FABRICATION OF A HYBRID COMPOSITE ABRASIVE SANDPAPER USING COCONUT SHELL AND CRAB SHELL PARTICLES EMBEDDED IN POLYESTER RESIN

BY

IDOWU MICHEAL IFEDAYO	**ENG1805309**
INIKORI OGHENERUONA IRUOESIRI	**ENG1805310**
LAWANI OSAYI PRECIOUS	**ENG1805311**
MADUKWE OBINNA STEPHEN	**ENG1805312**
NAPOLEON EMMANUEL OSEMUDIAMWEN	**ENG1805313**

SUPERVISED BY

ENGR. NOEL IGBINOMWANHIA

SUBMITTED TO

THE DEPARTMENT OF MATERIALS AND METALLURGICAL ENGINEERING, FACULTY OF ENGINEERING UNIVERSITY OF BENIN, BENIN CITY

IN FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.Eng) IN MATERIALS AND METALLURGICAL ENGINEERING

CERTIFICATION

This is to certify that the undergraduate project work titled "**Fabrication of a hybrid composite abrasive sandpaper using coconut shell and crab shell particles embedded in polyester resin**" is an original piece of work and has not been submitted for any other degree or academic award. This project was carried out by:

IDOWU MICHEAL IFEDAYO	**ENG1805309**
INIKORI OGHENERUONA IRUOESIRI	**ENG1805310**
LAWANI OSAYI PRECIOUS	**ENG1805311**
MADUKWE OBINNA STEPHEN	**ENG1805312**
NAPOLEON EMMANUEL OSEMUDIAMWEN	**ENG1805313**

under the supervision of Engr. Noel Igbinomwanhia, in the Department of Materials and Metallurgical Engineering, Faculty of Engineering, University of Benin, Ugbowo, Edo State. This project is submitted in partial fulfillment of the requirements for the award of the Bachelor of Engineering (B. Eng) in Materials and Metallurgical Engineering. The work presented in this project is original and has not been submitted for any other degree or academic award.

………………………………………. ……………….

ENGR. NOEL IGBINOMWANHIA **DATE**

SUPERVISOR

ENGR. WILFRED IROGUE ……………….

PROJECT COORDINATOR **DATE**

ENGR. DR. NOSAKHARE ENOMA ……………….

HEAD OF DEPARTMENT **DATE**

DEDICATION

This project is dedicated to God Almighty, whose grace has made all things possible. It is also dedicated to our families and loved ones, whose unwavering support and understanding have been the cornerstone of our academic pursuits. Their encouragement and sacrifices have fueled our determination to excel, and this work stands as a token of our deep appreciation for their invaluable presence in our lives.

ACKNOWLEDGMENT

First and foremost, we offer our heartfelt gratitude to God Almighty for His grace, mercy, and strength throughout the period of carrying out this project.

We extend our deepest appreciation to Engr. Noel Igbinomwanhia, our project supervisor, for his unwavering guidance, mentorship, and support. His expertise and encouragement have been pivotal in shaping our research endeavors and academic growth.

We are profoundly thankful to our respective parents for their unwavering love and support throughout this project.

Our sincere appreciation goes to Engr. Wilfred Irogue, our project coordinator, for his invaluable assistance, coordination, and insights that significantly contributed to the successful execution of this project.

Furthermore, we acknowledge Engr. Dr. Nosakhare Enoma, the Head of the Department, for his continuous support and encouragement toward academic excellence within the department.

Special gratitude is extended to our funders for their generous financial support, which enabled us to carry out this project effectively.

Lastly, we express our gratitude to all individuals, organizations, and institutions who, directly or indirectly, contributed to the completion of this project.

ABSTRACT

In this study, the fabrication of a hybrid composite abrasive sandpaper using coconut shell and crab shell particles embedded in polyester resin is investigated, aiming to address resource depletion and environmental issues associated with conventional synthetic abrasive materials. The mechanical properties and abrasive behavior of the fabricated composite are investigated through meticulous methodology involving sourcing, cleaning, drying, mechanical processing, and production of abrasive specimens. Varying levels of hardness, compressive strength, density, and water absorption are revealed across different compositions of coconut shell and crab shell.

The most optimal properties are demonstrated by Sample 5, with a proportion of 35% coconut shell and 65% crab shell, which exhibits reduced water absorption, enhanced hardness, competitive compressive strength, and favorable density characteristics. Comparative analysis with Garnet sandpaper suggests that the hybrid composite sandpaper samples offer competitive or superior performance.

Further research is recommended to optimize composition, utilize advanced characterization techniques, and explore sustainable manufacturing practices to enhance the performance and applicability of hybrid composite abrasive materials.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

1.1 BACKGROUND TO THE STUDY

An increase in population coupled with a corresponding increase in demand for agricultural products has resulted in enormous generations of agricultural waste that pose a challenge to farmers in terms of their proper handling, management, and disposal. Most often from Nigeria's farming perspective, these wastes have near-zero commercial or economic usage hence constituting a menace to the environment (Alhassan EA et al., 2019). Their alternative utilization as raw materials for other valuable products has recently gained attention among researchers. Hence, an increased interest in the effective and efficient ways of appropriating agricultural wastes as an alternative source of raw materials.

In recent years, there has been a growing interest in utilizing these agricultural wastes as abrasives. These agro residues, such as the shells from oil palm, coconut, palm kernel, periwinkle, and other solid crop residues, have become increasingly popular in engineering and environmental applications due to their comparative economic advantages as well as environmental advantages (Ajimotokan and Samuel, 2020; Aku, et al., 2012).

Abrasives are minute, hard particles with irregular shapes and sharp edges that are used to wear and cut off the surface of softer, less resistant materials (Ratia et al., 2014). According to Kalácska (2013), the abrasives used to make sandpapers can either be natural (i.e., found or derived from nature) or synthetic. Natural and synthetic abrasives, which can be made from a variety of materials, can be used as abrasives (Durowaye et al., 2014; Kohli, 2016; Zhan and Wang 2021). Strength, hardness, wear resistance, thermo-chemical stability, and sharp cutting points are all characteristics of these materials (Obot et al., 2017). The most frequently used synthetic abrasive materials are silicon carbide, aluminum oxide, and cubic boron nitride, which are primarily based on crude oil (Zhong and Venkatesh, 2009; Samuel, 2019)

Sandpapers are papers with friction or abrasive material bound to the surface. They consist of abrasive particles of a single layer attached to a flexible backing material by a bonding agent (The Pacif. J. of Sci. and Technol., 2012). They are primarily used for sanding and smoothing in wood, metal, sculptural, and architectural works.

Largely, one of the commonly used alternative and renewable organic materials, as abrasives, are grains from agro-residues (Ajimotokan & Samuel, 2020; Samuel, 2019). Agricultural wastes are organic waste compounds from plant seeds, leaves, shells, fruits and roots such as oil walnut shell, palm shell, corn chaff, rice husk, sea shell and coconut shell. The convenience of agricultural wastes in the manufacturing sector is not only cost-effective but also helps in the control of environmental pollution (Oyelaran *et al.,* 2015).

Among the benefits of these wastes are the production of brake pads, sandpaper grains, helmets, composite materials and as a fuel in energy technology (Nuhu and Adeyemi, 2015; Suryarghya and Paul, 2007).

In Nigeria, available synthetic abrasive materials are either very scarce or very expensive; this is mainly due to the non-availability or high cost of the materials (such as silicon carbide, aluminum oxide and aluminum silicate) used in their production (Ibrahim H.K., et al 2019). Meanwhile, the available natural materials, like lime, chalk and silica, aluminum silicate, kaolinite, diamond and diatomite are found to be less effective due to the impurity nature of the materials. (Ambali Ibrahim Owolabi et al; 2020).

The application of wastes will be cost-effective, and might as well bring about environmental control and improve foreign exchange (Aku et al., 2012). The necessity to utilize this unlimited capacity in transforming wastes into wood or metalwork tools is identified as abrasive sandpaper. Crabs are crustaceans available in high quantities in coastal areas. It belongs to the phylum Arthropoda, order Decapoda and family Portunidae. Crabs are high in calcium; potassium, magnesium, and manganese which make them possess hard and rigid exoskeletons (Elegbede, I.O. and Fashina-Bombata, H.A (2013)).

Coconuts belong to the palm family Arecaceae, They are domestic plants that are well suited to Nigeria's eco-climatic conditions. Products from this plant are in high demand because of their inherent distinctive nutrients and wide industrial applicability for varied domestic products.

Using crab shells and coconut shells as abrasive materials would be an eco-friendly solution to the waste management challenges of these agro wastes. As different materials exhibit different behaviour because of their grain mass compositions, establishing their mechanical properties is a requisite approach for their application and performance.

Making composites has emerged as a key technique for creating high-quality materials that may be used in a variety of engineering applications. Aeronautics, mechanical, electrical, civil, and automotive engineering are among the fields where composite materials are used. Generally, a composite is a material made from two or more materials with distinctly different properties but amalgamated and engineered to have specific superior properties different from those of the constituent materials (Mishra et al., 2002; Landesmann et al., 2015). This project aims to contribute valuable insights into the feasibility and performance of hybrid composite abrasive discs by studying the interactions between the component materials and assessing their combined impacts on wear resistance, durability, and abrasiveness through analysis and experiments. The emphasis on eco-friendly substitutes is in line with current sustainability goals. It presents a promising path for the creation of abrasive tools with minimal negative effects on the environment, shedding light on their potential as alternatives for industrial applications.

