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Fabrication of Recycled High Density Polyethylene composite with Natural Filler Pine-dust: Effect of Morphological Structure on Mechanical Properties

By

Utshav Pandey

A THESIS REPORT

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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Fabrication of Recycled High Density Polyethylene composite with Natural Filler Pine-dust: Effect of Morphological Structure on Mechanical Properties" submitted by Utshav Pandey in partial fulfillment of the requirements for the Degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

In the contemporary ere, composite plastics stand out as one of the most versatile engineering materials. The progress in materials science and technology, coupled with growing demands, has given rise to these remarkable and highly intriguing materials. This study explores the integration of pine-dust, a byproduct of the furniture industry, into recycled High-Density Polyethylene (HDPE) to create composites and assess its impact on morphology, mechanical properties, and water absorption characteristic of the composite. This study involved the examination of pine-dust categorized into three distinct size ranges: particles ranging from 425 µm to 1000 µm, particles between 212 µm and 425 µm, and particles smaller than 212 µm. Each of these particle sizes was then integrated into recycled High-Density Polyethylene (HDPE) at various inclusion levels, specifically 5%, 10%, 15%, 20%, 25%, and 30%. The fabrication of the composite materials was achieved through a single screw extruder extraction process. Visual inspection revealed strong bonding between natural fibers and recycled HDPE, indicating the potential for robust composite materials. Tensile testing indicated that an increased proportion of pine-dust enhanced ultimate load capacity for all particle sizes, with diminishing returns on exceeding a certain proportion. The maximum ultimate strength of 17.63 MPa achieved at 20% inclusion of pine dust of size range between 212 µm and 425 µm. Composites consistently outperformed pure recycled HDPE in ultimate strength. Notably, impact testing demonstrated a similar result; energy absorption consistently increased on inclusion of pine-dust. The maximum energy absorption of 10 Joules was achieved on composite with pine dust size less than 212 µm and inclusion of 10% by proportion. Water absorption increased with increase in pine-dust inclusion and as the size decreases of pine-dust in recycled HDPE. A detailed examination of composite morphology through stereoscopy microscopy provided insights. Initially, uniform pine-dust dispersion enhanced ultimate strength in recycled HDPE. However, increased pine-dust led to agglomeration, reducing strength. Consistent distribution is crucial. Smaller pine-dust exacerbated agglomeration, further diminishing strength. Pine-dust as a filler offers utilization of local waste materials with improved mechanical properties and reduced environmental impact of recycled HDPE.

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
HDPE	High-Density Polyethylene
LDPE	Low-Density Polyethylene
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
NFPD	Natural Filler Pine-dust
PA	Polyamides
PC	Polycarbonates
PEHD	Polyethylene High-Density
PMMA	Poly-methyl Methacrylate
POM	Poly-oxy-methylene
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
rPP	Recycled Polypropylene
RHDP	Reinforced HDPE
TPU	Thermoplastic Polyurethanes
vPP	Virgin Polypropylene
WPCs	Wood Plastic Composites

CHAPTER ONE: INTRODUCTION

In the field of material science and engineering, the query for sustainable and eco-friendly composite materials has gained significant momentum. The integration of natural fillers into polymer matrices offers a promising approach to enhance the performance of composites while reducing their environmental footprint (Kuan et al., 2021).

High Density Polyethylene, a widely utilized thermoplastic polymer, is renowned for its exceptional mechanical strength and chemical resistance. However, the non-biodegradable nature of HDPE raises environmental concerns, prompting researchers to seek sustainable alternatives. The incorporation of filler materials like pine-dust offers an enticing solution to address these challenges by imparting eco-friendly characteristics, while simultaneously enhancing its mechanical performance as well as utilizes the furniture industry waste that is either discarded or incinerated (Tabarsa et al., 2011).

1.1 **Background**

A thermoplastic, also known as thermos soft plastic refers to a type of plastic polymer materials that exhibit the ability to soften and take on a malleable form when subjected to a particular elevated temperature (Rennie, n.d.). The polymer chains interact through intermolecular forces, which weaken as the temperature rises, leading to the creation of a viscous liquid state. In this state, thermoplastics are amenable to reshaping and are frequently utilized for producing parts using various polymer processing techniques such as injection molding, compression molding and extrusion (Mallick, 2010).

High-density polyethylene (HDPE), also known as polyethylene high-density (PEHD), is a thermoplastic polymer derived from the ethylene monomer. Benefitting from a noteworthy ratio of strength to density, HDPE is harness in the manufacturing of plastic bottles, piping resistant to corrosion, geo-membranes, and plastic lumber (Gabriel, 2013).

Natural fillers refer to organic materials derived from nature such as wood fibers, plants particles, animals or agricultural residues. Incorporating natural fillers in thermoplastics serves several benefits, it not only lowers the expenses associated with thermoplastic composites but also aids in diminishing the accumulation of non-biodegradable plastic composite waste in the environment, thereby reducing the reliance on synthetic materials. Moreover, research indicates the natural fillers can also act as effective reinforcing agents, enhancing the mechanical properties and overall performance of the resulting composite materials (Zaaba & Ismail, 2019).

Growing environmental apprehensions and the depletion of petroleum resources have spurred both researchers and industries to contemplate the utilization of sustainable natural fillers, encompassing particles or fibers as alternatives to synthetic fillers. Beyond their eco-friendliness, natural particles and fibers can demonstrate superior attributes in comparison to synthetic counterparts. In addition to their commendable physical and mechanical traits, they are cost-effective, recyclable, non-harmful, and widely accessible. Consequently, natural fillers have evolved as apt materials for reinforcing various composite products. As a result, the worldwide market for polymer composites reinforced with natural fillers attained a value of $5.3 billion in 2019, displaying an anticipated growth of 11.4% between 2000 and 2017, with an expectation of sustained global expansion in the near future (Kuforiji et al., 2023).

Encompassing natural filler in thermoplastic polymer is gaining popularity in the last decade. Its value for durability, cost-effectiveness, reasonable strength drawing attention for researchers. It also resists decay, a key feature for outdoor use where untreated wood struggles, and makes efficient use of fire wood waste for sustainability. Additionally, its improved ability to handle heat and stress compared to plain plastics makes it suitable for structural applications like shapes, platforms, ceilings, and window edges (Liu et al., 2009).

The potential market demand for Wood-Plastic Composites (WPC) is substantial owing to the substantial production of both plastics and wood. This results in a significant volume of solid waste, a considerable portion of which, typically discarded rather than reclaimed (Woodhams et al., 1984).

1.2 Problem Statement

The environmental challenges linked to plastic and wood waste are gaining more attention. The issue of plastic waste is significant due to its large volume, inability to biodegrade, and its quick use of natural resources in its short lifespan. This is further worsen by the desirable mechanical strength and chemical resistance thermoplastic serves, making it a preferred choice in many industries, thereby increasing demand leading to high material consumption during production and disposal but as a non-biodegradable polymer, it poses significant challenges in waste management and contributes to plastic pollution, which adversely affects ecosystems and wildlife. Similarly, wood waste contributes to these concerns, though to a lesser extent, by adding to the decline of trees and forests. Normally, wood waste is either burned or improperly discarded, leading to more resource usage, faster depletion, and environmental pollution. Across the world, especially in developed countries, focused efforts been initiated to tackle these waste types, driven partly by the growing demand for alternatives to primary materials (El-Haggar et al., 2011). Currently, integrating wood and polymer research has gained significant prominence, particularly in the last decade, owing to its appealing properties and benefits. Researchers have been drawn to its features, such as remarkable durability, minimal upkeep requirements, satisfactory strength and stiffness ratios, competitive pricing compared to alternative materials, and its utilization of natural resources (Bhaskar et al., 2012). There is a lot of research potential to explore the various properties of wood and polymer composites. This research is an attempt to explore the effect in mechanical properties on inclusion of pine-dust on varying sizes and proportion in recycled HDPE using screw extrusion method and examine the effect on its morphology. This thesis has the potential to be a stepping-stone for utilizing pine-dust, which is a byproduct of pinewood, a highly utilized wood in the Nepalese furniture industry. By combining pine-dust with recycled HDPE, which is a commonly available plastic material. This research endeavors to present an environmentally conscious approach to developing composite materials effectively repurposing waste materials and promoting environmentally responsible practices.

