure the reliability of the test.

3.6.1 Tensile test

For testing the tensile properties, a universal testing machine with a computer-controlled system and a 20KN load cell capacity was utilized. Specimens were prepared from the samples, with measurement of 13mm narrow width, 57 mm narrow section length, 19mm overall width, and 165 mm overall length. All specimens had a standardized gauge length of 50 mm, and the distance between the grippers was maintained at 115mm. The test was carried out on the standards of ASTM D-638-14 with a constant crosshead displacement rate of 5 mm/min. The test continued until the samples fractured completely. The load and displacement data obtained during the test were used to calculate the stress and strain. The average strength and modulus values were determined based on three specimens for each sample.

$$\sigma_t = \frac{F}{A} \quad (3.6)$$

Where, σ_t - Tensile Strength

F - Applied Force

A - Cross-sectional Area

tensile modulus of the samples was calculated.

$E_t = \frac{\sigma_t}{\varepsilon}$..(3.7)

Where, E_t - Tensile Modulus

σ_t- Tensile Stress

ε - Tensile strain

3.6.2 Flexural test

The flexural testing as depicted in figure , is performed using a computer-controlled Zwick machine (Zwick Roell Z020, ZHU) with a load cell capacity of 20KN. The flexural test follows the guidelines outlined in the ASTM D90-17 standard. The crosshead displacement rate is set at 1.4 mm/min, with a pre-load of 0.1 MPa. To maintain a span length/thickness ratio of 16:1, all specimens have a span length of 52 mm. each volume fraction combination undergoes five tests, and the average data is provided for analysis. The tests continue until the specimen fails, and the stress-strain data is collected. The flexural modulus is calculated using the formula specified below;

$\sigma_f = \frac{3FS}{2bh^2}$...(3.8)

Where, σ_f - Flexural stress

S- Support span between the two outer points

b - Width of the specimen

h - Height of the specimen

F - Applied Force

Flexural modulus is given by

$E_{fm} = \frac{S^3 m}{4bt^3}$..(3.9)

Where, E_{fm} - Flexural modulus

S - Support span

m - The slope of the load/deflection curve

b -Width of the specimen

t - thickness of the sample

3.6.3 Compression test

The compression tests are conducted according to the ASTM D695-15 standards, using specimens with dimensions of the 12.7*12.7*25.4 mm. the compression force is applied to the face of the specimen using a Zwick Roell Universal testing equipment. The tests are conducted at a constant strain rate of 1.3 mm/min. the average values from three specimens of each arrangement are provided for analysis. In composite compression testing, compressive loads are applied to materials to assess their behavior without the risk of buckling.

$\sigma_c = \frac{F}{A}$...(3.10)

Where, σ_c - Compression Stress

F - Load applied force

A - Cross-sectional area

3.6.4 Impact strength test

To evaluate the ability of a material to withstand sudden increase in stress, impact test is used to measure the energy absorbed during fracture. Charpy impact test equipment Model IT-30 was used following the ASTM D-256 standard for test specimen preparation. During the test, a pendulum with 30 kg weight were utilized to deliver impact loads to the specimen until it fractures. The impact speed will be set at 3.8 m/s, and the specimen featured a notch cut 2.5 mm deep, with the striker pointing upwards in the opposite direction. The test will be conducted on samples with dimensions of 55*10*(3-6) mm. overall, impact testing serves as a crucial tool for assessing the strength and durability of materials.

$\sigma_I = \frac{E}{tb}$...(3.11)

Where, σ_I - impact strength,

E - energy absorbed by the material during test

t - thickness

b - width of specimen.

3.6.5 Water absorption studies

In order to assess the water absorption characteristics of avocado seed particulate -reinforced epoxy composite, water absorption test was conducted on the samples. The procedure involved immersing the samples in distilled water at room temperature for a duration of eight days, as depicted in figure. Prior to immersion, the initial weights of the samples were measured and recorded, as shown in figure. After the eight-day immersion period, the samples were taken out of the water, cleaned using dry materials, and allowed to dry completely. Once dry, the samples were weighed again using a precise digital scale to determine the amount of water absorbed.

$$W\% = \frac{W_a - W_b}{W_b} * 100 \qquad (3.12)$$

Where, $W\%$ is percentage of water absorption,

W_b = Weight of the sample before soaking in water and

W_a = Weight of the sample after soaking in water, and absorption coefficients are calculated by using the formula.

Figure 3.23: (a): Specimen for water absorption, (b): Specimen immersed in distilled water

3.7 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. X-rays are shorter wavelength electromagnetic radiation that are generated when electrically charged particles with sufficient energy are decelerated. In XRD, the generated X-rays are collimated and directed to a nanomaterial sample, where the interaction of the incident rays with the sample produces a diffracted ray, which is then detected, processed, and counted (Raja *et al*., 2022). 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). Since the fabricated composites in this investigation are not conductors, it was needed to put the specimen in smart coater to provide the ability to absorb the electrons. This process was conducted in Biology department of ASTU.

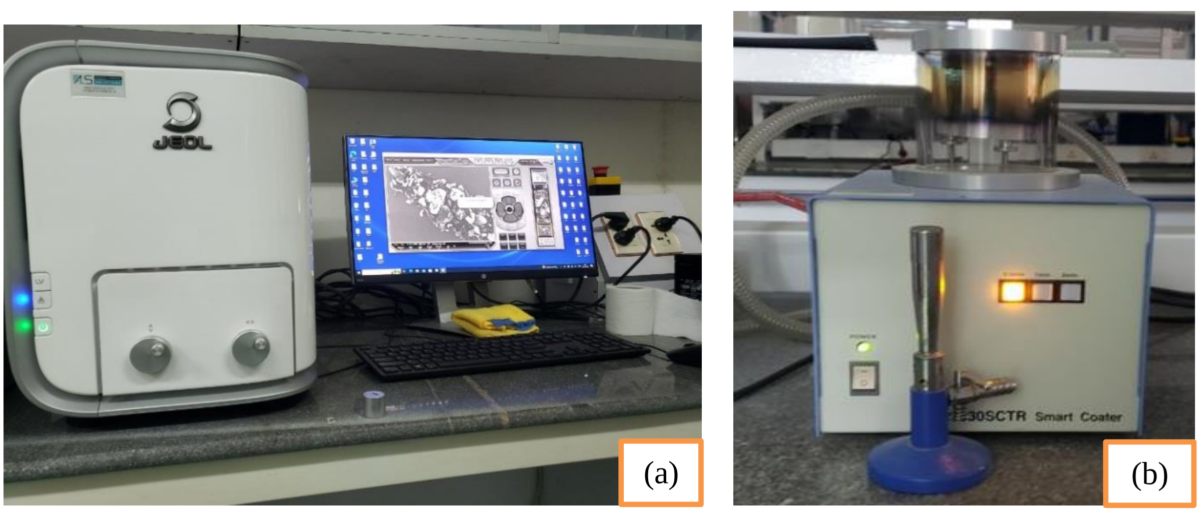


Figure 3.24: (a): Scanning Electron Microscope, (b): Smart Coater

3.7.3 Density and void fraction

The mechanical and physical properties of the composites are significantly reduced by the presence of void content in the composites. Any of its mechanical properties can be greatly influenced by the void material of a composite. Higher void contents typically indicate lower resistance to fatigue, greater susceptibility to water penetration and weathering, and increased strength property variance or dispersion. To estimate the quality of composites, knowledge of the void content is desirable (Praveena *et al*., 2022). The sample was prepared following the guidelines outlined in ASTM D-792 which defines density as the mass of the material per unit volume. The densities of the specimens were measured by calculating both theoretical and experimental density. The difference between these two values provides an indication of the void content in the sample. To determine the actual density of the composites, the principles of Archimedes are employed.

The actual density of the composite is given by the following equation:

$$\rho_a = \rho_w \left(\frac{m_a}{m_a - m_w}\right) \quad \ldots\ldots(3.13)$$

Where, ρ_a - Actual density of composites

ρ_w- Density of water

m_a- Mass of sample in air

m_w- Mass of sample in water

The theoretical density of composite materials in terms of rule of mixture can be obtained as:

$$\rho_t = \rho_m * V_m + \rho_{asp} * V_{asp} \quad \ldots\ldots(3.14)$$

Where, ρ_t - Theoretical density

ρ_m- Density of matrix

V_m- Volume of matrix

ρ_{asp}- Density of avocado seed powder

V_{asp}- Volume of avocado seed powder

The amount of void content in a sample is calculated as:

$$V_v = \frac{\rho_t - \rho_a}{\rho_t} \quad \ldots\ldots(3.15)$$

Where, V_v - Void Content

ρ_t - Theoretical density and

ρ_a - Actual density

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

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.

4.2 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. Hence, it is essential to determine these characteristics in order to effectively understand the link with the researched qualities. The ratio of reinforcing filler to matrix determines density significantly. Composites become lighter as their fiber content rises. As the amount of filler in a composite material grows, so does the void content.

Table 4.1: Density and void content estimation of specimens

Composition	Theoretical Density (kg/m^3)	Experimental Density (kg/m^3)	Void Content (%)
S1	1.192	1.192	0.00
S2	1.258	1.255	0.27
S3	1.242	1.236	0.45
S4	1.225	1.219	0.47
S5	1.209	1.203	0.46

Theoretical densities are determined by employing Equation 3.14 and are estimated to be greater than experimental densities (Table 4.1). The difference is due to air entrapment in the polymer during ingredient mixing. Equation 3.15 is used to compute void content (%). The void content grows as the avocado filler content increases. When compared to composites without reinforcement, the findings demonstrate that the density of composites decrease as the filler content increases. When the filler content is low, the B_4C filler reduces the void content (fills the gap between matrix and fiber) of the composites by reducing the likelihood of air entrapment, which minimizes the occurrence of pores and voids. Higher void contents are typically associated with greater vulnerability to moisture absorption.