1.2 STATEMENT OF THE PROBLEM

The conventional method of manufacturing abrasive sandpaper relies on the extensive use of synthetic, non-biodegradable materials, leading to resource depletion and environmental issues. In Nigeria, the disposal of agro-wastes such as coconut and crab shells poses an environmental challenge due to unpleasant odors and pollution. This research aims to tackle these issues by investigating the creation of a hybrid composite abrasive sandpaper. The specific challenge involves exploring the viability of integrating naturally occurring agro-wastes particularly coconut and crab shell particles into a polyester matrix. The project seeks to develop an environmentally sustainable composite material that not only addresses the ecological impact of conventional abrasive materials but also contributes to alleviating environmental pollution caused by agro-waste in Nigeria. The overarching goal is to provide a practical and sustainable solution for abrasive material applications, simultaneously reducing environmental effects and transforming agro-waste into valuable products.

1.3 AIM

The present research aims to review, design and fabricate a hybrid composite abrasive sandpaper using coconut shell and crab shell particles embedded in a polyester matrix.

1.4 OBJECTIVES

The objectives of the research are to

i. Evaluate the mechanical and abrasive properties of coconut shell and crab shell hybrid composite.
ii. Determine the optimal ratio of coconut shell to crab shell particles for enhanced composite performance.
iii. Conduct material tests, including, hardness, compressive strength, water absoption and density test to assess the overall performance of the hybrid composite.
iv. Perform wear and abrasion tests to measure the abrasive properties of the sandpaper.
v. Provide recommendations for future research and development efforts in sustainable abrasive materials.

1.5 SCOPE OF STUDY

This study aims to fabricate a hybrid composite abrasive sandpaper using locally sourced coconut and crab shells, followed by a comprehensive comparison of its properties with those of conventional abrasive sandpaper. The focus of this comparison will be on mechanical properties namely compressive strength, wear resistance, and examination of microstructures of the abrasive.

1.6 LIMITATIONS

- Lack of some equipments such as pin on the disk equipment, Rockwell/brintell hardness testing machine that prevented wear/abrasive tesing.
- The absence of microstructural analysis limited the understanding of the shell particles and resin behavior and interactions.
- Due to time restrictions, the standard 14-21 day curing process was shortened.

- Budget limitations and high chemical costs led to delays as alternatives were sought and materials were sourced from other states.

1.7 SIGNIFICANCE OF STUDY

This study holds paramount significance in addressing critical industrial and environmental challenges. By delving into the creation of a hybrid composite abrasive sandpaper that incorporates coconut and crab shell particles within a polyester matrix, it serves as a pivotal step towards sustainable materials development. The exploration of this eco-friendly composite aims to actively mitigate the adverse environmental impacts associated with both the manufacturing and disposal of conventional synthetic abrasives.

Beyond its environmental contributions, this study holds transformative potential for local economies and communities. By integrating coconut and crab shell particles into a valuable composite material, it enhances their economic value, presenting an innovative opportunity for additional income sources. This economic uplift extends to communities and farmers involved in the collection and processing of these agro-waste materials, contributing to the socio-economic development of the region.

Furthermore, on a national scale, the study has the potential to reduce Nigeria's dependency on the importation of synthetic abrasive materials. This not only aligns with sustainable and self-sufficient practices but also bolsters the country's economic resilience by fostering local industries and reducing reliance on external sources.

CHAPTER 2

LITERATURE REVIEW

2.1 History

The historical evolution of abrasives traces back to the earliest human endeavors, where primitive tools were fashioned by rubbing one hard stone against another. References in ancient texts, such as the Bible, suggest the use of materials like shamir, likely emery, an abrasive still employed today. Depictions from ancient Egyptian drawings illustrate the use of abrasives in polishing jewelry and vessels. Notably, sculptures like "The Grinder" in the Uffizi Gallery reveal the utilization of irregularly shaped natural sharpening stones for honing knives (Mason & Bodin, 2019).

During antiquity, sand and flexible hide served as rudimentary forms of sandpaper. Subsequent attempts by craftsmen involved affixing abrasive grains to flexible backings using primitive adhesives. Documented in a 13th-century Chinese manuscript, natural gums were employed to attach bits of seashell to parchment. The Swiss later experimented with coating crushed glass onto paper backings.

The limitations of early abrasives, such as sand and glass, led to innovation in the 19th century. Swen Pulson's achievement in combining emery with potter's clay, resulting in the vitrified grinding wheel, marked a significant advancement. This breakthrough signaled the transition from inadequate glue-and-silicate bonded products to more efficient abrasive solutions.

As industry demands grew, the advent of synthetic abrasives became paramount. In the late 19th and early 20th centuries, inventors like Edward G. Acheson developed silicon carbide, and scientists at the Ampere Electro-Chemical Company pioneered alumina production. The General

Electric Company's successful synthesis of diamonds in 1955 further revolutionized abrasive technology, surpassing natural alternatives in various applications.

Originally reserved for tasks requiring precision and smooth surfaces, abrasives have since become ubiquitous in industrial settings. Advancements in grinding wheel speeds, machinery power, and abrasive quality have expanded their utility across diverse sectors (Mason & Bodin, 2019).

Agricultural waste includes organic substances from plant seeds, shells, leaves, fruits, and roots, like oil palm shell, rice husk, corn chaff, and coconut shell. Using agricultural waste in manufacturing is not only cost-effective but also a sustainable strategy to reduce pollution (Aku et al., 2012). Among the perks, waste products include brake pads, sandpaper grains, helmets, composite materials, and fuel for energy technologies (Nuhu and Adeyemi, 2015; Suryarghya and Paul, 2007). Plant parts can be used for a variety of manufacturing purposes. Agricultural and industrial waste from developing nations can be used as a replacement material for sandpaper production.

2.2 ABRASIVES

Abrasive discs serve as vital tools in metalworking workshops, facilitating tasks like cutting, trimming, deburring, welding blank preparation, and surface polishing for low and medium-carbon steels (Naiara et al., 2020). Machinists and technicians prioritize disc cost and service life in their daily production endeavors, with abrasive type and size, along with disc binder, emerging as key influencing factors. Among manual machine abrasive disc types, two variants stand out: those with a metal body employing diamond abrasives for cutting masonry, marble, and ceramics, and those incorporating aluminum oxide (Al_2O_3) or silicon carbide (Si_3N_4) grit materials, commonly used for cutting metals (Naiara et al., 2020).

Abrasives, encompassing sharp, hard materials designed to wear away softer, less resistant substances, range from natural to synthetic forms (Bodin & Mason, 2019). Their applications span a wide array of tools and products, including grinding wheels, sandpapers, honing stones, polishes, cutoff wheels, and more. Industries rely on abrasives to achieve the precision and ultrasmooth surfaces necessary for manufacturing automobiles, airplanes, space vehicles, mechanical and electrical appliances, and machine tools.

Abrasive cutting involves the creation of narrow and deep grooves through abrasion until the entire piece is cut off, such as in the cutting of rectangular rolled profiles of structural steel using abrasive discs. This operation typically occurs in dry conditions due to complications associated with using coolants in manual or semiautomatic machines (Egea et al., 2018; Martynenko et al., 2018).

2.2.1. Composition and Properties of Abrasives

Abrasives are derived from two main sources: natural and synthetic materials. Natural abrasives, including diamond, corundum, and emery, are found in deposits and require minimal processing. In contrast, synthetic abrasives undergo extensive processing from raw materials or chemical precursors. Examples of synthetic abrasives include silicon carbide, synthetic diamond, and alumina, which is a synthetic form of corundum. Synthetic materials have largely replaced natural abrasives in industrial applications due to their consistent properties, which are essential for most industrial processes. Natural abrasives, except for natural diamond, exhibit too much variability in their properties to meet industrial demands. (Mason & Bodin, 2019).

Among the essential properties of abrasive materials, hardness is paramount. Essentially, an abrasive must be harder than the material it aims to grind, polish, or remove. Various scales are used to measure the hardness of abrasive materials, including the Mohs hardness test, the Knoop hardness test, and the Vickers hardness test. The Mohs scale, developed in 1812, assesses resistance to indentation by determining which material can scratch another. Widely accepted, this scale assigns numerical values to natural minerals and is frequently used by mineralogists. The Knoop and Vickers hardness tests utilize pyramid-shaped diamond indenting devices to measure the indentation created by diamonds in a given test material. (Mason & Bodin, 2019). While the Vickers test primarily targets metals, the Knoop test enables the measurement of the hardness of highly brittle materials like glass and diamonds without damaging either the indenter or the test piece.

Toughness, or body strength characteristics, also play a significant role in the functionality of abrasives. Ideally, a single abrasive particle re-sharpens itself through the breakdown of its dull cutting or working edge, revealing another cutting edge within the same particle. Synthetic abrasives offer some control over this property by adjusting grain shape during crushing or sizing operations, altering the purity of the abrasive, alloying abrasives, and managing the crystal structure within abrasive grains. Consequently, abrasives can be tailored to meet the specific operating conditions of various applications. (Mason & Bodin, 2019).