1.3 **Objective of Study**

1.3.1 Main Objective

To investigate the effect on morphology and mechanical properties of a composite material fabricated by integrating pine-dust as filler in Recycled HDPE, utilizing the single-screw extrusion method.

1.3.2 Specific Objectives

The specific objectives of the study are:

i. To create composite material samples by mixing pine-dust filler with recycled HDPE in various sizes and proportion in a screw extruder
ii. To evaluate mechanical properties of the composites
iii. To compare the obtained properties of composite with Recycled HDPE
iv. To characterize the morphology of composites using Stereoscopy Microscope
v. To assess the moisture absorption characteristics of the composites

1.4 **Definitions**

In this document, the terms have the following definitions

i. Blow molding: A manufacturing process creates hollow plastic objects, like bottles, by inflating a heated tube of thermoplastic material inside a mold to take its shape, then cooling and removing the resulting product (Akinfiresoye et al., 2017).
ii. Calendaring: The manufacturing process entails the smoothing and compressing of a material by feeding a continuous sheet through a sequence of heated roll pairs. These rolls, when used together in combination, are referred to as calendars.
iii. Casting: A manufacturing technique in which a liquid polymeric substance is poured into a mold with a desired hollow shape, allowed to cool and solidify, and then removed from the mold to produce a solid object.
iv. Composite Material: A material formed by assembling distinct constituents, typically including a matrix and reinforcements, into a cohesive whole (Zaaba & Ismail, 2019b).
v. Cross-Link: Chemical bonds connecting the molecular chains.
vi. Extrusion Molding: Extrusion is the process of changing the physical characteristics of substance by pushing it through a controlled opening or die.
vii. Foaming: A manufacturing process that involves the incorporation of gas bubbles into a material, resulting in the creation of expanded or porous materials characterized by attributes such as exceptional cushioning properties, lightweight composition, and minimal thermal conductivity.
viii. HDPE (High-density polyethylene): A thermoplastic resin derived from the polymerization of ethylene gas, characterized by a specific density ranging from 0.95 to 0.96 g/cm^3 (Dai et al., 2016).

ix. Injection molding is a manufacturing process that produces thermoplastic items by injecting molten material into a cold mold, allowing it to solidify, and then extracting the molded products.
x. Molding: A manufacturing process that employs both pressure and heat to fill a mold's cavity, which is a rigid frame, often called a matrix.
xi. Tensile Strength: A material's ability to withstand a force attempting to pull it apart along its axis.
xii. Thermoforming: A manufacturing technique that employs the heating of a plastic sheet to a flexible state, pressing it against a cooled mold, maintaining the shape until it solidifies, and subsequently trimming the formed part from the surrounding material to produce commercial products (*Thermoforming*, n.d.).
xiii. Virgin Resin: A resin that has undergone no prior use or processing beyond what is necessary for its initial synthesis.

1.5 **Assumptions and Limitations**

The assumption made during the course of study are:

i. The raw pine-dust utilized as a natural filler is assumed to be devoid of foreign particles or contaminants.
ii. Except for the variable under examination, all parameters governing the processes and criteria for testing remained consistent for every test subject created and examined.
iii. The effects observed in the HDPE composites are primarily due to the addition of pine-dust and not influenced by external factors or variables.

The Limitation made during the course of study are:

i. The processing technique had a restricted ability to manage process variables.
ii. Findings might not fully account for complexities in industrial-scale production.
iii. Focus on pine-dust limits generalization to other natural fillers or composites.
iv. Assumed purity, potential variations in pine-dust characteristics were not fully explored.

CHAPTER TWO: LITERATURE REVIEW

2.1 Thermoplastic Polymer

Thermoplastics belong to a group of polymers that exhibit the unique ability to soften and become liquid when subjected to heat. They can be molded and shaped while in a heated and pliable state, as observed in thermoforming, or in their liquid state, a characteristic evident in processes such as extrusion and injection molding. This key distinction separates them from thermosets, another class of polymers that do not undergo a melting transformation when exposed to heat. Unlike thermosets, thermoplastic polymers offer the advantage of being repeatedly processed using heat, making them highly recyclable and capable of being transformed into new products. However, it’s important to acknowledge that undergoing multiple processing cycles may lead to slight alterations in certain properties (Zaaba & Ismail, 2019).

The standard manufacturing techniques used for producing components from thermoplastics include extrusion, injection molding, blow molding, and thermoforming (Mărieş & Abrudan, 2018). Beyond the advantage of recyclability, thermoplastics boast several other benefits compared to thermosets. Generally, they offer superior ductility and impact resistance. Additionally, various welding methods, such as resistance welding, vibration welding, and ultrasonic welding, can be employed to join thermoplastic components together. Another advantage lies in the considerably shorter processing time required for thermoplastic parts in comparison to thermoset parts. This discrepancy is attributed to the fact that processing thermoset parts involves a chemical reaction within the mold, referred to as curing or cross-linking, which can take anywhere from several minutes to several hours based on factors like mold temperature and part thickness. Contrarily, the processing of thermoplastic parts does not entail any chemical reaction within the mold (Mallick, 2010).

Thermoplastics are often associated with flexible or branched polymers differing from thermosets which are linked to rigid, heavily cross-linked resins. Examples of thermoplastics include polystyrene and polyethylene (Rennie, 2012).

Some of the examples of thermoplastic polymers are Rigid PVC, Plasticized PVC, LDPE, HDPE, PP, PMMA, Shock resistant PS, PA, PC, POM, TPU etc. Due to their characteristics and abilities, thermoplastic polymers find applications in a wide range of sectors, including but are not limited to the electrical, automotive and electronics, toy manufacturing, sports equipment, packaging, home appliance, pharmaceutical, garden furniture, cosmetics, optical industries and medical (Mărieş & Abrudan, 2018).

2.2 High-Density Polyethylene (HDPE)

High-density polyethylene (HDPE) is a thermoplastic material composed of carbon and hydrogen atoms, forming high molecular weight products. Its polymer chain can vary in length from 500,000 to 1,000,000 carbon units, with the presence of short and long side chain molecules (Khan et al., 2020). The mechanical and chemical properties of HDPE are influenced by its molecular weight, distribution, and branching.

The crystalline structure of polyethylene enables thermal welding, as it can transition between an amorphous state upon heating and a partially crystalline structure upon cooling. HDPE and other thermoplastic materials can be shaped and molded when heated, as they lack cross-linked molecular chains (Dugvekar & Dixit, 2021).

High-density polyethylene (HDPE) is the most commonly utilized plastic, constituting approximately 34% of the worldwide plastic market. It is a polymer composed of numerous recurring monomer units, and its chemical formula is $(C_2H_4)_n$. HDPE exhibits relatively minimal branching compared to other types of polyethylene (Gabriel, 2021).

The High-density Polyethylene (HDPE) Market is estimated to reach over 45 million tons by the end of this year and is projected to register a CAGR of around 5% during the forecast period (Gabriel, 2021).

2.2.1 History of High-Density Polyethylene (HDPE)

High-Density Polyethylene (HDPE) has an intriguing history dating back to the late 19th century.

1898: German chemist Hans von Pechmann observed a precipitate while experimenting with a form of methane in ether.

1900s: German chemists Eugen Bamberger and Friedrich Tschirner identified the compound as polymethylene, a close cousin to polyethylene.