4.3 Tensile Test

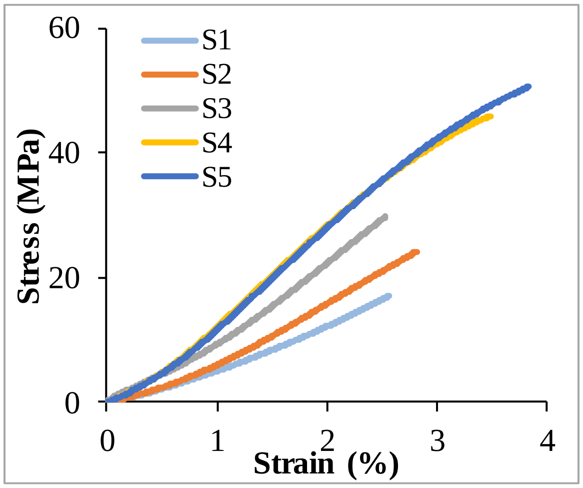


Figure 4.1: Representative tensile stress-strain curves of composites

Figure 4.1 represents the tensile stress-strain curves for neat epoxy and epoxy composites with avocado filler and B_4C particle reinforcement. All of the specimens' stress-strain curves show a similar pattern till the elastic area's maximum stress, which is followed by a sudden brittle failure. Figure 4.1 also shows how significantly the tensile stress is increased when avocado filler in an epoxy matrix is reinforced with B_4C filler particles. S1 has a 2.56% strain at 17 MPa tensile stress while S2 has a 2.83% strain at a 24.24 MPa tensile stress. 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. The stress-strain curves show tensile stress has increased up to fiber content of 15 vol.%.

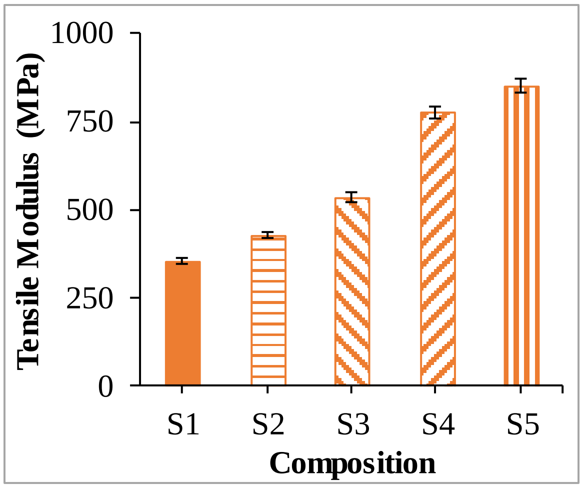


Figure 4.2: Young's modulus measured experimentally

Figure 4.2 shows the experimentally determined young's modulus. When compared to S1 (pure epoxy), the young's modulus of S2, S3, S4 and S5 increased. The reinforcement of avocado seed particulate and B_4C particles into the matrix is mostly responsible for the rise in modulus. S1 had a tensile modulus of 353.96 MPa while S2 had a tensile modulus of 427.67 MPa which was fabricated from 5 vol.% of B_4C and 0 vol.% of avocado seed particulate. 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.

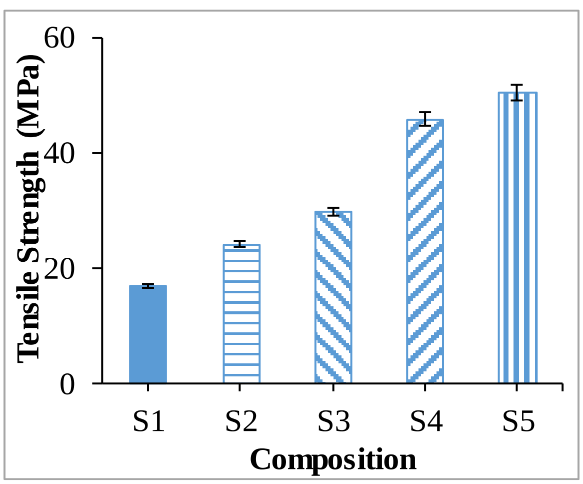


Figure 4.3: Tensile strength measured experimentally

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. The composite with 15 vol.% avocado had the highest values, approximately 50.22 MPa. Furthermore, the increase in stress transferred from matrix to fibers as a consequence of strong interfacial adhesion can justify this significant improvement in tensile strength (Alamri *et al.*, 2012). When avocado concentration rises to 15 vol.%, the tensile strength of B_4C filled avocado/epoxy composites rises. The illustration also shows that the tensile modulus increases with the amount of fiber in the composite.

Several parameters, including distribution of reinforcement, porosity, interfacial bonding, and filler vol.%, affect the tensile characteristics of avocado-reinforced epoxy (Essabir *et al.*, 2013). Rising the filler vol.% to 15% with 5 vol.% B_4C filler results in a high interface region between the fibers and the matrix, and the fibers in the sample facilitate load transmission from the matrix to the fibers across the interface. Even when the fiber ratio increases to 5%, the interaction between the fibers inside the composite does not result in higher fiber contact which results in poor interfacial bonding between the matrix and fiber. As a result, strong interfacial bonding and particle distribution were obtained, and effective load transfer occurred (Betelie *et al*., 2019).

Another likely interpretation for such a rise in tensile strength is that the B_4C filler (5 vol.%) bound to the particle helps to improve bonding between the epoxy matrix and particle via mechanical interlocking, hence increasing tensile strength. According to other studies, using more B_4C filler particles causes agglomerations and increases the quantity of voids in the composite, which inhibits compact adhesion at the interface (Zhou *et al*., 2019).

The addition of natural fibers into the matrix up to a certain percentage results in a lower amount of non-resin zones. This may help to prevent the formation of stress concentration and voids regions throughout the matrix system (Sullins *et al*., 2017). This will increase the composites' tensile strength.

4.4 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 powder reinforced epoxy composites fail in brittle mode.

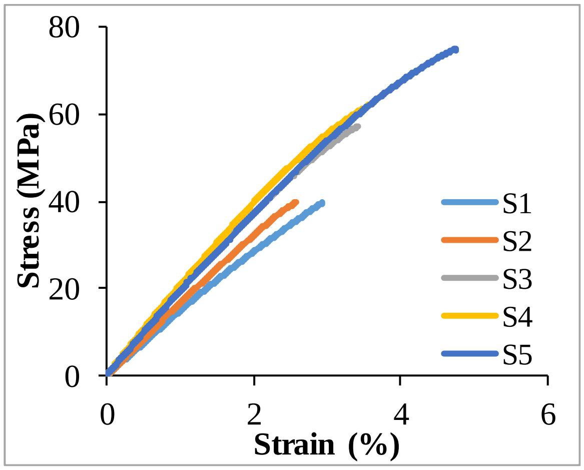


Figure 4.4: Representative flexural stress-strain curve of the composite specimens.

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. The flexural stress-strain curves show flexural stress has increased up to avocado filler content of 15 vol.%. This demonstrates that the vol.% of avocado filler has a considerable impact on flexural strength.

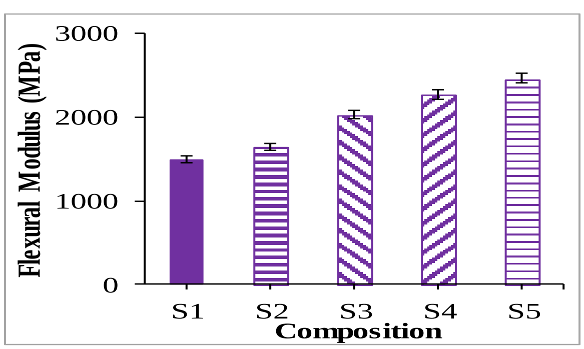


Figure 4.5: Flexural modulus measured experimentally

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.

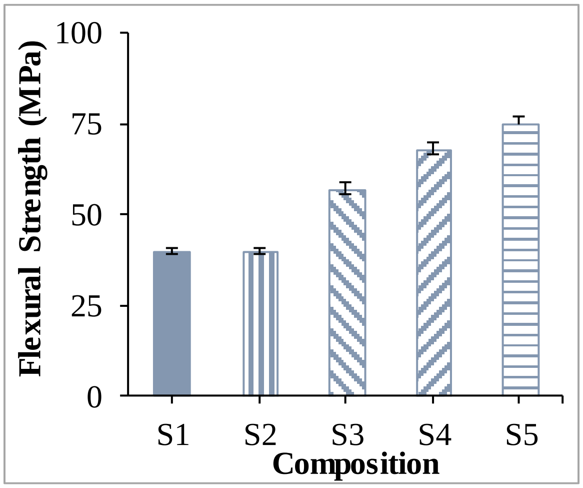


Figure 4.6: Flexural strength measured experimentally

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. As a result, flexural strength rises with increased avocado filler reinforcement. This demonstrates the effects of increased avocado filler volume fraction with B_4C in epoxy composites and exactly how it helps change composites' brittle behavior to ductile (flexural strength improves as the filler vol.% rises to 15 vol.%; this is due to the result of filler concentration and B_4C filler providing the composite with increased resistance to crack starting and spreading). The reason for the improvement in flexural strength is the rise of filler volume percentage up to 15%, which causes the bonding between the fillers to be stronger. Furthermore, the filler-matrix interfacial connection was so excellent that the formation of cracks during bending was stopped by the compatibility of the natural fillers and matrix (Fernandes *et al*., 2013).

4.5 Compression Test

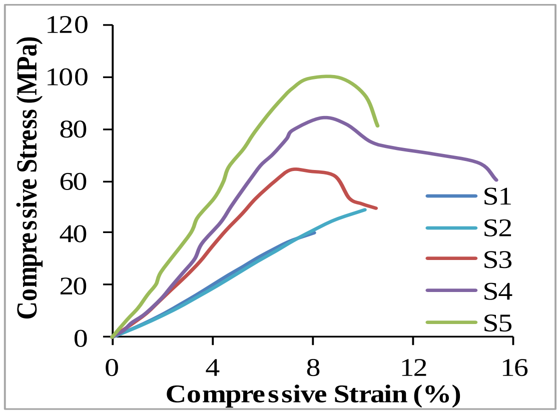


Figure 4.7: Representative compressive stress-strain curves of composite samples

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. Epoxy without filler reinforcement has a linear elastic zone that is followed by a region that decreases strain, which is seen by a decline in stress values. The stress value rises as the epoxy sample is compressed further, eventually causing rupture.