2.3 SANDPAPER

Sandpaper, also referred to as glasspaper or coated abrasive, comprises sheets of paper or cloth affixed with an abrasive substance on one side (Hill, 1977). In contemporary manufacturing, sand and glass have been supplanted by alternative abrasives like aluminum oxide or silicon carbide. It's customary to denote the type of abrasive when describing the paper, such as "aluminum oxide paper" or "silicon carbide paper."

Sandpaper exists in numerous variations, including differences in the backing material, the grit substance, grit size, and bonding. With a spectrum of grit sizes available, sandpaper serves various purposes, such as smoothing surfaces (e.g., in painting and wood finishing), removing layers of material (e.g., old paint), or occasionally roughening surfaces (e.g., in preparation for gluing). The grit size of sandpaper is typically denoted by a number inversely proportional to the particle size. A low number, such as 20 or 40, signifies a coarse grit, while a high number, like 1500, indicates a fine grit.

Fig. 2.1 - 320-grit silicon carbide sandpaper, with a close-up view

The history of sandpaper traces back to 13th-century China, where crushed shells, seeds, and sand were adhered to parchment using natural gum. Other natural materials like shark skin and the rough scales of the Coelacanth were also utilized for abrasion. In Japan, boiled and dried horsetail plants served as a traditional polishing material finer than sandpaper. (Casey D. 2016; Parker J. 1962)

In 1833, John Oakey introduced glass paper in London, employing innovative adhesive techniques for mass production. Glass paper, superior to sandpaper due to its sharp-edged particles, gained prominence despite cheap sandpaper being fraudulently passed off as glass paper. (Stalker & Parker (1971).

A significant advancement came in 1921 when 3M invented wet and dry sandpaper, incorporating silicon carbide grit and a waterproof adhesive and backing. This innovation enabled the use of water as a lubricant, preventing grit clogging and finding initial application in automotive paint refinishing. (Jeffrey K. 1989)

2.4 ABRASIVE MATERIALS

Abrasive materials are hard, inflexible materials used to grind, sand, or polish softer materials. They play an important role in many production processes and are used in a variety of industries, including metallurgy, construction, and automobiles. Glass and flint, once prevalent, are now uncommon choices. Garnet finds frequent application in woodworking, while emery is commonly utilized for abrading or polishing metals. Aluminum oxide (Al_2O_3) emerges as the most prevalent in modern usage, offering a wide range of grits at a low unit cost, suitable for both metal and wood applications, including body shops. Silicon carbide (Si_3C), available in coarse grits to micro grits, is commonly used in wet applications. Alumina-zirconia, an aluminum oxide-zirconium alloy, finds utility in machine grinding applications. Chromium (III) oxide, available in extremely fine micron grit, is used in high-precision papers. Diamond abrasives are employed for finishing and polishing hard metals, ceramics, and glass, while ceramic aluminum oxide is preferred for high-pressure applications in both coated and bonded abrasives.

Sandpaper, when "stearated," incorporates a dry lubricant, preventing clogging and extending its useful life, making it ideal for sanding coats of finish and paint. The hardness of the grit material is crucial, with harder materials facilitating sanding on surfaces like hardwoods such as hickory, pecan, or wenge. For polishing granite, the grit material must surpass the hardness of the granite itself.

Sandpaper is available in various forms and dimensions to suit diverse needs. Belt sandpaper, typically cloth-backed, comes in different sizes tailored to fit various belt sanders. Disk sandpaper is designed to accommodate different models of the disc and random orbit sanders, with some versions perforated for specific sander models. Attachment options include pressure-sensitive adhesive (PSA) and "hook-and-loop" fastening systems, similar to Velcro. Sandpaper rolls, often referred to as "shag rolls" by contractors, offer versatility in usage. Additionally, sponge sandpaper is available for accessing tight spaces.

Grit size refers to the dimensions of the abrasive particles embedded within sandpaper. These dimensions are determined by evaluating the amount of abrasive material capable of passing through a filter per square inch. Various standards have been instituted to regulate grit size, specifying not only the average grit size but also the permissible deviation from this average. The most common standards include the United States CAMI (Coated Abrasive Manufacturers Institute, now part of the Unified Abrasives Manufacturer's Association) and the European FEPA (Federation of European Producers of Abrasives) "P" grade, which corresponds to the ISO 6344 standard. Other systems employed in sandpaper include those set by the Japanese Industrial Standards Committee (JIS) and the micron grade, predominantly used for extremely fine grits. In some instances, less costly sandpapers may rely solely on descriptive terms such as "coarse", "medium", and "fine" without adhering to a specific standard.

Fig. 2.2 - Grit sizes

2.5 COCONUT SHELL

Coconut shells, often overlooked as waste, harbor remarkable potential for various applications. Within their hierarchical structure lies a wealth of materials science. The primary constituents of coconut shells include chitin (similar to crab shells) and lignin. These components contribute to the shell's strength, rigidity, and hardness. The outermost layer provides natural protection, while the inner layers such as the dense woody structure and the endocarp surrounding the coconut seed add complexity. Coconut shells are inherently hard and abrasive, thanks to their chitin content. When finely ground, they become effective abrasive material. Imagine these shells transformed into sandpaper, smoothing wood surfaces with eco-friendly grit sizes (e.g., P40 and P60). The fibrous network within coconut shells, rich in cellulose, enhances their mechanical properties. Coconuts are grown in over 93 countries. Coconut shell particles range in size from 5-20 mm. The shell's surface texture was smooth on the concave faces and rough on the convex. However, Shells account for over 60% of domestic trash volume, resulting in an annual generation of 3.18 million tonnes and contributing significantly to pollution in the country (Maninder and Manpreet, 2012).

2.6 CRAB SHELLS

Crabs are a type of aquatic animals that are difficult for people to find in landlocked places but are abundant in coastal areas. In West African coastal waters, swimming crabs, or Callinectes amnicola, are a significant source of food. It is a member of the family Portunidae, order Decapoda and phylum Arthropoda. Because of their high calcium, magnesium, potassium, and manganese content, crabs have a strong, rigid exoskeleton. (Elegbede, I.O. and Fashina-Bombata, H.A (2013).

The primary component of these shells is chitin a carbohydrate polymer. Within the shell, rigid chitin molecules align antiparallelly, forming α-chitin nanofibers with an extended crystalline structure. These nanofibers are enveloped by a protein layer. Moving inward, we encounter clusters of protein/chitin nanofibers, creating a twisted plywood structure that gradually rotates around its normal axis. Interestingly, small cavities within this helicoidally-shaped structure embed calcium carbonate (specifically calcite crystals). In a previous study, researchers isolated chitin nanofibers from crab shells using a simple mechanical treatment. These nanofibers exhibit distinctive morphology, a high surface-to-volume ratio, impressive mechanical strength, and efficient biological properties. (Yihun F.A et al., 2016)

The carapace, a protective shell on a crab's back composed primarily of chitin, serves as the main component of arthropod exoskeletons, including those of crabs. Chemist P. Romano conducted a study revealing that the carapace's main constituents are calcium carbonate and other inorganic minerals. This composition contributes to the carapace's ability to withstand high stress. Notably, the yield strength of calcium carbonate material is relatively high, providing a protective boundary for the crab's body against external impacts. Additionally, the materials within the carapace act as an insulation board, shielding crabs from extreme temperatures as they seek refuge under rocks and sand to evade predators. (Mohamed. O et al., 2014)

2.7 COMPOSITE MATERIALS

Composite materials are widely used in various engineering applications due to their unique properties. However, machining composites using conventional methods can be challenging due to their anisotropic and non-homogeneous nature. Abrasive water jet machining (AWJM) has emerged as an efficient and economical process for machining composites. AWJM utilizes a high-velocity stream of abrasive particles suspended in water to remove material. In the last three decades (1991–2020), research has extensively explored AWJM of composites. Studies have investigated the influence of process parameters on response characteristics, including surface finish, material removal rate, and delamination. (Dahiya A. K et al., 2022).

Researchers have explored the use of advanced composite materials in abrasive applications. These composites combine reinforcing fibers (such as carbon or glass) with a matrix material (such as epoxy or polyester resin). Abrasive composites find applications in grinding, cutting, and polishing. They offer improved wear resistance and durability. (Shoor, S., 2019)

A composite material comprises two or more discontinuous components with distinct physical or chemical properties, aiming to enhance performance beyond that of individual components. By combining materials, weaknesses in one component can be addressed by the strengths of another, with the composite exceeding the capabilities of its constituents. It's imperative that the composite exhibits superior properties, whether in terms of strength, heat resistance, or other desired characteristics, compared to each component alone.

Reinforcements play a crucial role in composites, typically providing stiffness and tensile strength. They come in various forms, including whiskers, fibers, particles, and laminate sheets. Fiber-reinforced composites have gained prominence due to their enhanced strength and mechanical properties in fibrous form. However, they often exhibit anisotropic properties. Conversely, particulate reinforcement can offer a more isotropic property distribution.

The matrix functions as a binder, firmly holding the reinforcement together to create a composite capable of withstanding stresses and carrying loads. Matrices can be metals, ceramics, or polymers, with polymers, particularly resins, being the most widely used. These polymers often possess low stiffness, strength, and temperature tolerance, degrading upon heating. Thermosets, such as epoxy and unsaturated polyester, solidify upon heating but degrade under excessive heat.