1935: British chemists Eric Fawcett and Reginald Gibson achieved a significant breakthrough by creating a solid form of polyethylene through high-pressure treatment of ethylene

HDPE's first commercial application emerged during World War II when the British used it to insulate radar cables.

1953: The pivotal moment in HDPE's development came when Karl Ziegler and Erhard Holzkamp invented high-density polyethylene (HDPE) at the Kaiser Wilhelm Institute (now the Max Planck Institute).

1955: HDPE was produced as a pipe, marking a significant milestone in its industrial applications. For this achievement, Ziegler was honored with the 1963 Nobel Prize for Chemistry.

Due to its remarkable mechanical properties and widespread industrial applications. HDPE stands out for its exceptional tensile strength, impact resistance, and durability, making it an ideal candidate for production of versatile applications material (Gabriel, n.d.).

2.3 **Recycled HDPE**

Recycled HDPE is the outcome of HDPE polymer that has undergone a reclamation and processing process undergone its initial use as HDPE product, making it suitable for reuse in various application.

In the current context, the significance of recycled HDPE cannot be exaggerated. Plastic waste has been one of the major environmental issue in our world due to its non-biodegradability nature, making recycled HDPE a pivotal step in lessening the footprint of HDPE. As HDPE is a versatile and extensively utilized plastic, contributes significantly to plastic waste. If not subjected to recycling HDPE can endure in the environment for centuries, posing harm to ecosystem and wildlife. Recycling HDPE helps reduces energy and resource because the recycling process demands notably less energy and fewer resources compared to the production of virgin HDPE from raw materials. Apart from its environmental advantage, recycled HDPE yields economic advantage by generating employment opportunities in recycling sector simultaneously reducing waste management expenses for business and local governments (Pattanakul et al., 1994).

The physical properties of recycled HDPE derived from the bottles of milk with different proportion ranging from 10 to 100% shows only a slight different from virgin HDPE on assessing key parameters such as MOE, breaking strength and elongation in percentage of test samples produced through a compression molding method (Pattanakul et al., 1994).

Furthermore, recycled HDPE finds application in a wide array of products, including:

i. Plastic Lumber: used for outdoor, decking, fencing, benches and other construction application
ii. Recycling Bins
iii. Playground Equipment
iv. Traffic and Rodway Products
v. Furniture
vi. Automotive Parts: bumpers and interior components
vii. Industrial and Manufacturing Components: water tanks, pipes (Mărieş & Abrudan, 2018).

2.4 **Natural filler in Polymer Composite**

Natural filler in polymer composite refers to incorporation of organic materials derived from renewable sources such as plant fibers, wood particles or agricultural residues into a polymer matrix (Kuan et al., 2021).

The interest in advancing and promoting composite materials derived from natural sources has significantly increased globally. This is primarily due to their considerable potential to reduce the reliance on material from non-renewable resources, such as petroleum. NFs are categorically renewable resources, readily available, cost-effective, and have the potential to replace synthetic fibers and inorganic mineral fillers. Consequently, the incorporation of NFs has the capacity to make remarkable contributions to environmental improvement and economic efficiency (Beshah et al., 2014).

Natural organic fibers derived from renewable natural resources offer the potential to act as a biodegradable reinforcing material alternative for the use of glass or carbon fiber and inorganic fillers. These fibers offer several advantages, including high specific strength and modulus, low cost, low density, renewable nature, biodegradability, absence of associated health hazards, easy fiber surface modification, wide availability, and relative non-abrasiveness (Adhikary et al., 2008).

Natural fillers, which often originates as waste materials from industrial sectors like food, clothing or woodworking are easily accessible. Their utilization is noteworthy in terms of promoting recycling. However, it is essential to acknowledge that employing natural materials can pose challenges during processing. The polymer matrix needs to be compatible with processing at temperature below than the thermal decomposition point of organic compounds (Bazan et al., 2020).

The characteristics of reinforced composite materials are influenced by six overarching factors:

i. The bond between the matrix and reinforcements at the interface
ii. Characteristics of the reinforcement material
iii. Dimension and shape of the reinforcement
iv. Percentage of the reinforcement present
v. The process technique used
vi. The arrangement and dispersion of the reinforcement within matrix (Vlachopoulos & Strutt, 2003).

2.5 **Polymer Processing Technique: Screw Extruder**

Polymer processing refers to the engineering processes conducted on polymeric materials or systems with the aim of enhancing their practical applications. This encompasses various tasks, such as shaping, compounding, and chemical reactions, which result in changes to the polymer's molecular structure and the stabilization of its physical characteristics, ultimately creating more valuable end products (Wilczyński & Buziak, 2021).

The different techniques used in the polymer process are:

i. Calendaring
ii. Casting
iii. Foaming
iv. Thermoforming
v. Molding: The advantages of molding encompass increased precision, flexibility, and efficiency in production. It is further classified as:
    A. Injection Molding
    B. Blow Molding

C. Extrusion Molding

Extrusion is the process of changing the physical characteristics of substance by pushing it through a controlled opening or die. The process is carried out using various types of extrusion equipment, including ram, roll, and radial screen and screw extruders. Among these, screw extruders play a pivotal role because they turn raw materials into finished shapes like rods, tubes, or films. Through the rotation of screws, the feed material is propelled towards the die, and the heat provided along the barrel wall softens the material, thereby making the material viscous. The viscous fluid is pushed through the die and shaped according to requirement (Patil et al., 2016).

2.5.1 Two broad categories of extruders:

a. Single-screw extruder

A single-screw extruder comprises a cylindrical barrel with external heaters. The screw is powered by an electric motor through a gear reducer designed for the specific speed and power requirements of the screw. Electric heaters maintain the temperature of the barrel. Solid polymer is fed into the extruder through the feed throat and moved along by the turning motion of the screw. The screw's flights gather molten polymer from the barrel surface, pushing it towards the extruder's end. By the end of the screw's path, the polymer is fully molten. The screw's rotation ensures proper mixing of the melt and generates the necessary pressure to force the melt through a die, progressing to the subsequent stages. For a long time and even today, the single-screw extruder remains the top choice in extrusion. This is because it offers simple production, cost advantages, and the capability to handle significant torques when working with polymers.