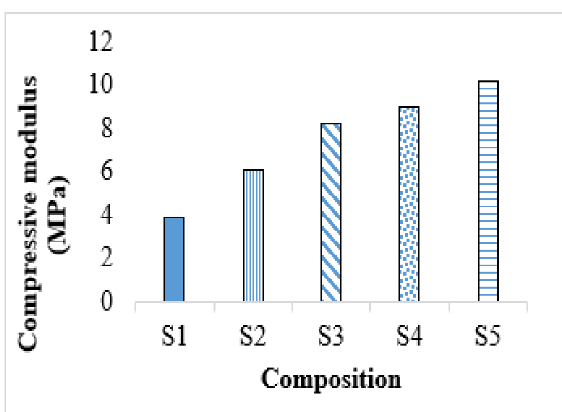


Figure 4.8: Experimentally measured compressive modulus

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.

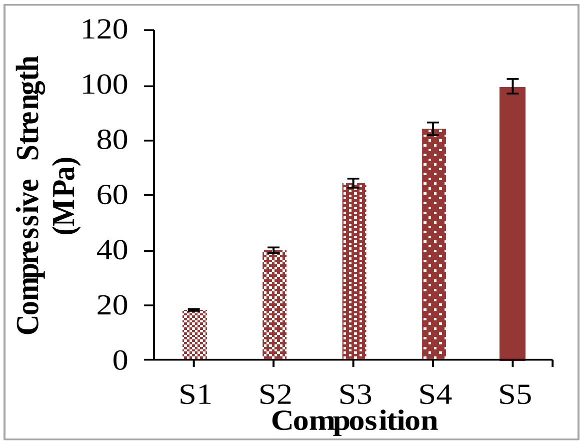


Figure 4.9: Experimentally measured compressive strength

Figure 4.9 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. This shows that the composites' compressive strength is greatly influenced by the filler. When avocado filler is added to an epoxy resin, it is observed that the mechanical properties degrade due to inadequate interfacial contacts between the matrix and filler beyond a certain amount of reinforcement (i.e., beyond S5). 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.

4.6 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.

Table 4.2: Results of impact strength

S. No.	Sample Name	Energy absorbed in (KJ/m2)
1	S1	34.5
2	S2	32.5
3	S3	30.5
4	S4	19.5
5	S5	19

From table 4.2, The addition of the avocado powder and B_4C has resulted in a major decrease in the impact strength of the composites compared to the neat epoxy composite. This is due to the fact that the impact strength of a filled-composite is dependent on the properties of the filler itself, as it can either increase or decrease the impact properties of the composites (Yusriah & Sapuan, 2018). The reduction in the impact strength of avocado powder and B_4C reinforced epoxy composite is attributed to the fact that the composite is brittle due to the high lignin content in the avocado powder. The ability of lignin as a cementing material in natural fiber has provided stiffness to the fiber and its corresponding composites. Hence, the decrease in the avocado seed powder and B_4C reinforced epoxy composite is observed.

4.7 Hardness Test

The hardness of the composite's specimens that are exhibited during the Rockwell hardness test was illustrated in table 4.3.

Table 4.3: Tabular description hardness test result

Sample Name	Trial 1	Trial 2	Trial 3	Average
S1	30.2	29.2	27.1	28.83
S2	32.3	33.7	31.5	32.50
S3	38.1	37.2	40.0	38.43
S4	32.9	34.0	33.5	33.46
S5	34.3	34.6	33.9	34.26

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 (B_4C). 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.

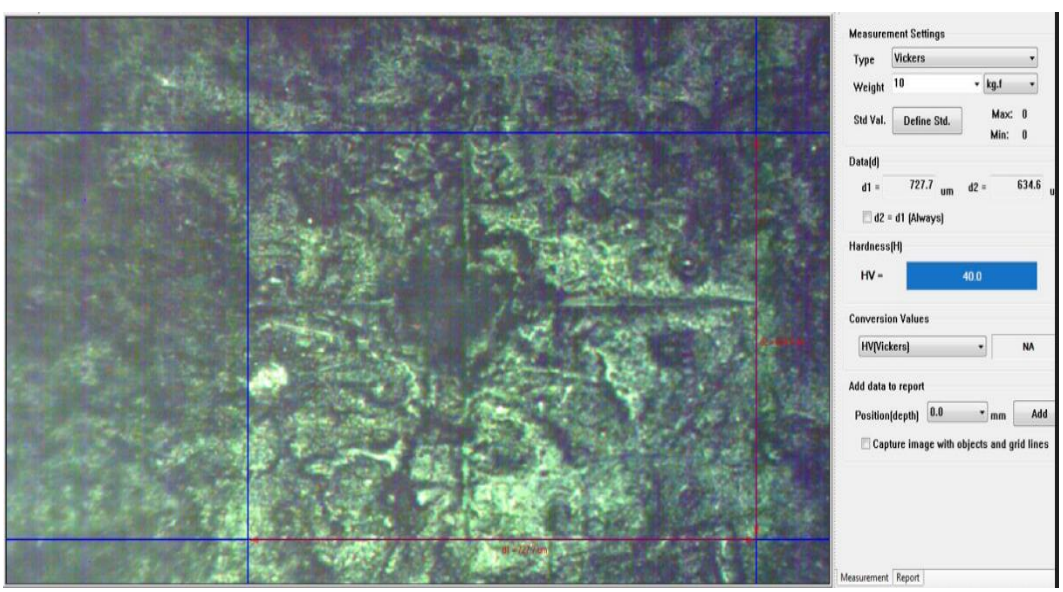


Figure 4.10: Hardness result for sample S3

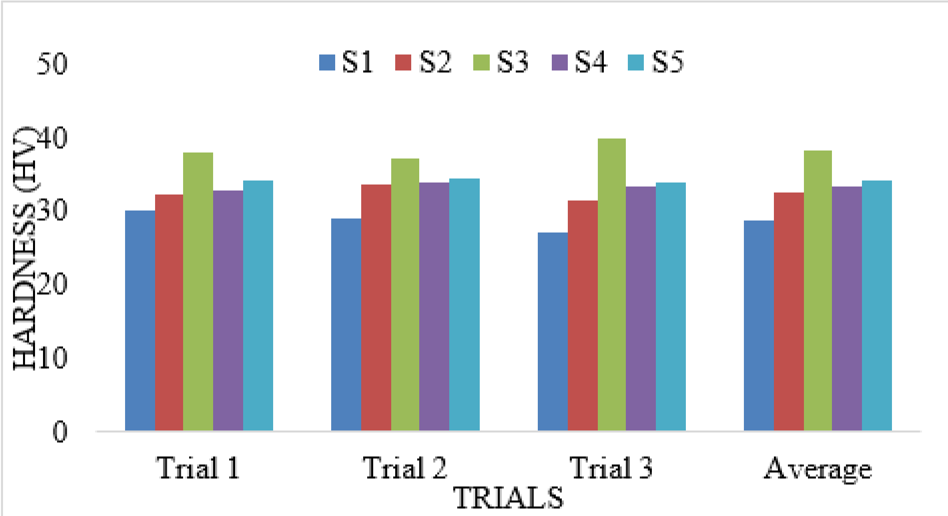


Figure 4.11: Experimentally measured hardness results

4.8 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 4.14 depicts the percentage of water that the composite specimens absorbed after 24, 48, 72, 96, and 120 hours. It can be clearly observed that the water absorption of S1 (neat epoxy) is the highest as compared to all other specimens at different absorption time. S3, S4 and S5 specimens consisting of 5, 10 and 15 vol.% of avocado filler reveal the lowest water absorption owing to the uniformly distributed avocado and boron carbide fillers assisting in lower water absorption. It was found that the composite specimen (S4), which contains 10 vol.% avocado fiber powder and 5 vol.% B_4C particles, takes far less water than other composite specimens over the course of the water absorption test. The spaces in the avocado filler were filled with the addition of 5% of the filler powder, which is B_4C particles, enhancing the quantity of interfacial interaction between the fiber and the epoxy matrix. The process of absorbing water is found to begin fast before leveling out as it approaches equilibrium. The composites' densities & the empty spaces have a big influence on how quickly water is absorbed (Das *et al.*, 2015). Furthermore, it is evident that the amount at which water is absorbed increases with filler content. Composites containing 15 vol.% avocado filler show a greater amount of water absorption than those that contain 10 vol.% filler.

Table 4.4: Measured sample before immersion

Sample Name	S1	S2	S3	S4	S5
Average weight of sample before immersion (gm)	7.9	8.95	9.57	7.28	7.85

Measured values of the immersed samples in distilled water from day 1 to 8 was reported below in table 4.5.