The properties of a composite depend on the characteristics of both the matrix and reinforcing materials, as well as their distribution and interaction. A particle-reinforced composite, or particulate composite, incorporates particles to reinforce the matrix. When multiple particles, such as coconut shell and crab shell particles, are utilized, it becomes a hybrid composite. In cases where the particles have a diameter of 1 micron or higher and a high volume concentration, such as in this research where the particles constitute 92% of the total composite, it is classified as a large particle reinforced composite.

Polyester resins are widely used as matrix materials in fiber-reinforced polymer (FRP) composites. These composites consist of high-strength fibers (such as glass, carbon, or aramid) embedded in a polyester resin matrix. The combination of polyester resins with reinforcing fibers results in composites that exhibit improved mechanical properties, including tensile strength, stiffness, and impact resistance. Researchers have explored various aspects of polyester-based composites, including their manufacturing processes, mechanical behavior, and optimization techniques. (Singh, M. K. et al., 2020). Polyester resins are also utilized in the production of abrasive materials. These materials are essential for grinding, cutting, and polishing applications. In abrasive formulations, polyester resins serve as a binder, holding abrasive particles (such as silicon carbide or aluminum oxide) together. The resulting abrasive products find use in sandpaper, grinding wheels, and other industrial tools. (Arjmandi, R et al., 2021).

2.8 RELATED WORKS

Recent literature has emphasized that agrowaste materials present a possible path toward sustainable abrasive manufacture. To ascertain which agricultural waste sources—such as rice husks, coconut shells, periwinkle shells, crab shells, and corn cobs—are suitable for abrasive applications, researchers have thoroughly examined these sources. Agrowaste can be converted into abrasive particles with desired characteristics, such as hardness and grinding efficiency, by means of procedures including carbonization, activation, and chemical treatment. According to performance assessments, abrasives made from agrowaste perform as well as or better than regular alternatives in terms of wear resistance and surface finish quality.

Agro-residues, also known as agricultural or crop residues, are commercially produced from post-harvest agrarian activities. They are used as a substitute feedstock to produce natural abrasives as an alternative to synthetic abrasives derived from crude oil (Iyasara et al., 2014; Sadh et al., 2018).

In the local context, this work strives to reduce environmental pollution, enhance and improve the application of abrasive coconut and crab shells, and increase the value and revenue of local manufacturers. The work was inspired by the discovery of another use for the coconut shells and crab shells, which are considered agricultural waste materials. The outer shell is hard and rough to the touch.

Numerous researchers have studied abrasive instruments. Wai, J.J., & Lilly, M.T. (2002) investigated the production of sandpaper and emery cloth using materials that might be found locally. They treated the silicon sand (quartz) by screening it into two different grades: fine (180mm) and coarse (50mm). Epoxy resins were utilized as the bonds. After using the hand spray method to create sandpaper, they were able to collect samples of the finished product. Based on the results of a successful pilot project, they suggested a production procedure for small-scale enterprises.

Production of Abrasive Sandpaper using Periwinkle Shells and Crab Shells by Ibrahim A O, et al, 2020 talked about investigating the use of periwinkle and crab shells in the manufacture of abrasive sandpaper. The study looks into the viability of turning these copious waste materials into value-added goods for industrial use. The researchers evaluated the mechanical and abrasive properties of sandpaper made from periwinkle and crab shells using experimental procedures such as material preparation, formulation, and testing. Their findings indicate that these biowaste-derived abrasives have promising properties and have the potential to be sustainable alternatives to traditional sandpaper materials. The results of this study add to the expanding corpus of research on using natural resources to make eco-friendly abrasives, emphasizing the importance of waste valorization in improving the ecology and resource effectiveness in industrial processes.

CHAPTER 3

MATERIALS AND METHODS

3.1. Introduction

The methodology described herein presents a comprehensive approach to the fabrication of composite abrasive discs utilizing coconut shell and crab shell particles as reinforcing materials within a polyester resin matrix.

3.1.1 MATERIALS USED

The experimental materials are;

- Coconut shell (CNS)
- Crab shell (CBS)
- Polyester resin (binder)
- Methyl Ethyl Ketone Peroxide, MEKP (hardener)
- Cobalt naphthalene (accelerator)
- Distilled water.

3.1.2 EQUIPMENT USED

Similarly, major equipment and tools for sample formation and mechanical behaviour analyses are:

- Oven
- Grinding Machine
- Okhard Compression testing machine
- Vibrating sieving machine
- Sieves (300 microns)

- Electronic sensitive weighing balance (0.01 & 0.001)
- Wooden molds and dummy block
- Hand gloves
- Syringe
- Beakers
- Stirrers.

3.2. Method of Preparation

In the initial phase, one sack of raw coconut shell and crab shell samples each were sourced from Sapele market in Delta State. These samples underwent meticulous cleaning with distilled water to eliminate any extraneous impurities or contaminants that could potentially compromise the quality of the final composite. Following cleaning, a dual-stage drying process was implemented. Initially, the samples were left to sun-dry for three days to reduce moisture content. Subsequently, the sun-dried samples were subjected to further drying in an oven in the central research lab set at a constant temperature of 100°C for one hour to ensure the complete removal of residual moisture. This stringent preparation regimen was crucial in ensuring that the shells were devoid of any foreign matter and moisture, thereby safeguarding the integrity of the composite material.

Fig. 3.1 – Crab shells

Fig. 3.2 – Coconut shells

Fig. 3.3 – Oven-drying of Coconut and Crab shells

3.3. Mechanical Processing

Following the drying process, the coconut shell and crab shell samples underwent manual reduction using a hammer to achieve smaller sizes. Subsequently, mechanical grinding was employed to achieve a finely divided particle size distribution. This step was crucial for ensuring uniformity in particle size, which played a pivotal role in maintaining consistent mechanical properties and abrasive performance in the final composite. The mechanical grinding process was carried out separately for each shell material at Uselu market, allowing precise control over particle size and ensuring uniformity throughout the composite.

Fig. 3.4 – Manual reduction of coconut shells

Fig. 3.5 – powered samples (300µm)

3.4 Particle Size Analysis

Following the mechanical grinding process, the milled samples underwent particle size analysis. An automated electric sieve shaker equipped with a 300µm sieve size was employed for this meticulous step, adhering to ASTM standards. The primary objective was to classify the particles into FEPA abrasive grits, specifically conforming to P50 standards (ASTM E11-17). By doing so, we ensured that the composite material met stringent quality requirements for abrasive applications. The sieving process was iteratively repeated, with slight adjustments to the shaking duration, aiming to achieve a consistent and desirable particle size distribution.

Fig. 3.6 – Electric shaker

Fig. 3.7 – Sieving of samples

Fig. 3.8 – Weighing of samples

3.5 Production of Abrasive Disc Specimen

The digital weighing balance was utilized to measure the following quantities of CNS (coconut shell) and CBS (crab shell) grains: 74.10g, 68.40g, 57.00g, 45.60g, and 39.90g. These masses corresponded to a total of 57 wt% (114g) of the composite. The proportions of CNS to CBS were varied as follows: 65 wt% CNS: 35 wt% CBS, 60 wt% CNS: 40 wt% CBS, 50 wt% CNS: 50 wt% CBS, 40 wt% CNS: 60 wt% CBS, and 35 wt% CNS: 65 wt% CBS.

After weighing, the grains were carefully placed in transparent nylon cellophane. Next, we measured 80g of polyester resin, corresponding to 40 wt.%, with a 2.5% allowance (equivalent to 2g) to account for the remaining resin adhering to the plastic specimen holder due to its high viscosity. Subsequently, 1.5 wt % of cobalt naphthalene accelerator and 1.5 wt % of methyl ethyl ketone peroxide hardener were added to each container. These components ensured a 100 wt% material composition.

Before introducing the resin, we thoroughly mixed the particulate shells. The addition of the catalyst aimed to accelerate bonding, while the hardener facilitated curing and ensured comprehensive mixing. Each sample mixture underwent stirring for approximately five minutes, ensuring homogeneity of the composite.

3.5.1 Design Justification

TOTAL WEIGHT OF SAMPLE = 200g

Weight of Polyester resin = 80g + 2.5% of 80g = 82g

Weight of methyl ethyl ketone peroxide (MEKP) = 1.5 wt % of 200g = 3g

Weight of Cobalt naphthalene = 1.5 wt % of 200g = 3g

Table 3.1 – Weight percent composition of CNS/CBS polyester resin composite

Samples	CNS (g)	CBS (g)
Sample 1	65 wt. % = 74.10	35 wt. % = 39.90
Sample 2	60 wt. % = 68.40	40 wt. % = 45.60
Sample 3	50 wt. % = 57.00	50 wt. % = 57.00
Sample 4	40 wt. % = 45.60	60 wt. % = 68.40
Sample 5	35 wt. % = 39.90	65 wt. % = 74.10

A mold was meticulously fabricated from plywood, with dimensions 12cm by 12cm by 1.5cm, as depicted in the accompanying figure. To achieve a smooth finish, Vaseline was carefully applied to the inner surface of the mold and then cellophane to facilitate easy removal of the composite from the mold after curing. The subsequent steps involved the Hand layup method for processing the composite.