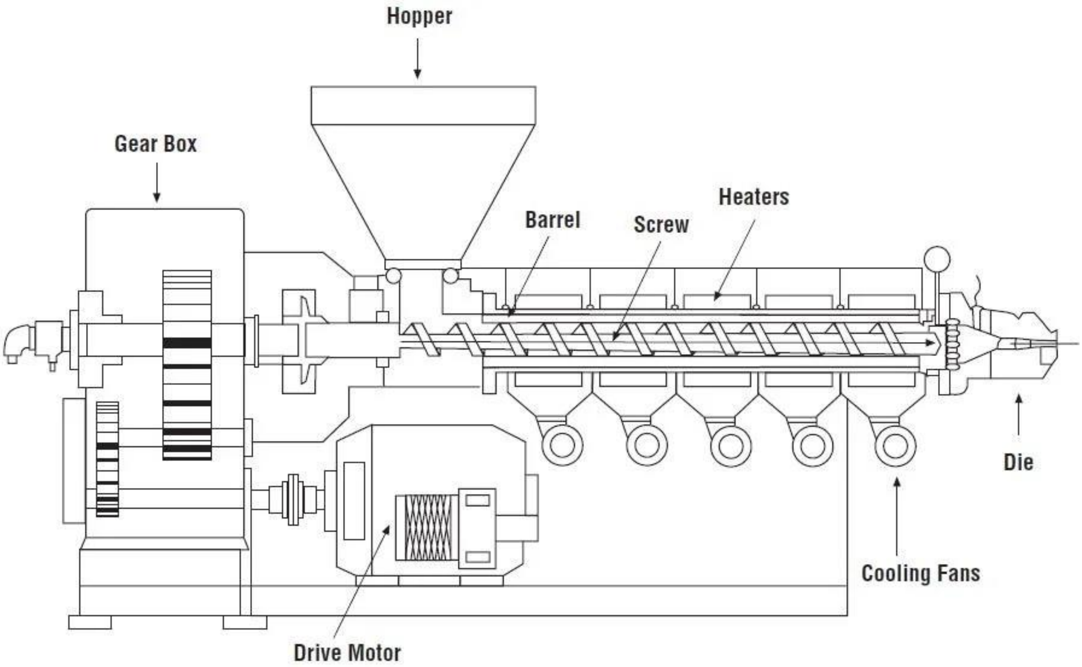

Figure 2-1: Single-screw Extruder

b. Twin-screw extruder

Originally, twin-screw extruders found their primary purpose in working with polymer powders and compounding. They excelled in achieving high-quality mixing and precise residence times, beneficial for processes like devolatilization, dealing with polymers sensitive to temperature, and reactive extrusion involving polymer modification and synthesis. As time progressed, advancements in twin-screw technology significantly augmented their torque capabilities. Twin-screw extruders come in variations such as non-intermeshing and fully intermeshing designs. Additionally, the screws within these machines can rotate either in unison (co-rotating) or in opposing directions (counter-rotating). Furthermore, these configurations enable an overall improvement in the efficiency of the extrusion system compared to single-screw extruders. This optimization results in achieving higher production rates while maintaining reduced melt temperatures (Wilczyński & Buziak, 2021).

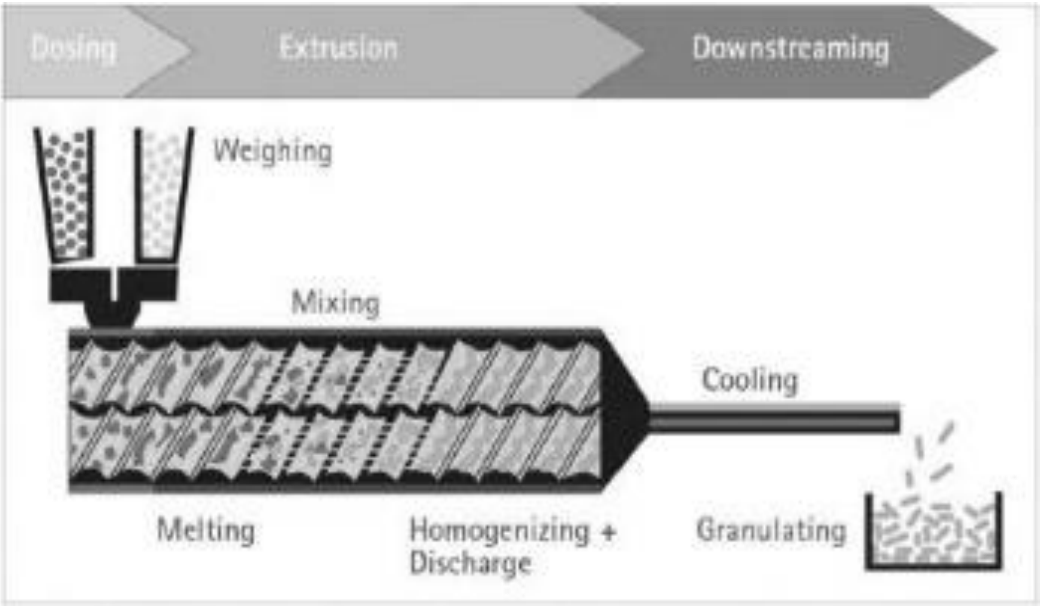

Figure 2-2: Twin-Screw Extruder (Patil et al., 2016)

The significance of screw extrusion technology lies not only in its current widespread use but also in its continual evolution to meet the diverse and evolving demands of modern industries (Patil et al., 2016).

2.6 **Instrument Specification in Prior Research**

This section offers a detailed account of the instruments employed in this research to facilitate various testing procedures.

2.6.1 Universal Testing Machine (UTM)

A Universal Testing Machine (UTM) is a versatile apparatus used to assess the mechanical properties (e.g., tension, compression) of test specimens by applying various stresses, such as tensile, compressive, or transverse forces. Its name derives from its ability to conduct a wide array of tests on diverse materials. Test procedures, typically outlined by standardization bodies, detail aspects like sample preparation, fixturing, gauge length, and analysis.

During testing, the specimen is positioned between grips, and an extensometer may be employed to automatically monitor changes in gauge length. In the absence of an extensometer, the machine itself records the displacement between its crossheads, encompassing not only the specimen but also any accompanying components.

Upon initiation, the machine gradually applies increasing loads to the specimen. Throughout the tests, the control system and accompanying software meticulously log load and specimen extension or compression. UTMs come in various sizes, ranging from compact tabletop systems to those with capacities exceeding 53 MN (12 million lbf). These machines enable a wide range of tests, including peel, flexural, tension, bending, friction, and spring tests (PraneethS & AnandD, 2022).

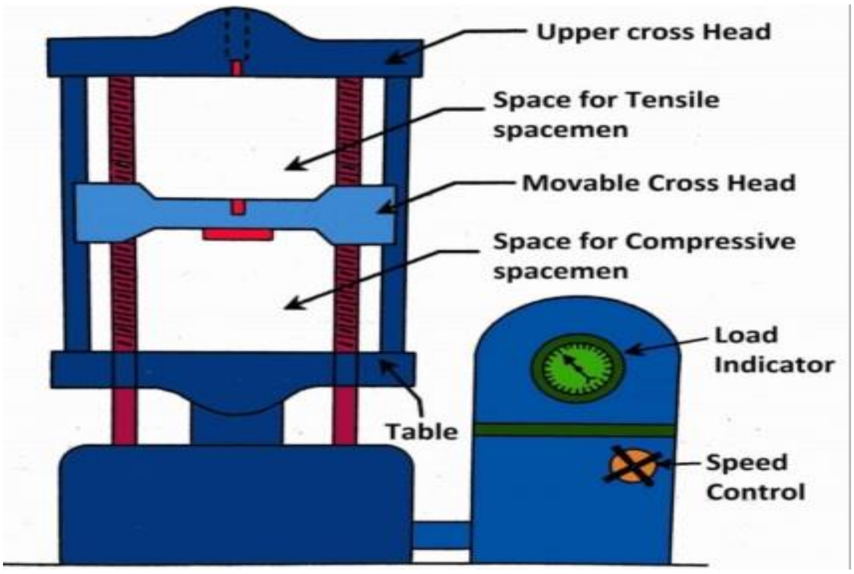

Figure 2-3: Universal Testing Machine Components

2.6.2 Impact Test

The primary objective of an impact test is to assess the response of materials, such as ceramics, polymers and composites, when subjected to a sudden application of stress. This testing procedure is specifically employed to evaluate critical material properties, including toughness, brittleness, susceptibility to notching, and the ability to withstand high-speed loading in engineering materials. Impact test specimens can feature various notch configurations, including V-notch, U-notch, and keyhole notches. Among the most commonly used specimen configurations for impact testing are the Charpy and Izod specimen configuration.

a. Charpy Impact Test

It is a widely used and cost-efficient method for assessing material toughness. It assesses the amount of energy absorbed by a standard notched sample when it fractures due to an impact force. The test serves as an economical quality control method for assessing notch sensitivity and impact toughness in engineering materials such as metals, composites, ceramics, and polymers. A standard Charpy impact test sample typically has the following dimensions: 55 mm x 10 mm x 10 mm and features a machined notch along one of its longer edges.