Table 4.5: Measured samples after immersion

Sample Name	Immersion period in hour								
	24	48	72	96	120	144	168	192	Average
S1	0.31	0.36	0.42	0.47	0.53	0.6	0.68	0.66	0.51%
S2	0.2	0.29	0.37	0.5	0.52	0.53	0.6	0.58	0.45%
S3	0.03	0.11	0.16	0.21	0.25	0.27	0.3	0.24	0.20%
S4	0.04	0.07	0.1	0.16	0.19	0.22	0.28	0.26	0.17%
S5	0.05	0.09	0.15	0.28	0.31	0.35	0.37	0.32	0.24%

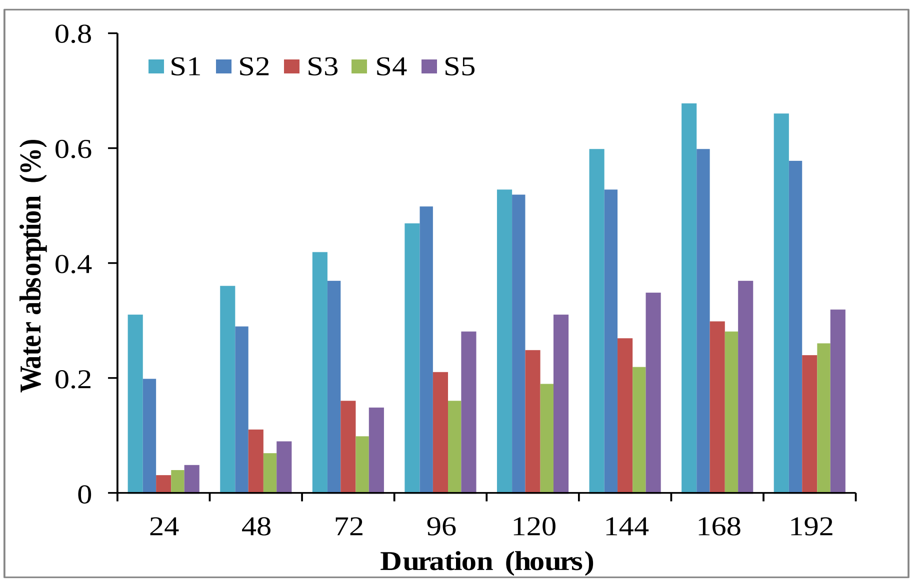


Figure 4.12: Water absorption percentage of epoxy composites with avocado filler and B_4C particles reinforced specimens after immersed in distilled water

4.9 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. An increase in the diffraction peak angle results in a decrement of the spacing between intermolecular layers (Bragg's Law). This decrease in the interplanar spacing (d) results in a dense structure with better interface bonding between the polymer and reinforcing (Verma *et al*., 2018).

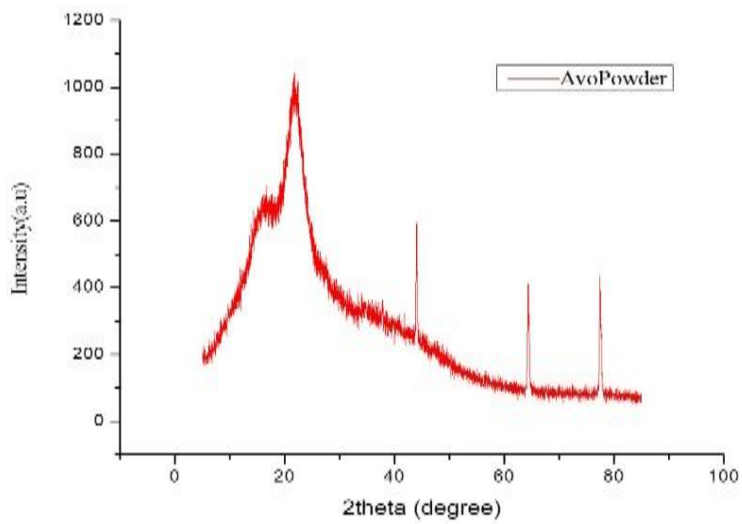
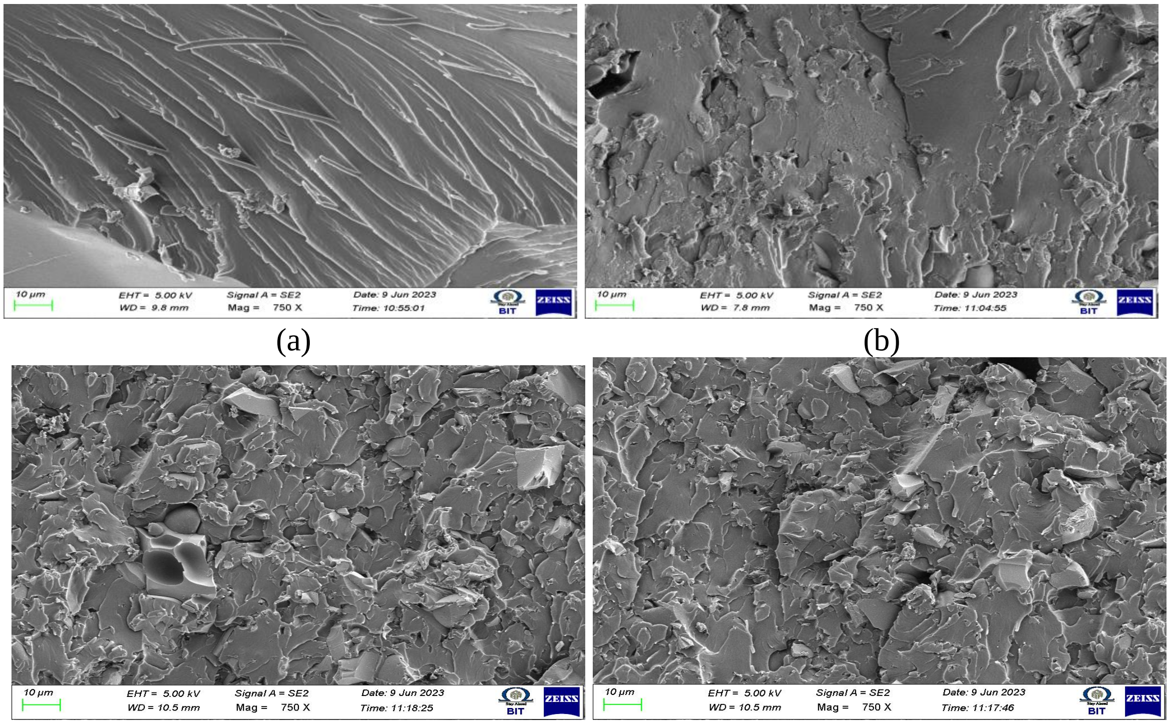


Figure 4.13: XRD graph

In Figure 4.13, the X-ray curve of the avocado powder is displayed, exhibiting four distinct diffraction peaks at 2θ = 21.84, 44.04, 64.36, and 77.46. These peaks suggest the presence of cellulose, amorphous $(C_6H_{10}O_5)n$ in the composition of the avocado powder.

4.10 SEM

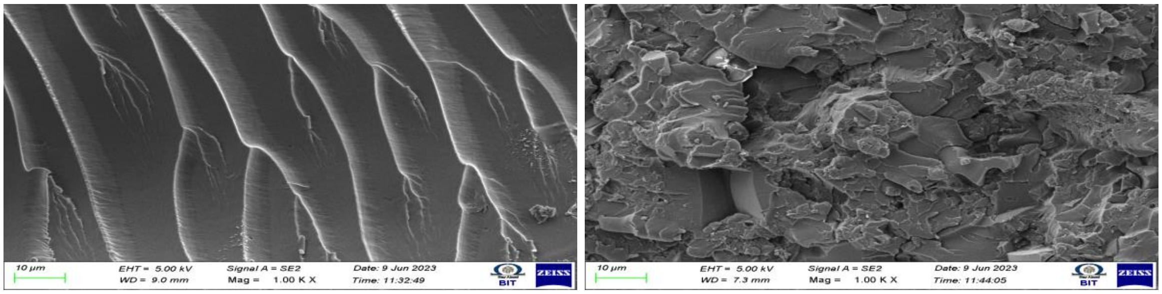


(a) (b)

(c) (d)

Figure 4.14: Scanning electron micrographs of (a) S1, (b) S3, (c) S4 and (d) S5.

Figure 4.14 depicts the fracture characteristics of composites subjected to tensile test (S1, S3, S4 and S5). The microscopic images are captured on as-fractured surface without any surface modification other than gold sputter coating. Figure 4.14's micrographs in their entirety demonstrate that the microstructure is free of debris, a typical occurrence in most of the composites. Brittle fracture is regulated by crack formation near the necking area under tensile stress, leading to a lack of debris on the fracture surface. Additionally, it can be observed from Figure 4.14(a) that neat epoxy specimen reveals cabbage like striation marks revealing brittle mode of failure with low deformation to failure while S3, S4 and S5 composites depict lower striation marks (Figure 4.14(b), (c) and (d)) than neat ones indicating relatively higher deformation and good energy absorption capability. Figure 4.15 presents high magnification micrographs of neat epoxy (S1) and S5 composites. Observations can be clearly made regarding the brittle striations marks in neat epoxy as compared with S5 wherein constituents (avocado, B_4C and matrix) can be seen properly bonded together implying that tensile loading leads to crack formation rather very easily in neat ones as compared with S5 composites. These instances enhance the response of avocado and B_4C reinforced composites than neat epoxy.



(a) (b)

Figure 4.15: Higher magnification fracture features of composites at (a). S1 and (b). S5.

4.11 Comparison with Previous Work

Researchers have been investigating the use of natural fiber reinforced epoxy composites for automotive brake pad applications. Some key findings and comparisons are as follows:

Table 4.6: Comparison with previous work

Reinforcement	Matrix	Tensile Strength	Flexural Strength	Hardness	Water absorption	Authors
Coconut fiber	Epoxy resin	33.2MPa	80.24MPa	37.14	2.10%	(Pramujati et al., 2018)
Bamboo fiber	Epoxy resin	28.3MPa	90.3MPa	44.1	1.80%	(Ajibade et al., 2019)
Avocado fiber	Epoxy resin	50.22MPa	74.74MPa	38.3	0.24%	Present work

In summary, the research efforts on natural fiber reinforced epoxy composites and avocado powder reinforced epoxy composites have highlighted the potential for these materials to be used in automotive brake pad applications. The improved mechanical properties make them viable alternatives to traditional brake pad materials.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Recently, many researchers are beginning their study to replace metallic products with composite materials in order to reduce weight. For reasons of reduced price and eco-friendliness with cleaner production, NFRPCs are preferred for such kinds of applications. In this research, avocado seed particles and B_4C particles are utilized to produce composite materials using an open molding process, and their mechanical behaviors like tensile, compression, flexural, and impact properties are examined. Various mechanical tests were done in order to assess the mechanical qualities of an epoxy composite reinforced with avocado seed powder and B_4C filler.