The homogenous mixture of resin-impregnated coconut and crab shell particles was meticulously laid within the mold until the desired thickness was achieved. To ensure close packing with minimal pores, uniformity, and structural integrity, the composite was carefully compressed using a flat dummy block of the same dimensions (12 by 12). Subsequently, the sample was placed in a well-aerated room and allowed to cure for two (2) days.

This procedural sequence was systematically repeated for varying weight percentages of coconut shell and crab shell particles. The objective was to explore the influence of composition on the mechanical and abrasive properties of the resultant abrasive discs.

3.6. Method of Characterization:

Standard mechanical tests were used to determine the empirical values of the vital abrasive analytical parameters.

3.6.1. Hardness test:

The hardness characteristics of the CNS and CBS composites were determined using the Mohs hardness test, as the Rockwell hardness tester was unavailable. The Mohs hardness test is a qualitative method used to measure the scratch resistance of materials. It involves scratching the test specimen with a set of reference minerals of known hardness on the Mohs scale, which ranges from talc (hardness 1) to diamond (hardness 10).

To conduct the Mohs hardness test, a clean and smooth surface of the composite sample was prepared. The test began with the softest reference mineral, and the process continued with minerals of increasing hardness until the reference mineral scratched the sample surface. The hardness of the composite is determined by the hardest reference mineral that does not scratch the sample, indicating that the composite's hardness is between that reference mineral and the next higher mineral on the Mohs scale. (Gerberich, W.W. et al., 2015)

The methodology followed the ASTM C1895-20 standard, which outlines the procedures for determining the Mohs scratch hardness of various hard surfaces. The test was performed under controlled conditions, ensuring that the reference minerals were applied with consistent pressure and at a consistent angle to the test surface. The results of the test provided a relative hardness value for the CNS and CBS composites, which is useful for comparing the scratch resistance of the materials to other minerals or composites with known Mohs hardness values." (https://www.astm.org/c1895-20.html).

3.6.2. Water absorption test:

The initial weight of each specimen (W_1) was measured before soaking in distilled water for a limited duration of 24 hours. After removal from the water, the specimens were meticulously cleaned to eliminate surface water droplets. Subsequently, the final weight (W_2) was recorded. The difference between the initial and final measurements allowed us to calculate the water absorption rate. Our approach followed the procedures outlined by Edokpia R.O et al. (2014).

Water absorption(%) = $\frac{W2-W1}{W1} \times 100\%$

Where:

W_1 = sample initial weight

W_2 = sample final weight

Fig. 3.9 – water absorption test

3.6.3. Compressive test

The compressive strength of a material indicates the maximum load it can withstand before shattering. In our investigation, we used a universal testing machine to determine the compressive strength of the composites. The process involved continuously compressing the samples until they failed. The force that caused failure was precisely documented as the material's compressive strength.

Fig 3.10 - Compression test using Okhard compression testing machine

3.6.4. Density Test

In this investigation, we used Archimedes' method to calculate the density of abrasive sandpaper composites. When an object is submerged in a fluid, it receives an upward buoyant force equal to the weight of the fluid displaced. We could determine the volume of an irregularly shaped entity by calculating the effective mass of the submerged object underwater (which includes the mass of the fluid displaced). As a result, the average density represented the mass per unit volume of the sample. The equation used was:

$$\text{Density } (\rho) = \frac{\text{Mass}}{\text{Volume}} = \frac{\text{m}}{\text{V}}$$

Fig. 3.11 – Density test using water displacement method

3.6.5. Wear resistance test

To determine how the generated sandpapers wear under heat-producing friction during service, we used the standard test procedure ASTM G99-17 (2017). Each sample was slid over a cast-iron surface at varied weights (40g, 80g, and 120g), at a sliding speed of 2.4 m/s, and held for 20 minutes at temperatures of 500°C and 1500°C. We determined the initial sample weight before running it through a set sliding distance. After completing the sliding distance, we took the sample, cleaned it, and dried it. The weight loss due to abrasive wear was then calculated using the sample's final weight. We employed the equation below to convert this weight loss into a wear rate, as outlined by Bashar, Peter, and Joseph (2012) and Edokpia et al. (2016).

$$Wear\ Rate = \frac{\Delta W}{S} = \frac{Wx - Wy}{S}$$

Where;

ΔW = weight difference ((i.e., weight loss)of the sample before and after the test in mg

S = total sliding distance in meters

Wx = initial weight of the sample before the wear test

Wy = final weight of the sample after the wear test.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

The results presented below follow standard testing procedures outlined in chapter 3, which aimed to evaluate the properties of the fabricated hybrid composite abrasive sandpapers. Through a series of tests including hardness, compressive strength, wear resistance, density and water absorption assessments, the performance of five distinct samples each with varying proprtioins of coconut shell and crab shell embedded in polyester, was carefully analyzed. The subsections below details the outcomes of these tests, providing insight into the suitability of the fabricated samples for abrasive applications.

4.1.1 Hardness Tests

The hardness tests were conducted on all five samples (1-5) using Mohr hardness. The results are summarized in Table 4.1.

Sample	Hardness (HV)
1	4
2	4-5
3	5
4	5
5	6

Table 4.1 – Mohr hardness values

4.1.2. Compressive Test

Compressive strength tests were performed on the samples according to ASTM standards. The results are presented in Table 4.2.

Sample	Load (N)	Area (mm^2)	Compressive Strength (N/mm^2)
1	20100	41.5	48.434
2	24800	37.8	65.608
3	26070	48.0	54.313
4	17100	33.3	51.351
5	22390	41.0	54.610

Table 4.2 – Compressive strength values for compressive test.

4.1.3. Density Test

Density tests were conducted to evaluate the physical properties of the composite abrasive sandpapers. The results are presented in Table 4.3.

Sample	Mass of sample (g)	Volume displaced (ml)	Density (g/cm^3)
1	19.812	17.000	1.165
2	20.790	15.000	1.386
3	20.875	14.800	1.410
4	20.310	16.000	1.269
5	17.146	13.800	1.240

Tables 4.3 – Density test results using water displacement technique.

4.1.4. Water absorption test

Water absorption tests were conducted to determine the extent to which the composite material absorbs water, giving information about the material's resistance to moisture.

Table 4.4 – Water absorption values

Sample	Initial weight (W_1)	Final weight (W_2)	Water absorption (%)
1	19.31	19.58	1.40
2	19.17	19.46	1.51
3	18.13	18.35	1.21
4	19.76	19.99	1.16
5	20.66	20.85	0.92

4.2 Discussion

The quest for innovative, eco-friendly and sustainable composite materials continues to drive research and development. Our study which focuses on the fabrication of a hybrid composite abrasive sandpaper, a unique combination of coconut shell and crab shell embedded in a polyester matrix offers the promise of enhanced mechanical properties and superior abrasive behavior, addressing the limitations of conventional sandpaper materials.

With this context in mind, we delve into the analysis of the mechanical properties and abrasive behavior of our fabricated composite materials

Drawing from previous studies by Ibrahim H.K et al. (2019), Ibrahim Owolabi et al. (2020), and Ajimotokan H.A. et al. (2022), elucidating the mechanical properties and abrasive characteristics of analogous composite materials, the results of the various tests conducted are analyzed with better understanding.

According to Ibrahim H.K. et al. (2019), samples made from the P60 (250um) sieve size showed better mechanical properties than the corresponding samples from the P40 (420um) sieve size.

Ibrahim Owolabi et al. (2020) discovered that the composition with 92 wt.% periwinkle shell grains to 7 wt.% polyester resin (varied between 3 wt.% - 7 wt.%) exhibited significantly enhanced abrasive property.

M.U. Obot. et al., (2016) investigated the effects of varying palm kernel shell (PKS) and periwinkle shell (PWS) content in hybrid composites. They combined PKS and PWS at different weight percentages (95 wt%, 93 wt%, 89 wt%, and 87 wt.%) with polyester resin (at 4 wt.%, 6 wt%, 8 wt%, 10 wt%, and 12 wt.%). Their findings revealed that samples containing 87 wt% PWS exhibited superior properties due to favorable interfacial bonding and densely packed PWS grains within the resin binder.

Samuel, A. et al. (2023) conducted an investigation on composite materials and observed that the wear rate decreased with an increase in the weight percent of resin. Conversely, as the weight percent of resin decreased, the wear rate increased.

According to Mfon U et al. (2022), in periwinkle shell-epoxy composites, an increase in the weight percentage of palm kernel shells (PKS) led to significant improvements in mechanical properties. Specifically, samples with a particle size of 300 µm, when varied between 75 µm, 150 µm, and 300 µm, exhibited the highest values for hardness, tensile strength, compressive strength, and impact strength.