During the test, the specimen is securely held at both ends while a hammer strikes it opposite the notch. The energy absorbed is precisely determined by measuring the reduction in motion of the pendulum arm. Factors influencing material toughness include low temperatures, high strain rates (from impact or pressurization), and the presence of stress concentrators like notches, cracks, and voids(Saba et al., 2018).

b. Izod Impact Test

In the Izod impact test, a specimen is prepared with a square or round cross-section and may have one, two, or three notches, each measuring 70 mm x 15 mm x 3 mm. This test involves a pendulum with a weighted end swinging down to strike the securely held specimen in a vertical position. Impact strength is calculated by measuring the precise loss in the pendulum's height, reflecting the energy lost during the test (Saba et al., 2018).

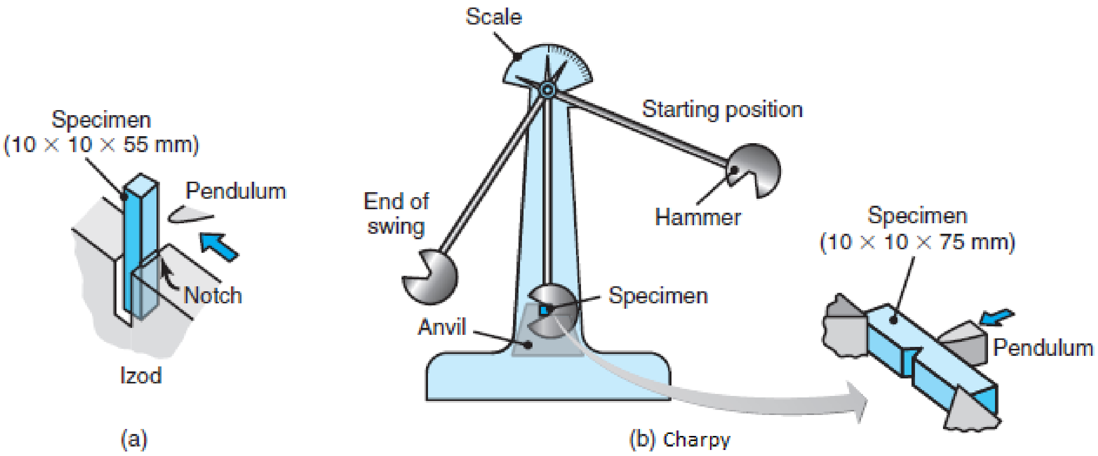

Figure 2-4: Impact Test (Izod and Charpy)

2.6.3 Stereoscopy Microscope

A stereomicroscope, often called a dissecting microscope, serves as a specialized optical tool specifically engineered to provide exceptional clarity and depth perception through three-dimensional magnification when examining objects. Stereomicroscopes, considered among the most basic microscope types, find less extensive application in analytical microscopy compared to other microscope variants. When using a stereomicroscope, the analysis heavily relies on lighting rather than the microscope itself. By employing various wavelengths of light, it becomes possible to induce luminescence or fluorescence in a specimen, which can subsequently be observed through a stereomicroscope (Kwon et al., 2010).

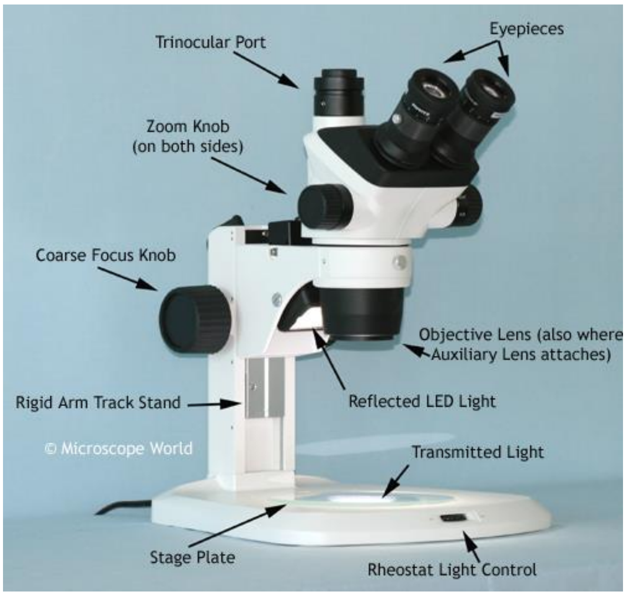

Figure 2-5: Stereoscopy Microscope(Stereo Zoom Microscope)

2.7 **Relevant Works**

Wood Plastic Composites (WPCs), produced by blending wood flour and polypropylene granules, exhibited enhanced MOR, MOE, and water absorption up to a wood flour weight percentage of 35%. Beyond this threshold, an incremental rise in the proportion of wood flour led to a decrement in both mechanical and physical properties. Additionally, an increment in the weight proportion of wood flour up to 40% correlated with an increase in specimen hardness. This trend underscores the critical influence of wood flour content on the structural and mechanical attributes of WPCs (Tabarsa et al., 2011).

The incorporation of saw dust particle into HDPE matrix composites using a compression molding technique reveal the presence of web like structure and cross linking, typically, a characteristic of polymers. The sawdust particle enhance the composite properties Notably, sample containing sawdust particle size 1.1 to 1.4 mm with sawdust weight proportion 30% and compatibilizers weight proportion 3% exhibits the lowest water absorption. Likewise, Sample with sawdust particle size less than 1 mm with sawdust weight proportion 30% and compatibilizers weight proportion 7% exhibits the highest tensile strength (Kuforiji et al., 2023).

A study on composites made from recycled HDPE and fibers of wood emphasized the development of these composites. Combining wood fibers with recycled plastics, highlighted not only the chance to make use of a plentiful natural resource but also a potential solution to address the significant problem of plastic waste disposal. The influence of several factors, including pre-treatment of fiber, configuration of screw, and temperature, on the mechanical properties of these composites were investigated. A twin-screw extruder was used to manufacture the test samples. Notably, they noted that with an increase in fiber content, the composite tensile strength declined. Furthermore, it was observed that the flexural yield strength initially decline to a minimum point, subsequent increase, and another decrease with the increase in fiber content. This conclusion prompted them to determine that a crucial minimum level of fiber content was essential to enhance the composite, and the way fibers were distributed had a significant influence on their practical experimentation. Furthermore, it was established that changes in configuration of screw and temperature had a significant influence on the mechanical characteristics of these composite materials. They also observed that variations in configuration had the potential to cause mechanical degradation of the fibers, resulting in a reduction in fiber length. This highlighted the intricate relationship between processing conditions, material composition, and the mechanical performance of the composite (Yam et al., 1990).

Composite specimens were fabricated using waste plastics (HDPE, Janitorial waste, Kerbside waste I, and Kerbside waste II) with Pinus radiata wood fibers through melt blending and injection molding. The mechanical properties of these composites were found to be significantly impacted by the content of fiber, matrix type, and interfacial bonding. Higher the content generally led to improved mechanical properties, with MDF/HDPE waste composites showing the highest strength. However, MDF/Kerbside waste I composites displayed inferior properties. To address this, MDF/Kerbside waste II composites with 1% EpoleneTM exhibited enhanced interfacial bonding and demonstrated cost advantages (Lim et al., 2009).

Recycled polypropylene (rPP) is used in Wood-Plastic Composites (WPCs) with pine radiate wood flour as a filler. WPCs' mechanical properties and Melt Flow Index (MFI) were investigated. The result shows that vPP has lower viscosity than rPP due to its higher MFI, suggesting rPP's greater molecular weight. Introducing the coupling agent MAPP enhances composite properties, particularly in rPP-based WPCs. Furthermore, study demonstrates that composite panels produced from rPP display superior dimensional stability and mechanical properties when compared to those crafted from vPP. The tensile and flexural properties of rPP-based composites are either on par with or slightly higher than those of vPP-based composites, showing a similar performance trend. This investigation offers advantages in terms of tensile and flexural strength, making the material well-suited for building applications (Bhaskar et al., 2012).