The flexural and tensile properties of epoxy composites with avocado seed powder and B_4C particle reinforcement are highly impacted by the vol.% of avocado in the epoxy matrix. As the avocado content increases from 5 to 15% volume fraction, the strength properties also increase. With a rise in avocado percentage to the resin, the avocado-epoxy composites of S1, S2, S3, S4 and S5 composites have an average hardness of 28.83, 32.50, 38.43, 33.46 and 34.26 HV, respectively. Composites' hardness is greatly influenced by avocado powder. The addition of avocado seed powder from neat epoxy to 15 vol.% increased the Vicker's hardness by 18.83%. The composites' impact strength decreases with respect to neat epoxy with an average impact strength of 34.5, 32.5, 30.5, 19.5 and 19 kJ/m^2, for S1, S2, S3, S4 and S5, respectively.

The compressive modulus of B_4C particles and avocado seed powder reinforced epoxy composites is improved in comparison to neat epoxy samples. When compared to neat epoxy samples (S1), the improvement in compressive modulus is 60.10, 114.95, 89.05 and 162.89% for S2, S3, S4 and S5 respectively. When compared to no filler-reinforced epoxy samples, all avocado-epoxy composites have superior strength. With the increase of avocado seed powder 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, 84.25, and 99.56 MPa, respectively.

Water absorption results affirm that, at various absorption times, S1 (neat epoxy) exhibits the maximum water absorption when compared to the other specimens. The specimens S3, S4, and S5, which include 5, 10, and 15% of avocado filler, exhibit the lowest water absorption. This may be attributed to the uniform distribution of boron carbide and avocado fillers, which help to reduce water absorption. The composite specimen (S4), which has 5 vol.% B4C particles and 10 vol.% avocado fiber powder, was shown to require much less water during the water absorption test than the other composite specimens.

5.2 Recommendations

The current work illustrates the feasibility and manufacturing of epoxy-based composite materials reinforced with avocado seed powder and B_4C particles. These materials are environmentally safe, lighter, and have reasonably good characteristics. Furthermore, the use of avocado seed powder minimizes waste and environmental problems. The recommendations below were made after considering the fabrication and characterization of epoxy composites with avocado seed powder and B_4C particle reinforcement.

- This composite material is recommended for automotive, manufacturing, and construction sectors to use this abundantly available avocado fiber resource.
- Any agricultural industry seeking to replace heavy metals with lightweight, recyclable, sustainable, ecologically safe, and green composites should give attention to such kinds of materials.
- They can be used to make automobile parts because they enhance strength and durability while also minimizing the total machine weight. This results in low fuel consumption and longer machine life.

5.3 Future Scope of the Research

Avocado seed powder in the range of 0 to 15 vol.% was investigated in this research. This can be expanded to include a greater avocado seed powder volume fraction to investigate the influence on the physical and mechanical properties of the composite. It is also possible to explore the mechanical and physical characteristics of avocado powder in combination with other kinds of natural fibers. The open molding method can also be changed to other precise manufacturing techniques and use the powder filler materials at a nanoparticle size. Across the country, avocado fibers of varying ages, weather, and soil conditions should be employed by doing more research into the material's physical, mechanical, morphological, thermal, and chemical properties. This research can also be expanded by including the wear characteristics and machinability of the developed material.

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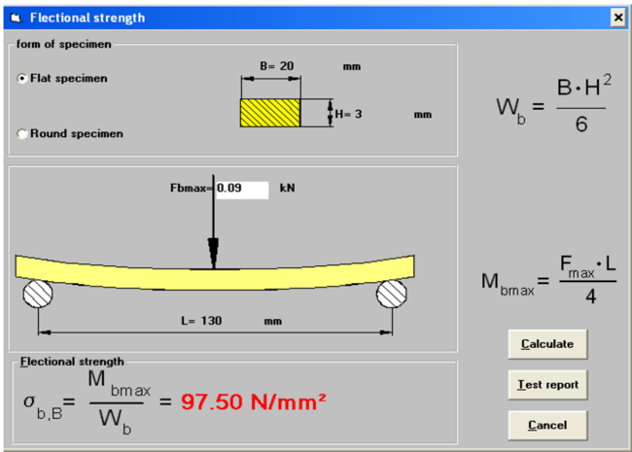
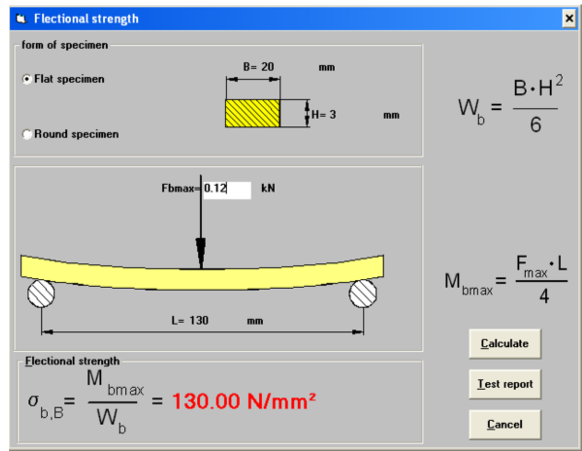
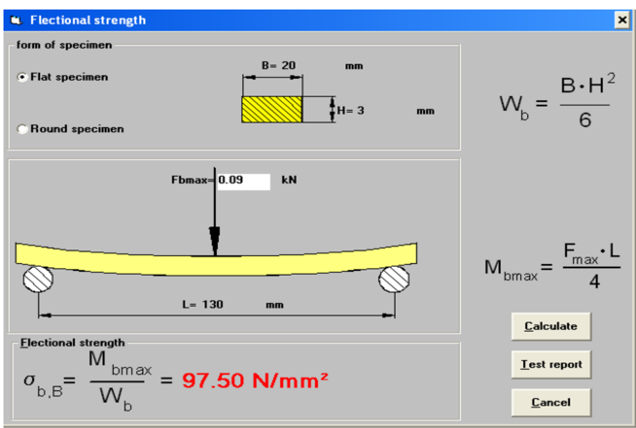
APPENDIXES