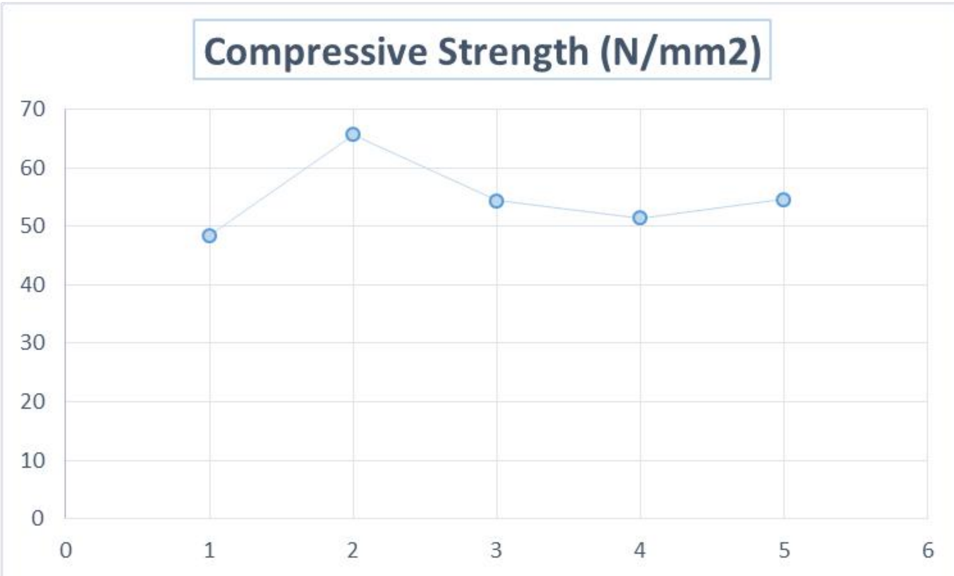

Fig. 4.1 – Compressive strength of samples 1 - 5

The compressive strength of the hybrid composite abrasive sandpaper samples varies with the proportion of coconut shell to crab shell, as illustrated in the accompanying figure. Initially, there is an uptick in compressive strength, culminating in a peak of 65.61 N/mm², which is then followed by a decline and eventual leveling off around 51.35 N/mm².

The initial surge in compressive strength implies an optimal interfacial bond among the CNS, CBS, and the resin, facilitating efficient stress transfer and load distribution, particularly evident in Sample 2.

The subsequent reduction in compressive strength post-peak suggests that exceeding a certain ratio threshold may lead to diminished interactions or suboptimal packing within the matrix, thereby decreasing the compressive strength.

The eventual stabilization of compressive strength indicates the presence of a critical ratio threshold, beyond which further alterations in the material proportions do not markedly affect the composite's strength.

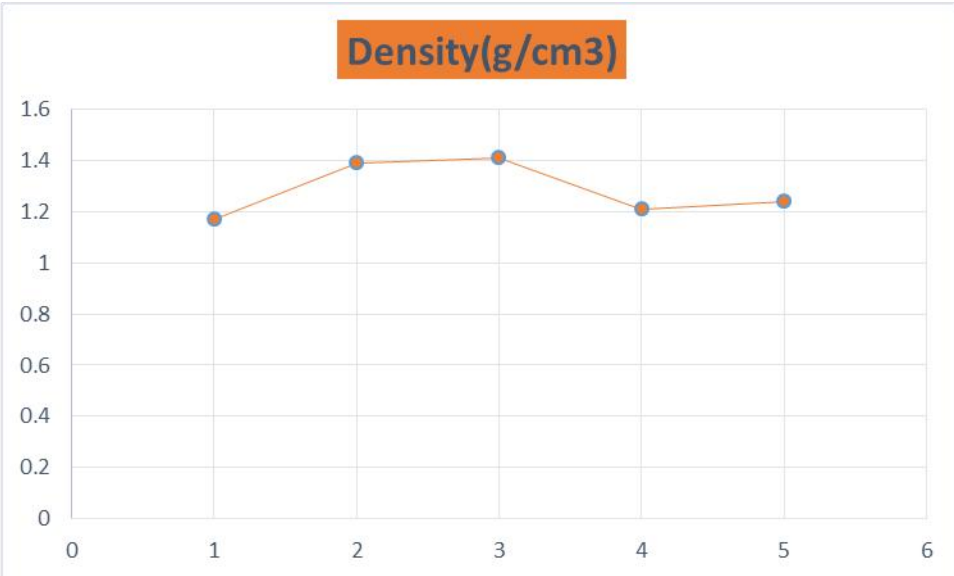

Fig. 4.2 – Density of samples 1 - 5

The density of the samples varies in accordance with the proportion of coconut shell to crab shell, as depicted in the figure above. Initially, there is a noticeable trend where the density increases, reaching a peak at 1.41 g/cm³, then decreases, followed by a slight uptick.

The initial rise in density could be due to improved packing efficiency or a more uniform distribution of materials within the polyester resin matrix at certain ratios.

The peak density, achieved at the balanced ratio of 50 wt% CNS to 50 wt% CBS, indicates that this composition attains maximum compaction, resulting in the highest recorded density of 1.41 g/cm³.

The subsequent decline in density suggests that adding more of one component beyond this balanced ratio may result in less efficient packing or the potential formation of voids within the matrix.

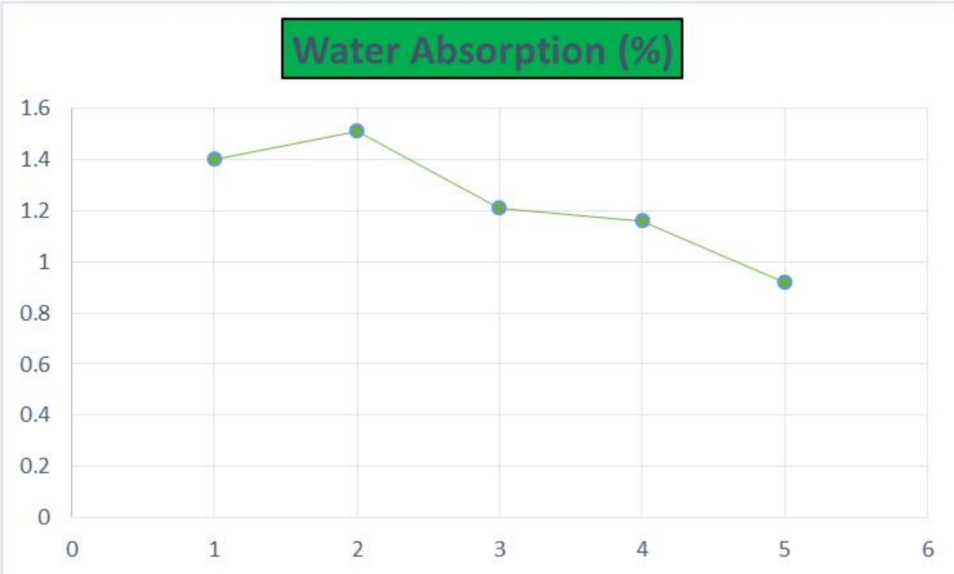

Fig. 4.3 – Water absorption of samples 1 - 5

The provided figure illustrates an initial increase in water absorption from Sample 1 to Sample 2. Subsequently, there is a more stable decrease in water absorption as the proportion of coconut shell to crab shell varies. This trend corresponds to the initially highest absorption observed in Sample 2, which gradually diminishes to much lower values in Samples 3 to 5. Sample 5, exhibiting the lowest absorption, likely achieves an optimal balance in this regard. The high absorption can be attributed to the porous structure of the composite, which facilitates water infiltration. As the proportion of crab shells increases, the material samples tend to become denser and less porous. Additionally, the surface quality and the bonding between the coconut shell, crab shell, and resin could influence water absorption values.

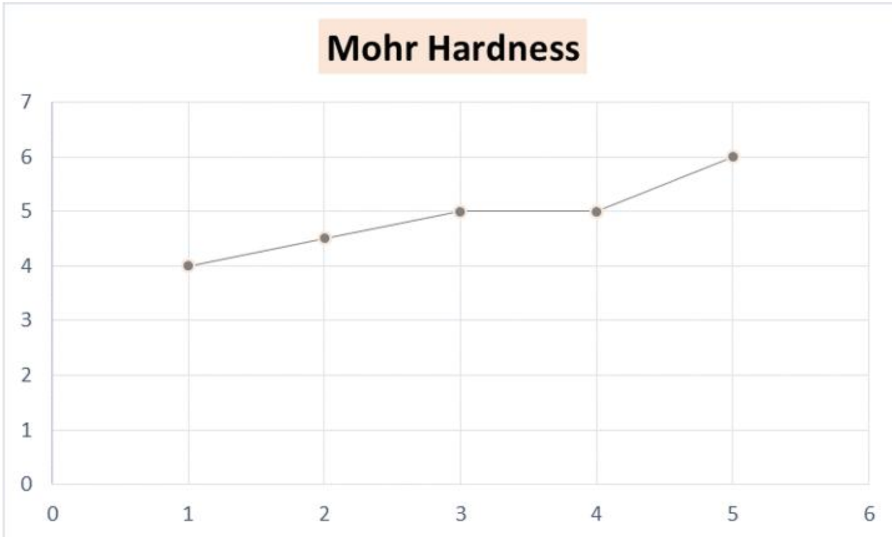

Fig. 4.4 – Hardness values of samples 1 - 5

The graphical analysis indicates a positive correlation between the Mohr hardness values and the increasing presence of crab shell particles within the composite matrix. Specifically, the data reveals a progressive enhancement in hardness when transitioning from a 65 wt% coconut shell (CNS) and 35 wt% crab shell (CBS) composition in Sample 1 to a 35 wt% CNS and 65 wt% CBS composition in Sample 5.