HDPE bars and composites incorporating sawdust and recovered HDPE have been the subject of significant research efforts. Notably, these composite materials have demonstrated remarkable improvements in bending characteristics compared to neat HDPE. Such enhancements make them particularly suitable for medium loading applications, including decking, railing, and fencing (Arnandha et al., 2017).

Plastic recycling has gained significant global attention due to the imperative to recover and reuse plastics. The possibility to produce plastic lumber from used recycled HDPE and and its composite with wood to proof usability and applicability for different purpose were studied. The recycled material exhibited mechanical properties below the expected range, possibly due to the plastic recycling process, which lacked pressure during cooling. The absence of pressure negatively influences material integration, leading to porosity from air bubble formation and reduced load resistance. Despite weaker mechanical properties, Wood-Plastic Composites (WPCs) offer favorable machining conditions, can be shaped with conventional woodworking tools, and are considered sustainable as they utilize recycled plastics and wood industry waste. WPCs can also be easily recycled into new composites, offering flexibility in molding into various shapes, including strong arching curves, though they generally have lower strength and stiffness compared to wood (Beshah et al., 2014).

The existing research highlights the benefits of natural organic fibers as biodegradable reinforcing materials in composites. Hence, utilizing pine-dust and recycled HDPE provides excellent way of utilizing waste and helps to reduce environmental footprint.

However, there are notable gaps for investigating the desirable properties on encompassing pine-dust as a natural filler specifically for recycled High Density Polyethylene (HDPE) composites. The mechanical performance and interfacial bonding of HDPE with pine-dust remain underexplored. Thus, this research focuses on assessing the morphology, mechanical and water absorption property of the composites on varying size and proportion of pine-dust with recycled HDPE.

CHAPTER THREE: RESEARCH METHODOLOGY

The project started with a thorough analysis of the core problem and existing solutions in the field. Related research papers, as well as review papers, were studied, current breakthroughs related to the project were analyzed, and the research gap existing across the literature were noted with the goal to contribute meaningfully to the field by devising innovative solutions through a well-structured methodology. The general procedure for the project is as follows:

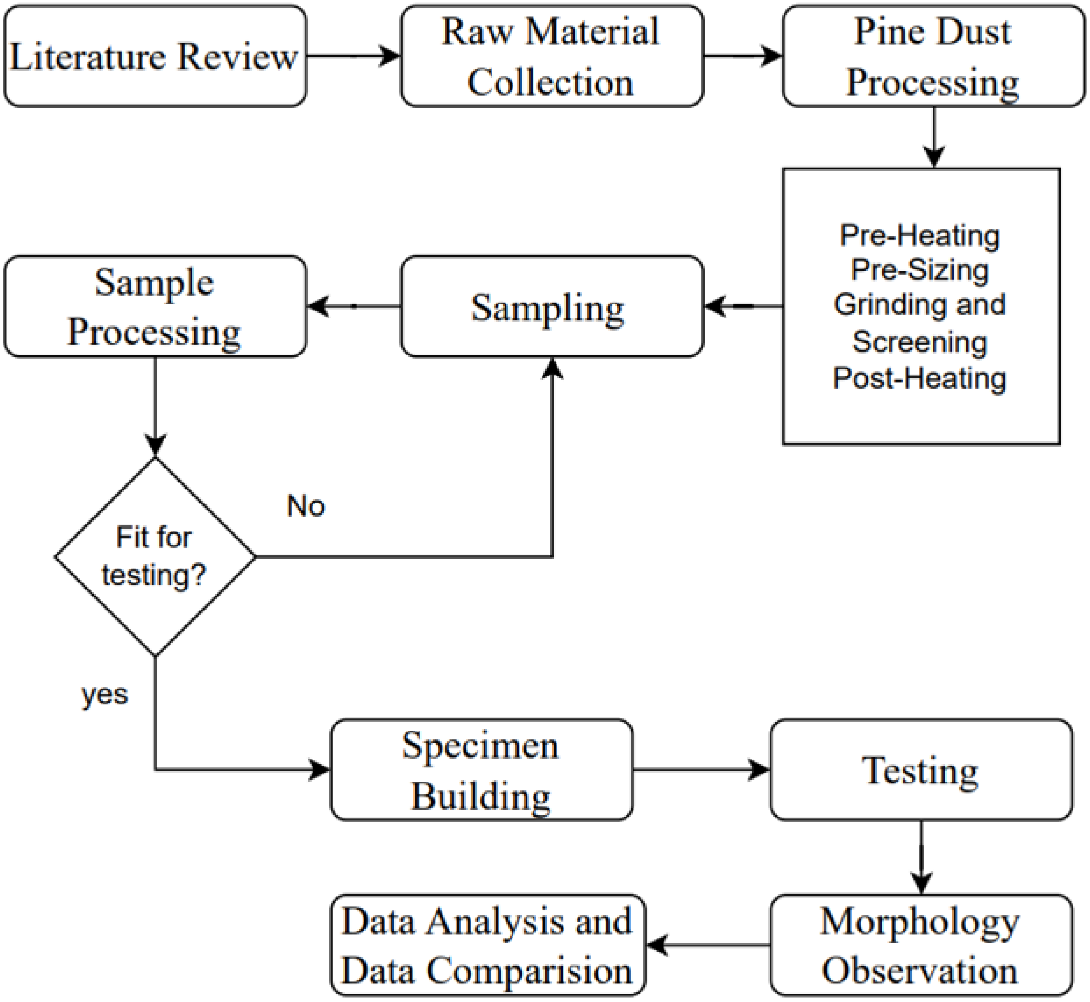

Figure 3-1: Methodology Flow Chart

3.1 **Literature Review**

A significant portion of the research is dedicated to an extensive literature review, covering a wide range of sources, including books, journals, papers, and articles. This review has been thorough and will continue to be so throughout the entire research process. The focus of the literature review is mainly on use of natural filler on polymer, extrusion technique, mechanical testing, and morphology study. This comprehensive review lays the essential groundwork for the research.

3.2 Raw Material Collection

In this study, we collected two crucial raw materials: Recycled HDPE from the plastic processing industry and pine-dust from the wood industry. Recycled HDPE was sourced from reliable manufacturers, ensuring its quality, while pine-dust was obtained from sustainable sawmills. These materials form the basis of our investigation.

3.3 Pine Dust Processing

3.3.1 Pre-heating

In the preliminary stage of the methodology, natural solar energy was harnessed to facilitate the heating process for the collected raw material, pine-dust, which, being a natural material, may contain moisture, potentially affecting its weight behavior during the subsequent experiments while embracing an eco-friendly approach.

3.3.2 Pre-sizing

In the pre-sizing phase of methodology, home sieving process was used to effectively reduce the size of the collected pine-dust sourced from the wood industry. Given that the initial collection contained materials of varying sizes, it was important to segregate them to facilitate efficient handling.

3.3.3 Grinding and Screening

Two crucial techniques were implemented, grinding and screening, to size the processed pine-dust collected from the wood industry.

Grinding: To further refine the pine-dust, household grinding equipment was utilized. This mechanical process effectively reduced the size of the pine-dust particles, increasing their homogeneity and surface area.

Screening: To extract different particle sizes and ensure precise control over the size distribution, sieving was employed of size 212 micron, 425 micron and 1000 micron in the screening process. Pine-dust particles of respective sizes ranges were obtained by carefully passing the grinded pine-dust through a series of sieves. As a result, distinct fractions of pine-dust particles were obtained, each falling within specific size ranges. This step allowed to isolate and select the most suitable particle sizes for different aspects of our research, enabling a targeted investigation of their properties and potential applications.

The residues left are re-grinded and sieved repeatedly until required amount of the products were obtained.