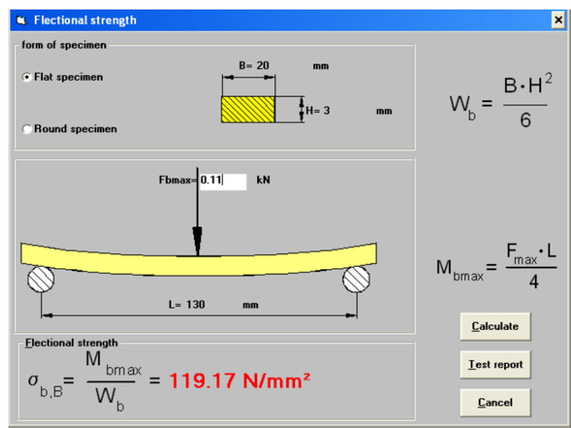
Appendix A

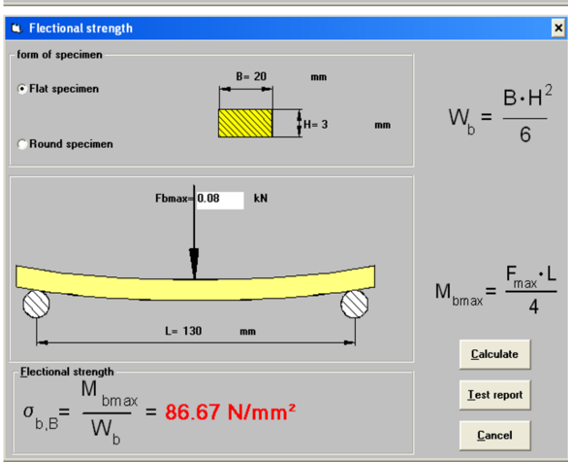
Flexural Test

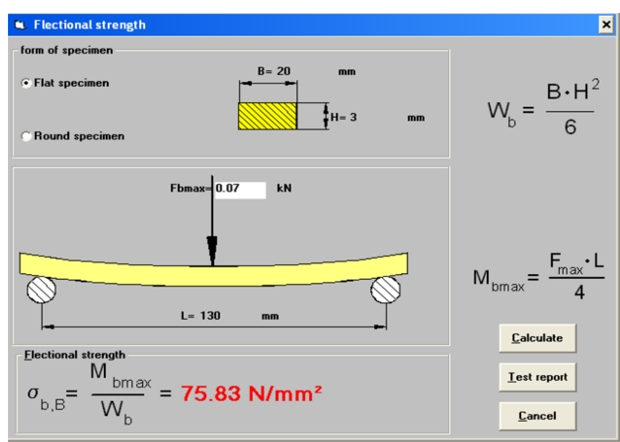






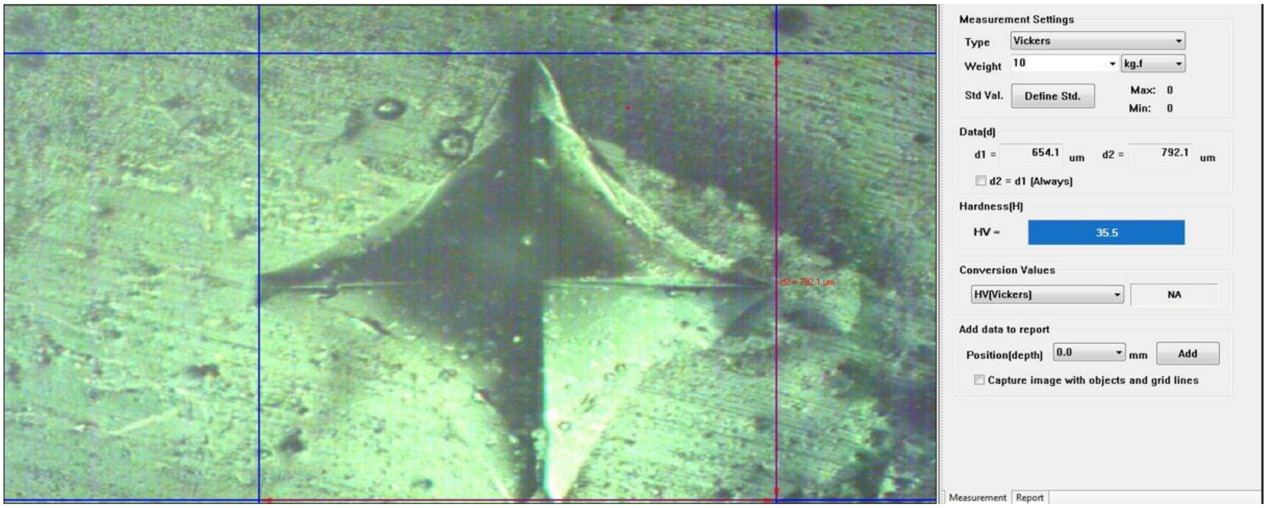


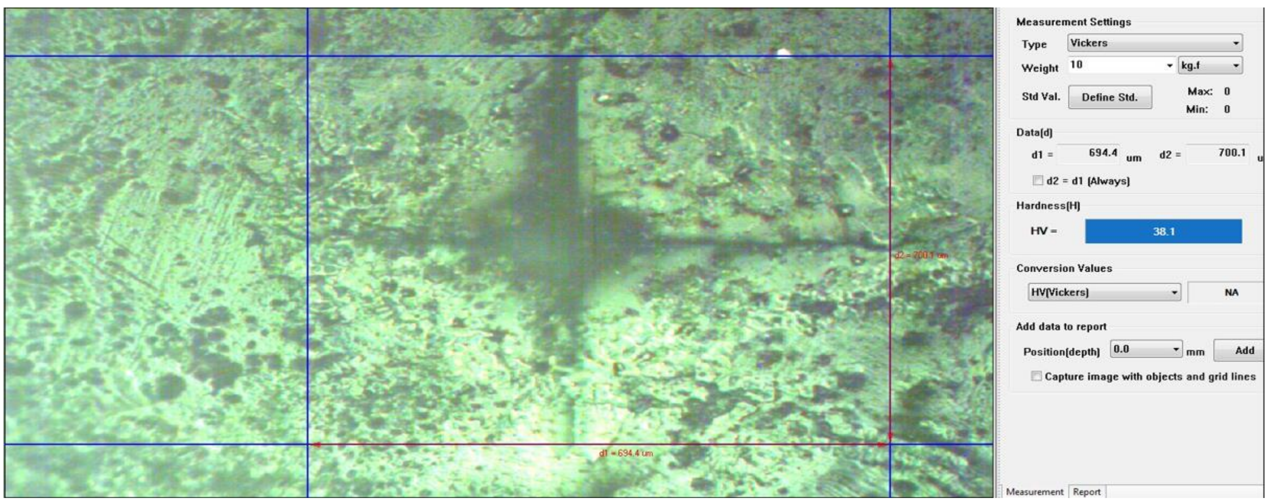


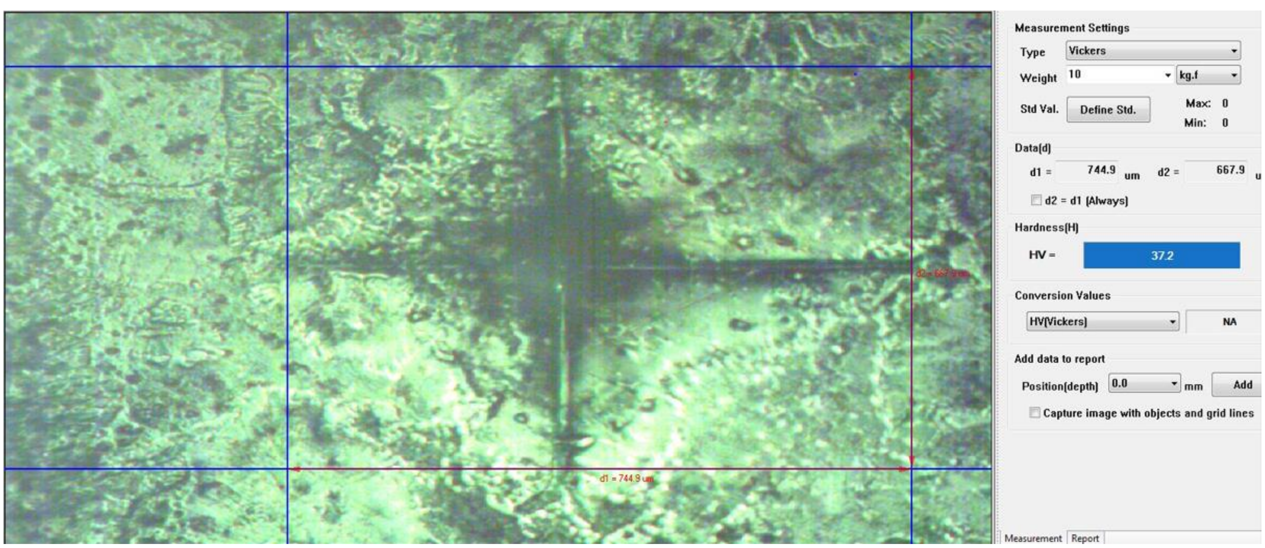


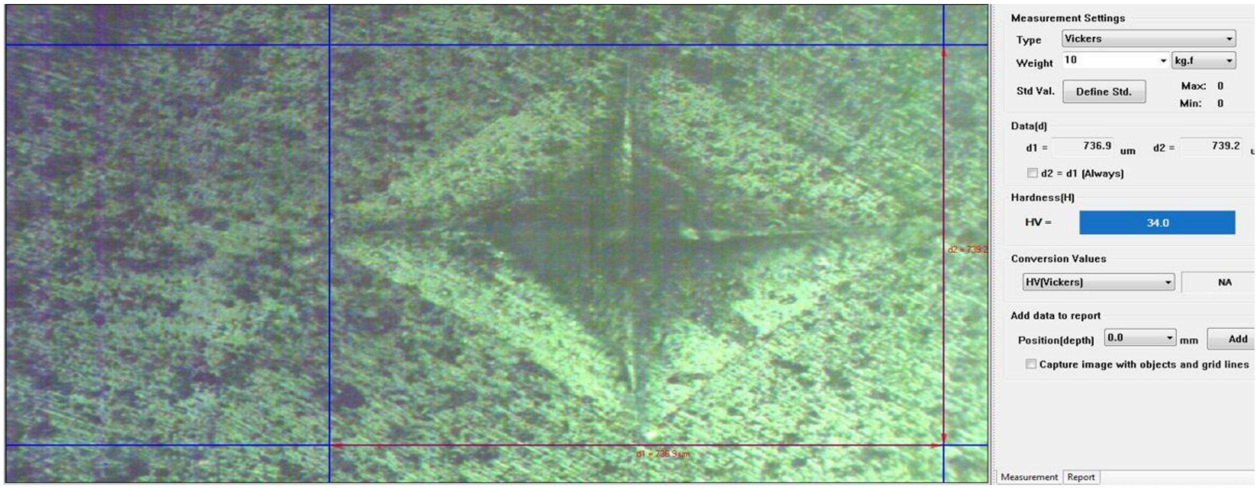
Appendix B

Hardness Test





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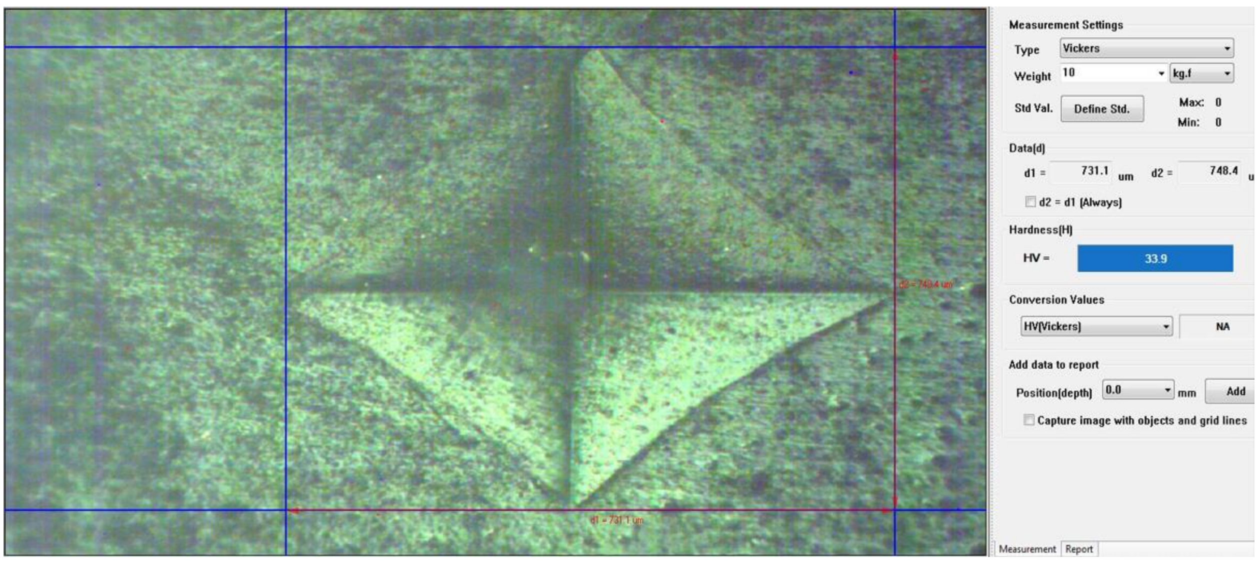
Type
Vickers
Weight
10
kg.f
Std Val.
Define Std.
Max: 0
Min: 0
Data(d)
d1 =
736.9
um
d2 =
739.2
d2 = d1 (Always)
Hardness(H)
HV =
34.0
Conversion Values
HV(Vickers)
NA
Add data to report
Position(depth)
0.0
mm
Add
Capture image with objects and grid lines
Measurement
Report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Vickers
Weight
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Std Val.
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Min: 0
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d1 =