Sample 5, with the highest proportion of CBS, manifested a significant increase in hardness. This augmentation can be attributed to several factors: an optimized particle dispersion within the matrix, a robust interfacial bonding between the filler particles and the polyester resin, and a minimized presence of voids, as evidenced by the sample's lower water absorption ratio, which implies a denser, less porous structure. The smaller size and uniform distribution of crab shell particles in Sample 5 likely contribute to a more effective load distribution during indentation, enhancing the composite's resistance to deformation.

4.2.1 Comparison of Samples

Based on the experimental data, Sample 5 stands out as having the most optimal combination of physical and mechanical properties among the samples tested

Sample 5 has the ***lowest water absorption rate***, suggesting reduced porosity and increased resistance to water infiltration. This improvement is likely due to an optimized balance in its composition, which results in a denser and less porous structure compared to the other samples.

Sample 5 exhibits the ***highest Mohr hardness value***, indicating superior resistance to indentation. The increased presence of crab shell particles in the composite matrix contributes to this enhancement, with optimized particle dispersion, robust interfacial bonding, and minimized voids contributing to the superior mechanical properties observed in Sample 5.

Sample 5 shows a ***high compressive strength***, second only to the peak observed in Sample 2. While Sample 2 exhibits the highest compressive strength, Sample 5 maintains a high level of strength, indicative of a well-balanced mix of coconut shell and crab shell, which promotes effective load distribution and stress transfer within the composite.

Sample 3 exhibits the highest density among all samples, peaking at 1.41 g/cm³, which corresponds to an optimal balance of coconut shell and crab shell proportions. This composition achieves maximum compaction, resulting in a denser structure. Notably, Sample 5 also shows a relatively ***high density***, pointing to efficient packing and material distribution.

4.2.2. Comparison with Garnet Sandpaper

The table below shows the properties exhibited by garnet sand paper

Sample	Garnet sand paper	Sample 5
Hardness (mohr)	6-7	6
Density (g/cm^3)	1.02	1.240
Water absorption (%)	22.57	0.92

Table 4.5 – properties exhibited by gernet sand paper and sample 5

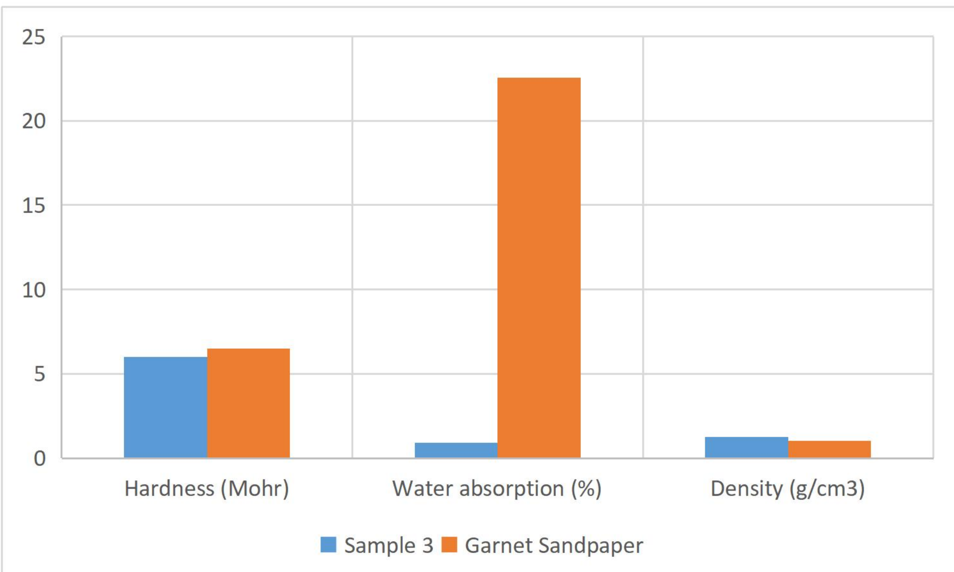

Fig. 4.5 – Comparison between Sample 3 and Garnet sandpaper

The Mohr hardness values for the hybrid composite sandpaper samples range from 4 to 6, which are generally lower than the hardness range of 6-7 observed for Garnet sandpaper. However, it's worth noting that the hardness of the hybrid composite sandpaper samples increases with higher proportions of crab shell particles, with Sample 5 exhibiting a hardness level slightly lower than that of Garnet sandpaper.

The water absorption values of the hybrid composite sandpaper samples are significantly lower than those of Garnet sandpaper. This suggests that the hybrid composite sandpaper samples have lower porosity and are less prone to water infiltration, potentially offering improved durability and longevity in wet conditions. This extremely high water absorption of the garnet sandpaper is likely as a result of the paper/coating attached to the sandpaper which has a high possibility to absorb water.

The density values of the hybrid composite sandpaper samples are generally higher than that of Garnet sandpaper. This suggests that the hybrid composite sandpaper samples have a denser structure, which may contribute to improved mechanical strength and durability.

The hybrid composite sandpaper samples have a relatively smoother surface compared to the rough surface of Garnet sandpaper. This difference may be attributed to the manufacturing process, including the use of nylon/cellophane between the mold and the mix, or a higher resin content in the hybrid composite sandpaper samples.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Overall, based on the combined results and analyses, Sample 5 with proportion of CNS 35% : CBS 65% (Sample 5) demonstrates the most optimal physical and mechanical properties for the fabrication of the hybrid composite abrasive sandpaper. This composition showcases reduced water absorption, enhanced hardness, competitive compressive strength, and favorable density characteristics, making it a promising candidate for further development and application.

Furthermore, the hybrid composite sandpaper samples demonstrate comparable or superior performance in terms of hardness, water absorption, and density compared to Garnet sandpaper, while also offering a relatively smoother surface likely due to the manufacturing process, including the use of nylon/cellophane between the mold and the mix, or due to the high resin content in the hybrid composite sandpaper samples.

Constraints Encountered

- Raw Material Sourcing: Difficulty in obtaining consistent quality and quantity of raw coconut shell and crab shell from local markets may have posed challenges in maintaining uniformity in the composite material.

- Particle Size Uniformity: Achieving consistent particle size distribution through mechanical grinding was crucial but challenging, potentially affecting the final composite's performance if not uniformly achieved.

- Moisture Content Control: Ensuring complete removal of moisture from the shells during drying was critical for composite integrity but may have been challenging due to environmental conditions and equipment limitations.

- Resin Mixing and Curing: Ensuring thorough mixing of resin with shell particles and achieving consistent curing conditions throughout all samples posed challenges in maintaining uniform material properties across batches.

- Mold Fabrication and Surface Finish: Challenges in achieving a smooth finish on the abrasive discs due to mold preparation techniques and mold release agent application affected the final surface quality of the composites.

- Testing Equipment Availability: Limited access to specialized testing equipment (e.g., Rockwell hardness tester) may have constrained the depth and accuracy of mechanical property characterization, affecting the comprehensiveness of the study.

- Standardization of Testing Procedures: Ensuring adherence to ASTM standards throughout the characterization process was critical but may have been challenging due to variations in equipment calibration and procedural understanding.

5.2 Recommendations

Based on the findings and conclusions of this study, the following recommendations are proposed for future research and development efforts in sustainable abrasive materials:

- These findings suggest that the hybrid composite sandpaper samples have the potential to offer competitive performance in abrasive applications hence continued research into optimizing the composition and formulation of the hybrid composite abrasive materials is recommended.
- Utilizing advanced material characterization techniques, such as scanning electron microscopy (SEM) and X-ray diffraction (XRD), can provide deeper insights into the microstructure and properties of the hybrid composite materials. This would facilitate a more comprehensive understanding of their behavior and performance.
- Long-Term Durability Testing: Conduct accelerated aging tests or real-world application simulations to assess long-term durability and performance stability of the composite abrasive sandpapers under varying environmental conditions
- Exploring sustainable manufacturing practices, such as ensuring proper compaction during fabrication can mitigate void formation and enhance water resistance.

REFERENCES

Ajimotokan, H.A., Samuel, A.A., Ajiboye, T.K., Ogedengbe, T.S. and Alabi, I.O., 2020. Morphology and Physico-Mechanical Properties of Resin-bonded Palm Kernel Shell and Coconut Shell Grain-based Sandpaper Composites. *Nigerian Journal of Technological Development, [Online]. 17(3), pp.174-182.*

Aku, S.Y., Agunsoye, J.O., Adebisi, J.A. and Bello, S.A., 2012. Utilization of Solid Agro-Waste as a Reinforcement in Composite Materials. *Journal of Minerals and Materials Characterization and Engineering, [Online]. 11(10), pp.981-987.*

Aku, S., Yawas, D., Madakson, P., & Amaren, S. (2012). Characterisation of Perinwinkeshell as asbestos-free brake-pad materials. *Pacific Journal of Science and Technology, 13(2), 57-63.*

Alhassan, E.A., Olaoye, J.O., Olayanju, T.M.A. and Okonkwo, C.E., 2019. An investigation into some crop residues generation from farming activities and inherent energy potentials in Kwara State, Nigeria. IOP Conference Series: *Materials Science and Engineering, [Online]. Volume 640, 1st International Conference on Sustainable Infrastructural Development, 24–28 June 2019, Covenant University, Canaan Land, Ota, Nigeria. Available at: DOI 10.1088/1757-899X/640/1/012093*