3.3.4 Post-heating

After grinding and screening the pine-dust, post-heating was employed using microwave energy to further remove any moisture present, contributing to more accurate and reliable measurements during the weighing process.

3.4 **Sampling**

After grinding and segregation, samples with different proportion of pine-dust of three different sizes were prepared incorporating with recycled HDPE as shown in the Table 3-1.

%Weight of Pine-dust /Weight of Recycled HDPE	**425-1000 micrometer**		**212-425 micrometer**		**Less than 212 micrometer**	
	Pine-dust (in gm)	Recycled HDPE (in gm)	Pine-dust (in gm)	Recycled HDPE (in gm)	Pine-dust (in gm)	Recycled HDPE (in gm)
5	35	665	35	665	35	665
10	70	630	70	630	70	630
15	105	595	105	595	105	595
20	140	560	140	560	140	560
25	175	525	175	525	175	525
30	210	490	210	490	210	490
Total	**735**	**3465**	**735**	**3465**	**735**	**3465**

Table 3-1: Weight proportion of Pine-dust of Three Different Sizes in Recycled HDPE

Altogether, 18 samples were prepared to process.

Table 3-2 specifies the unique nomenclature for representing each specimen in accordance to size and proportion of pine-dust inclusion in recycled HDPE to facilitate ease of use and provide a convenient reference for our study

Size	**% of Pine-dust**	**Name**

425 µm-1000 µm	5	L-5%
	10	L-10%
	15	L-15%
	20	L-20%
	25	L-25%
	30	L-30%
212 µm- 425 µm	5	M-5%
	10	M-10%
	15	M-15%
	20	M-20%
	25	M-25%
	30	M-30%
212 µm or less	5	S-5%
	10	S-10%
	15	S-15%
	20	S-20%
	25	S-25%
	30	S-30%

Table 3-2:Identification Name for Specific Size and Proportion

3.5 Sample Processing

3.5.1 Extrusion

The samples that have been prepared were introduced into the extruder through a hopper. Inside the heated tube of the extruder where each sample are heated at 210ºC. A rotating screw access the uniform mixing of pine-dust with molten polymer and also pushes the molten composite towards the nozzle. The resulting molten product is then guided through a circular outlet, onward collected in the rectangular die of cross-section 50 mm ×20 mm.

3.5.2 Cooling

The formed pieces were subsequently immersed in water at room temperature to cool the molten composite so it solidifies.

3.5.3 Extraction

The composite was extracted by applying pressure using a mandrel in a mechanical clamper.

3.6 **Specimen Building**

The extracted extruded product underwent cutting to achieve specific lengths which is crucial to ensure that the specimen fit the exact specifications needed for subsequent testing and evaluation.

3.7 **Mechanical Testing**

3.7.1 Tensile Test

Tensile experiments were employed to ascertain the response of materials when subjected to stretching forces. To conduct tensile test, specimens of dimension 300 mm × 45 mm × 15 mm were taken. This tensile test was executed at room temperature, employing a test speed of less than 10 mm/ min using AMI-652-1 universal testing machine. The specimen were securely clamped onto the testing machine taking gauge length of 170 mm. Loading and elongation data were extracted from its computerized system. The data were further extracted in MS Excel to further analyze and to compute ultimate strength, percentage elongation and yield strength of the composite.

3.7.2 Impact Test

Impact assessment was conducted using Charpy Impact Testing instrument , specimens of dimension 50 mm × 10 mm ×10 mm with notch of 2 mm depth inclined an angle of 45^0 are taken and executed at room temperature. This test involves striking an appropriate specimen with a pendulum arm while securely holding the specimen at both ends. The hammer strikes the specimen on the opposite side of the notch. The precise measurement of the energy absorbed by the specimen was achieved by carefully assessing the reduction in the pendulum arm's motion (Saba et al., 2018).

3.8 **Morphological Observation**

In the context of this study, the "Morphological Observation" phase was investigated to thoroughly investigate the structural characteristics and features of the composite materials. Stereoscopy microscope, which provide a three-dimensional perspective of the specimens, was employed with the aim of gaining comprehensive understanding of the intricate features, particle distributions, and surface textures of pine-dust within the polymer composite, thereby contributing to a deeper understanding of how the composite's morphology influences its mechanical properties and overall performance

3.9 **Water Absorption**

The assessment of water absorption involves determining the percentage increase in weight of a plastic specimen through the following procedure. In adherence to the ASTM D570 standard, the specimens were subjected to a 24 hours drying period in an oven at 105^o C. Afterward, the samples were immediately weighted. Subsequently, the specimens were submerged in water at room temperature for a 24 hours period, which afterward soaked and re-weighted for the computation of water absorption using the equation provide below(Saba et al., 2018):

$$\text{Water absorption \%} = \frac{wet\ weight - dry\ weight}{dry\ weight} \times 100\ \%$$

3.10 **Data Analysis and Data Comparison**

A comprehensive examination of the all the experimental results were thoroughly investigated using statistical tool and the specimen exhibiting the best property of parameter undertaken among different proportion of same size, repeating this process, the obtained best specimens from each sizes were further compared among themselves and with the base material.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Sample Preparation

The careful preparation of samples, involving pine-dust sizing and precise proportioning laid the groundwork for investigating the effects of pine-dust on recycled HDPE composites. The extrusion was carried out using single-screw extruder, which was sized into respective sizes to be fit for tests to be performed.

4.2 Visual Inspection

The visual examination of composite was carried out regarding NFs alignment, distribution, bonding and resin's color.

The alignment of pine-dust particles was random within the composite; the pine-dust was found scattered in different directions without specific patterns. The pine-dust was uniformly distributed throughout the extruded product and a denser distribution was observed at the central area as compared with surface. The bonding between NFs and recycled HDPE was observed to be excellent. The recycled HDPE showed black color as of raw material but inclusion of pine-dust exhibits scattered brownish color of the composite. However, minority of specimens displayed hollow areas within the structure. The result will be, further interpreted based on morphological observation using stereoscopy microscope.

These irregularities is attributed due to technical faults and inclusion of foreign debris during manufacturing, such as inadequate mixing or compaction as majority of specimens displayed solid structure without any hollow areas.

4.3 Effect of Pine-dust Size and Proportion on Mechanical Properties of Composite

This section delves into a comprehensive analysis on how varying size and proportion of pine-dust influences the mechanical properties in composite.

4.3.1 Effect of loading on elongation of composite

The raw data obtained from tensile test were extracted in excel with the aim to analyze effect on loading and elongation properties of composite materials. This sub-section presents the graphical illustration of results obtained from the experimental analysis.

The graph illustrating the relationship between elongation and loading for composites with varying sizes and proportions of filler are presented below.