731.1
um
d2 =
748.4
d2 = d1 (Always)
Hardness(H)
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HV(Vickers)
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Position(depth)
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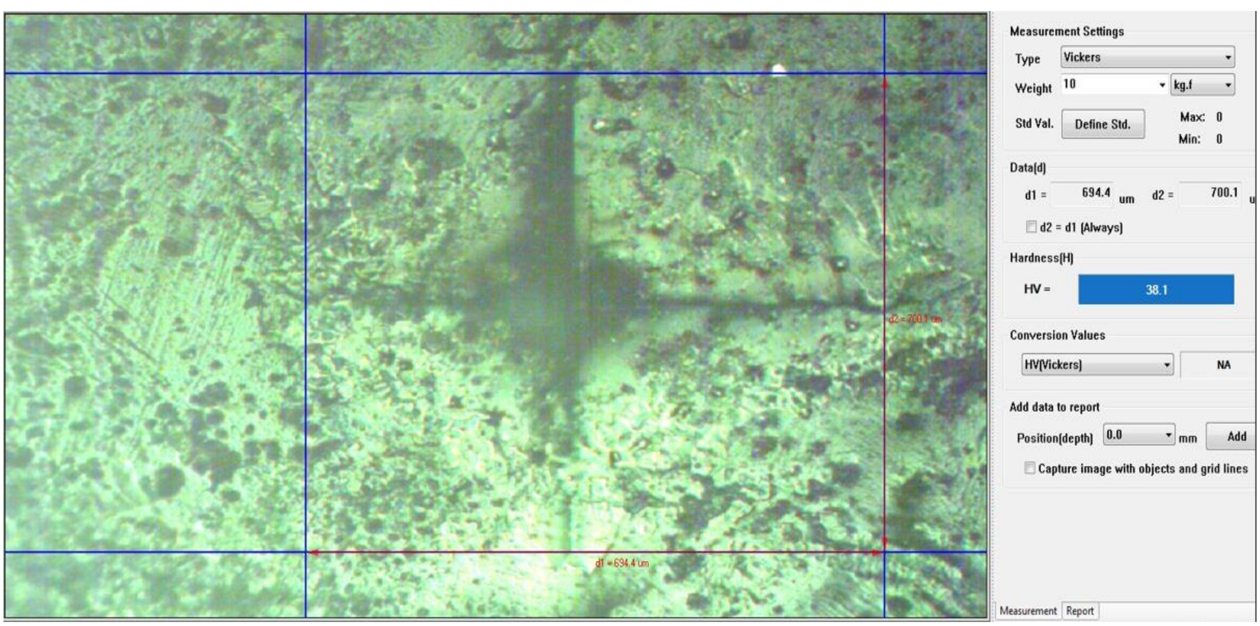
mm
Add
Capture image with objects and grid lines
Measurement
Report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Vickers
Weight
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kg.f
Std Val.
Define Std.
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Min: 0
Data(d)
d1 =
694.4
um
d2 =
700.1
d2 = d1 (Always)
Hardness(H)
HV =
38.1
Conversion Values
HV(Vickers)
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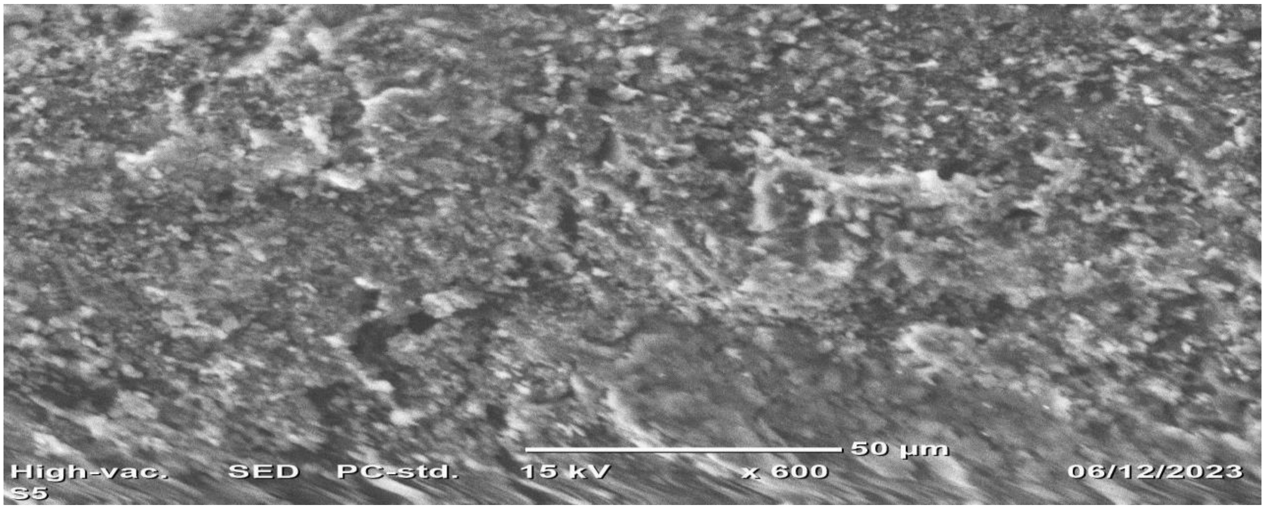
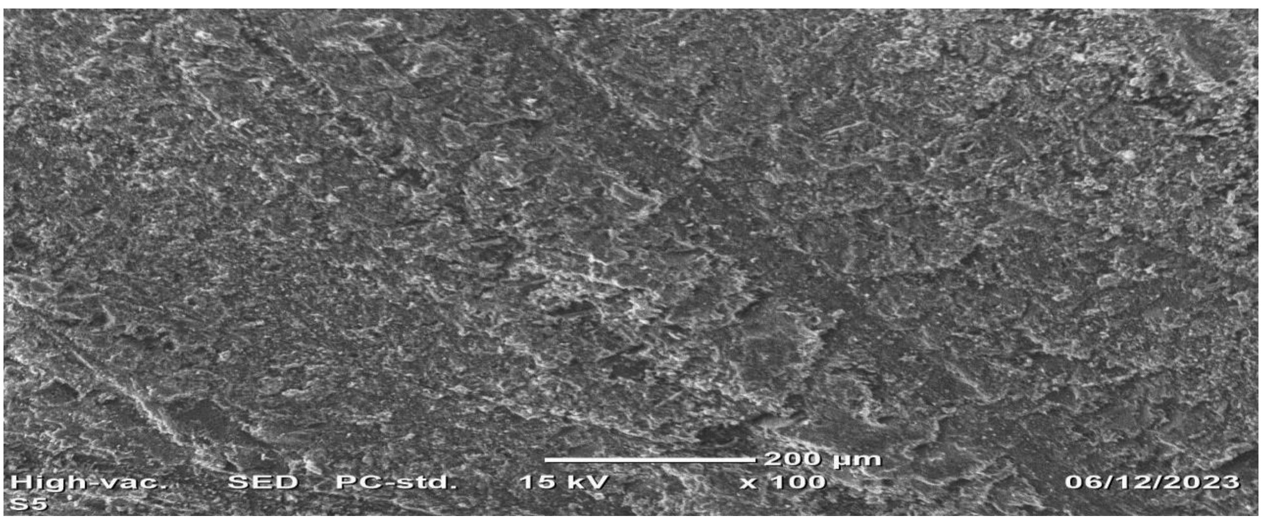
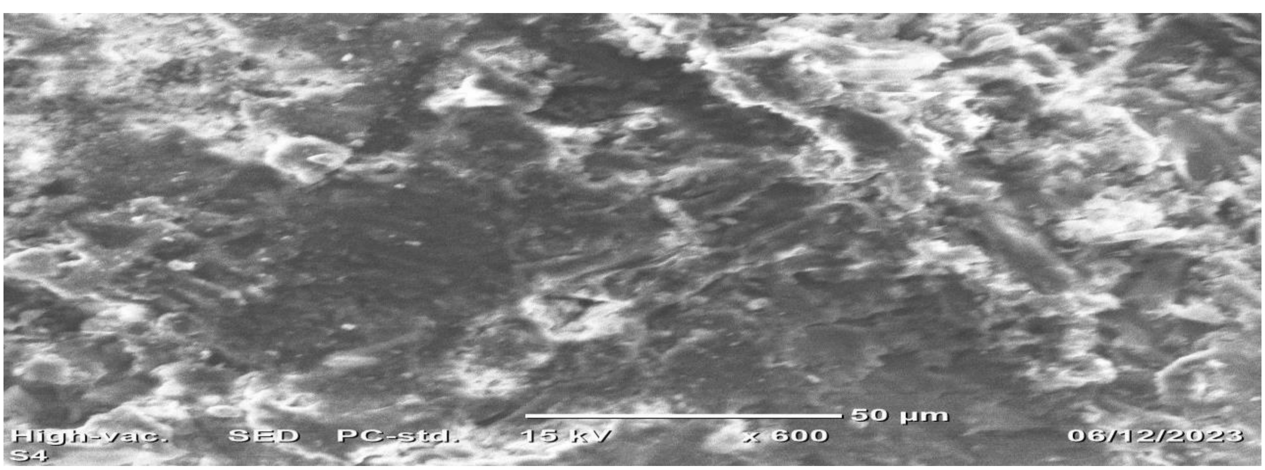
Position(depth)
0.0
mm
Add
Capture image with objects and grid lines
Measurement
Report