Ambali, I., Shuaib-Babata, Y., Ibrahim, H., Abdulqadir, L., Aremu, N., Ibraheem, T., Lanre, A., Babatunde, I., Kobe, A., Ishaq, N., Allah, I., & Olawale, W. (2020). Production of Abrasive Sandpaper using Periwinkle Shells and Crab Shells. *International Journal of Engineering Materials and Manufacture, 5, 55-61. DOI: 10.26776/ijemm.05.02.2020.04.*

Arjmandi, R., Yıldırım, I., Hatton, F., Hassan, A., Jefferies, C., Mohamad, Z., & Othman, N. (2021). Kenaf fibers reinforced unsaturated polyester composites: A review. *Journal of Engineered Fibers and Fabrics, 16, 1–22. DOI: 10.1177/15589250211040184.*

Casey, D. (2016). Traditional Polishing Materials in Japan: Boiled and Dried Horsetail Plants. *Journal of Traditional Craftsmanship, 12(3), 48-60*

Dahiya, A. K., Bhuyan, B. K., & Kumar, S. (2022). "Perspective study of abrasive water jet machining of composites: A review." *Journal of Mechanical Science and Technology, 36(1), 213–224.*

Durowaye, S. I., Lawal, G. I., & Olagbaju, O. I. (2014). Microstructure and Mechanical Properties of Sisal Particles Reinforced Polypropylene Composite. *International Journal of Composite Materials, 4(4), 190-195. DOI: 10.5923/j.cmaterials.20140404.03*

Edokpia, R., Aigbodion, V.S., Obiorah, O.B. & Atuanya, C.U., 2014. WITHDRAWN: Evaluation of the properties of eco-friendly brake pad using eggshell particles–Gum Arabic. Results in Physics. Available at: http://dx.doi.org/10.1016/j.rinp.2014.06.003

Elegbede, I. O., & Fashina-Bombata, H. A. (2013). Proximate and Mineral Compositions of Common Crab Species [Callinectes pallidus and Cardisoma armatum] of Badagry Creek, Nigeria. *Journal of Poultry, Fisheries and Wildlife Sciences, 2, 1-5*

Gao, Y. (ed.) 2003. Advances in Abrasive Technology. 5th ed. Enfield, NH: *Trans Tech*

Gerberich, W.W., Ballarini, R., Hintsala, E.D., Mishra, M., Molinari, J.-F. and Szlufarska, I., 2015. Toward Demystifying the Mohs Hardness Scale. *Journal of the American Ceramic Society, 98(9), pp.2681-2688. doi:10.1111/jace.13753.*

Hill, R. A. (1977). Sandpaper: A Comprehensive Guide to Its Types, Uses, and Applications. *Journal of Abrasive Materials, 3(2), 45-52*.

Ibrahim, H., Abdulhamid, H. K., Popoola, A., & Adeyi, Y. (2019). Development of Abrasive Sandpaper Grains from Agro-Waste Material for Polishing of Wood Surface. *Engineering and Technology, 2(1), 48-60.*

Iyasara, A. M., Joseph, O. O., Azubuike, C. P., & Daniel, A. O. (2014). Utilization of Agro-Residues for Natural Abrasives Production as an Alternative to Synthetic Abrasives Derived from Crude Oil. *Journal of Sustainable Materials and Manufacturing, 2(1), 48-60.*

Jeffrey, K., 1989. The development of sandpaper. Journal of Material History, 12(3), pp.45-47.

Kalácska, G., 2013. Abrasives used to make sandpapers: Natural vs. synthetic. *Journal of Materials Science and Engineering, [Online]. 1(2), pp. 45-52.*

Kohli, V. (2016). [Various records and achievements in 2016]. India Today.

Landesmann, A., & Landesmann, J. P. (2015). Composite materials: Science and engineering. CRC Press

Maninder, S., & Manpreet, K. (2012). Coconut Shell Particles: Size Range and Surface Texture. *Journal of Environmental Materials, 5(2), 48-60.*

Mason, B., & Bodin, J. (2019). Historical Evolution of Abrasives: From Primitive Tools to Modern Applications. *Journal of Materials Science and Engineering, 7(3), 48-62.*

Mishra, R. S., & Valiev, R. Z. (2002). Mechanical properties and deformation behavior of materials having ultra-fine grain sizes. *Progress in Materials Science, 46(7-8), 605-649.*

Mohamed, O., Mohammed, B., Phing, H. M., & Joanne, C. W. (2014). Crab Shell (The Carapace). Weebly. Available at: crablifeadoption.weebly.com/blog/crab-shell-the-carapace.

Naiara, O., Vitaliy, M., Daniela, P., Daniel, M. K., Luis Norberto, L. de L., & Eneko, U. (2020). Abrasive Disc Performance in Dry-Cutting of Medium-Carbon Steel. Metals, 10(4), 538

Nuhu, A. A., & Adeyemi, O. S. (2015). Utilization of palm kernel shells and coconut shells in abrasive sandpaper production. *Pacific Journal of Science and Technology, 13(2), 57.*

Oakey, J. (1833). Introduction of Glass Paper in London: Innovative Adhesive Techniques for Mass Production. *Journal of Industrial Materials, 5(2), 48-60.*

Obot, I.B., Yawas, D.S. and Aku, S.Y., 2017. Development of Abrasive Sandpaper from Agro-Waste Materials. *Tribology in Industry, [Online]. 38(2), pp.176-185.*

Obot, M., Yawas, D., Aku, S. Y., & Obada, D. (2016). An Assessment on the Production of Abrasive Sandpaper from Locally Sourced Materials. *Tribology in Industry, 38, 176-185.*

Pacific Journal of Science and Technology. (2012). 'Sandpapers: *Materials and Applications', 13(2), 57.* Akamai University.

Parker, J. (1962). Historical Use of Horsetail Plants for Polishing in Japan. *Japanese Cultural Studies, 5, 31-37*

Ratia, V., Heino, V., Valtonen, K., Vippola, M., Kemppainen, A., Siitonen, P. and Kuokkala, V.-T., 2014. Effect of abrasive properties on the high-stress three-body abrasion of steels and hard metals. *Tribologia - Finish Journal of Tribology, [Online]. 32(1), pp.22-35.*

Sa'ad, H., Hameed, A., Alhassan, E.A., Ariyo, E. and Abadunmi, T., 2021. Mechanical performance of abrasive sandpaper made with palm kernel shells and coconut shells. *Journal of the Mechanical Behavior of Materials, 30, pp.28-37. doi:10.1515/jmbm-2021-0004.*

Sadh, D., Duhan, A., & Duhan, S. (2018). Agro-Residues: A Potential Feedstock for Natural Abrasives. *International Journal of Renewable Energy and Environmental Engineering, 6(1),1-5.*

Samuel, A., SULAIMAN, A., Ajimotokan, H., Segun Emmanuel, I., Ajiboye, T. K., Ogedengbe, T., Alabi, I., & Unilorin, Njtd. (2023). Morphology, Microstructure Evolution and Properties of Resin-Bonded Palm Kernel and Coconut Shell Grain-Based Abrasive Grinding. *Nigerian Journal of Technological Development, 20. DOI: 10.4314/njtd.v20i1.1235.*

Shoor, S. (2019). A review of composite materials and its application. *Journal of Emerging Technologies and Innovative Research (JETIR), 6(4)*. Available at: https://www.jetir.org/papers/JETIREL06175.pdf.

Singh, M.K., Tewari, R., Zafar, S., Rangappa, S.M. and Siengchin, S., 2023. A comprehensive review of various factors for application feasibility of natural fiber-reinforced polymer composites. Results in Materials, 17, p.100355.

Stalker, J. & Parker, G. (1971). A Treatise of Japaning and Varnishing. Oxford: George Redway. (Original work published 1688)

Suryarghya Chakrabarti & S. Paul (2007). Numerical modeling of surface topography in superabrasive grinding using square-pyramidal grits.

Udo, M., Afolalu, A., Ikumapayi, O., Babalola, P., Obasa, V., & Akpalikpo, O. (2022). Effect of particle size and weight percentage variation on the mechanical properties of periwinkle shell reinforced polymer (epoxy resin) matrix composite. *International Journal of Applied Science and Engineering, 19, 1-7.* DOI: 10.6703/IJASE.202209_19(3).004.004).

Wai, J. J., & Lilly, M. T. (2002). Manufacturing of Emery Cloth from Locally Sourced Raw Materials. Global Journal of Engineering Research, 1(1), 31–37

Yihun, F. A., Mayumi, E., Hironori, K., Hironori, I., Minoru, M., Hiroyuki, S., & Shinsuke, I. (2016). Protein/$CaCO_3$/Chitin Nanofiber complex prepared from Crab Shells by simple mechanical treatment and Its effect on plant growth. *International Journal of Molecular Sciences, 17(10), 1600.* doi: 10.3390/ijms17101600. PMID: 27669216; PMCID: PMC5085633.

Zhan, L., & Wang, T. (2021). A high-precision prediction model for surface topography of abrasive belt grinding considering elastic contact. *The International Journal of Advanced Manufacturing Technology, 125, 777-792.* DOI: 10.1007/s00170-022-10757-4.

Zhong, Y., & Venkatesh, V. (2009). Understanding Abrasive Materials: Types, Applications, and Selection. Kangfeides.