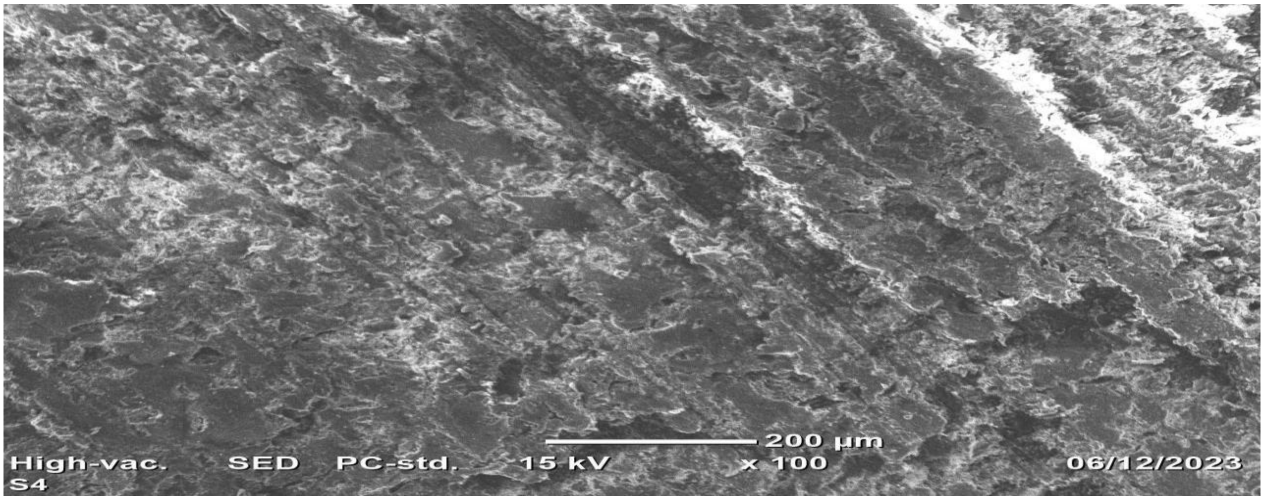
Appendix C

Morphology





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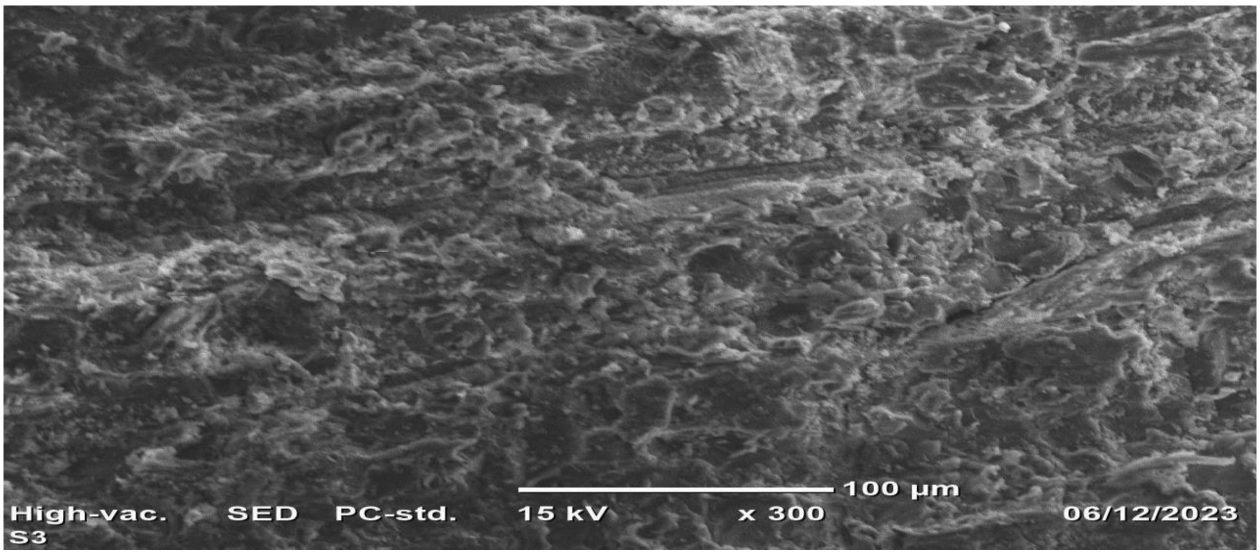
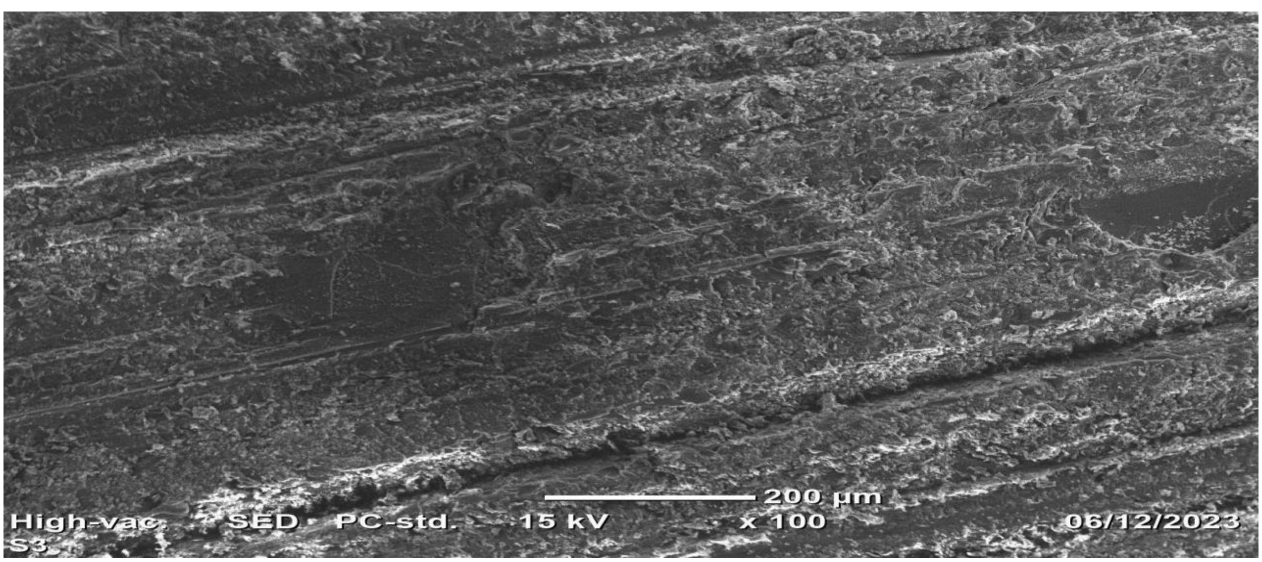
High-vac. SED PC-std. 15 kV x 100 06/12/2023
S4


100 µm
High-vac. SED PC-std. 15 kV x 300 06/12/2023
S3


200 µm
High-vac. SED PC-std. 15 kV x 100 06/12/2023
S3

Appendix D

XRD Analysis

********** SEARCH / MATCH RESULT **********

<Unknown Data>

Group Name : Standard

Data Name : Avo--Powder

File Name : Avo--Powder.PKK

Sample Name : Avocado

Comment : Test 1

Date & Time : 09-01-23 18:28:00

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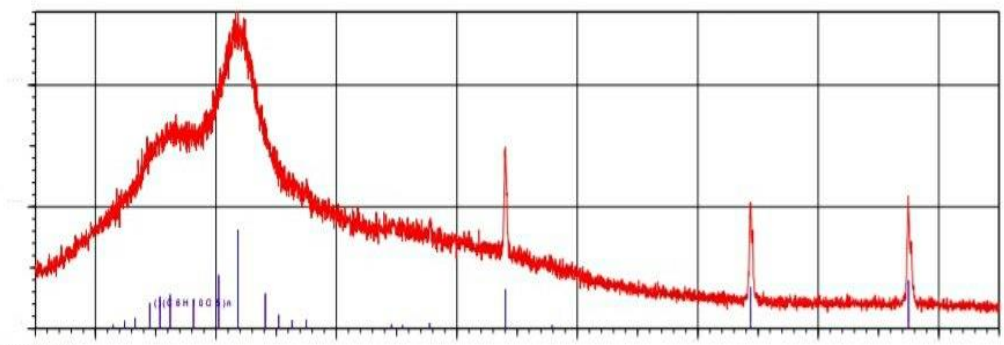

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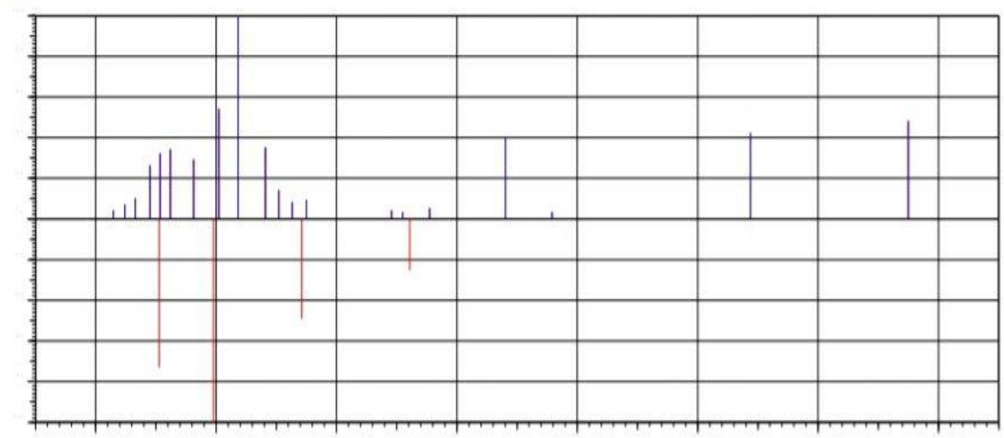

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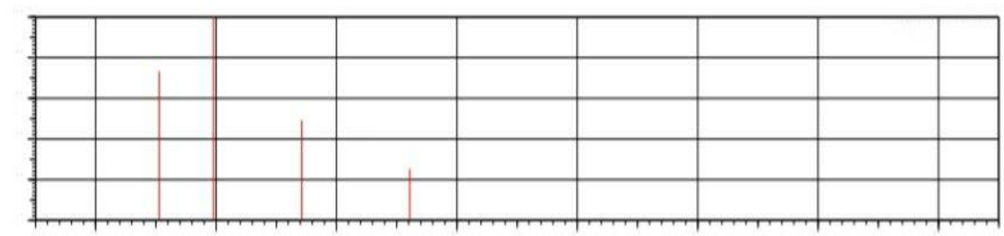

Appendix E

Samples before and after performing test

Appendix F

5 vol. % B_4C and 5 vol.% avocado seed particulate reinforced epoxy composite

This sample was made with 5 vol.% ASP and 5 vol.% B_4C in which B_4C were sieved with coarse sieve size. The unevenness of the size of the avocado powder and the boron carbide were the key factors for the high sedimentation as shown in the figure.