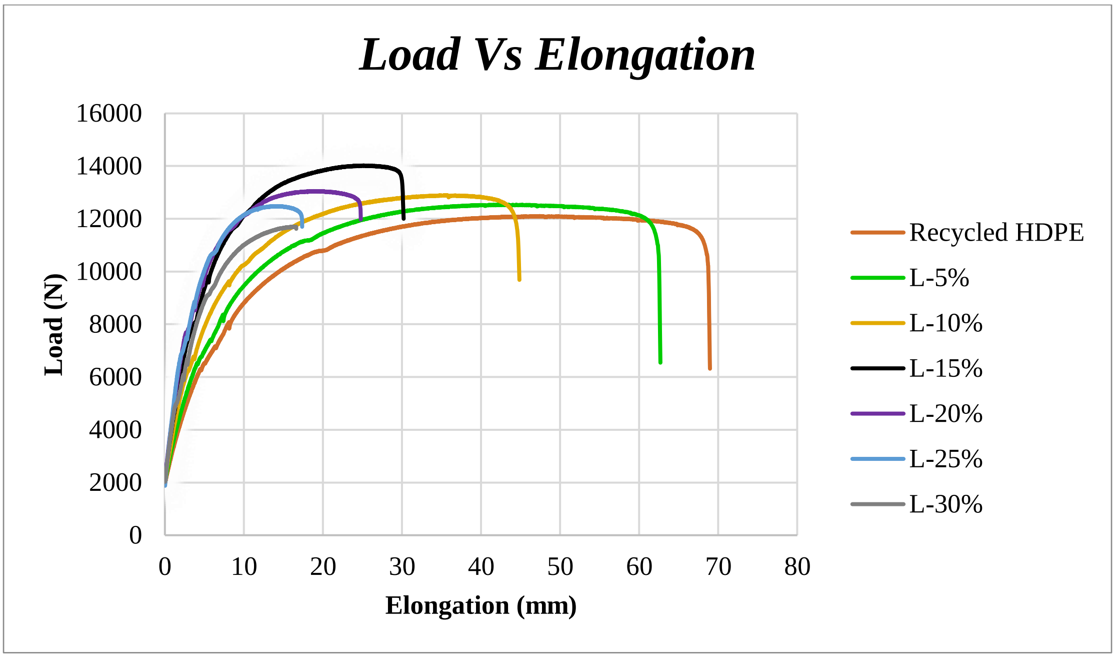

Figure 4-1 Loading vs. Elongation for Pine-dust (425 µm - 1000 µm) in Recycled HDPE Composites

The Figure 4-1 illustrates the elongation with loading of recycled HDPE and composite of different proportion with filler pine-dust size ranging from 425 µm – 1000 µm. The graph revealed a distinct characteristic. With an increase in the proportion of pine-dust within the composite, it was observed that there is a remarkable enhancement in ultimate load to 15 % inclusion of pine-dust in recycled HDPE, whereas the elongation shows a continuous decreasing trend, on increasing the proportion of pine-dust in recycled HDPE. Increasing the proportion of pine-dust in recycled HDPE decreases the ductility of recycled HDPE, thereby enhancing its brittleness.

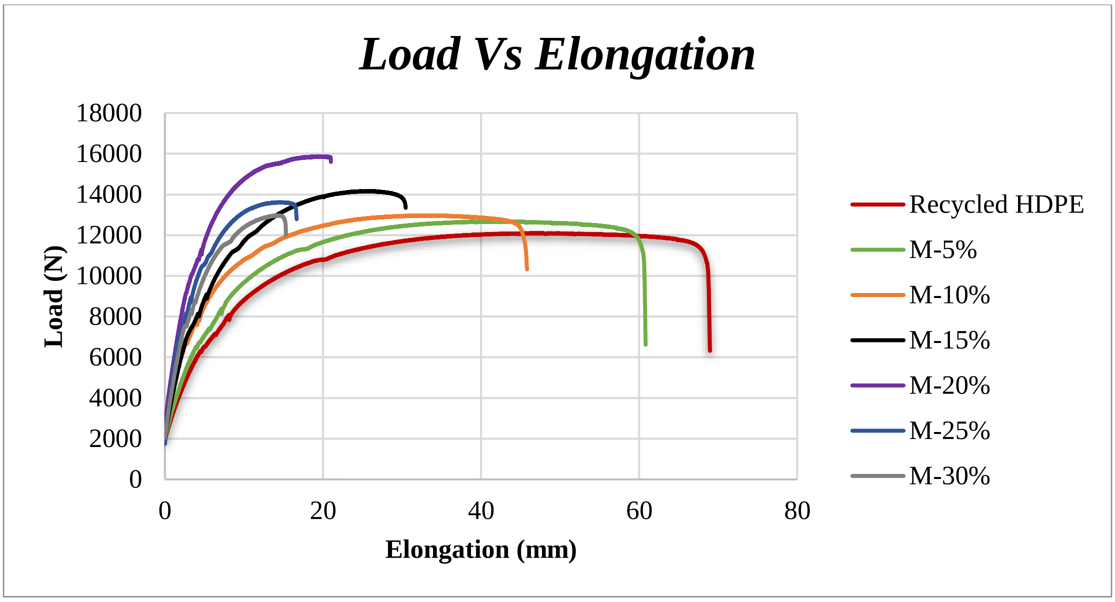

Figure 4-2: Loading vs. Elongation for Pine-dust (212 μm -425 μm) in Recycled HDPE Composites

The Figure 4-2 shows the elongation with loading of recycled HDPE and composite of different proportion with pine-dust size ranging from 212 μm – 425 μm. The graph displays a distinctive pattern. Similar to the previous observation, an increase in the pine-dust content within the composite leads to a significant improvement in ultimate load capacity, with a notable enhancement observed up to 20% inclusion of pine-dust in recycled HDPE, afterward revealed a decreasing trend. Conversely, the trend in elongation remains consistent, showing a continuous decline as the proportion of pine-dust in recycled HDPE increases. This trend indicates that augmenting the pine-dust content in recycled HDPE results in decreased ductility while enhancing its brittleness, aligning with the previous findings for larger pine-dust particles.

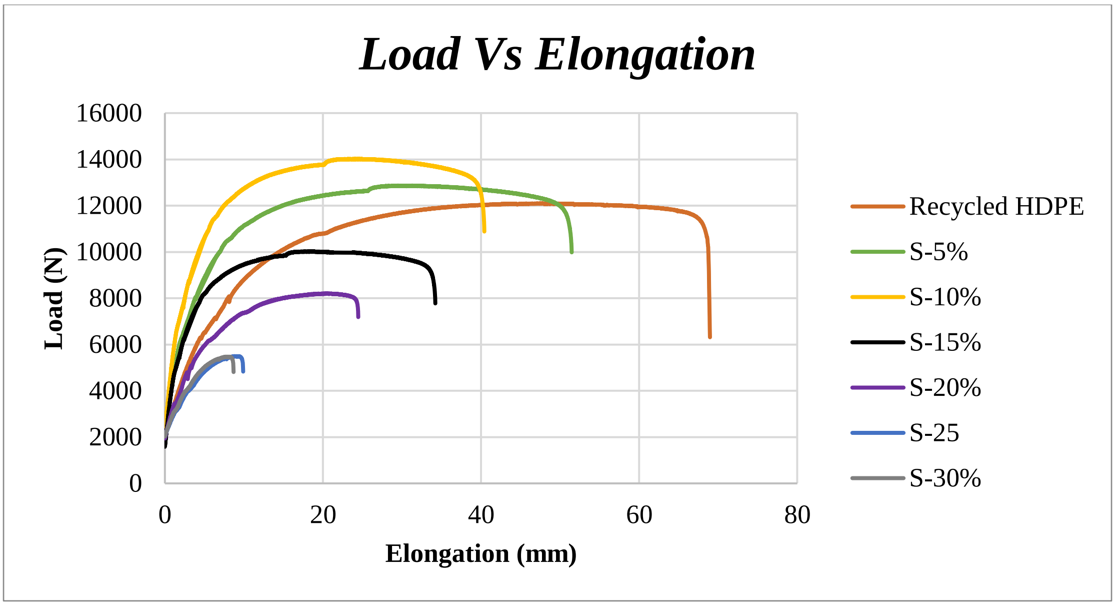

Figure 4-3: Loading vs. Elongation for Pine-dust (less than 212 µm) in Recycled HDPE Composites

The Figure 4-3 shows the elongation with loading of recycled HDPE and composite of different proportions with pine-dust size ranging less than 212 µm. The graph exhibits a distinctive pattern akin to previous observations. Notably, we observe a significant enhancement of up to 10% inclusion of pine-dust in recycled HDPE; however, beyond this point, there is a noticeable decrease in the ultimate load. Conversely, the elongation trend remains consistent but it demonstrates a more pronounced decrease than observed previously as the proportion of pine-dust in recycled HDPE increases.

4.3.2 Effect on various tensile parameter

The Table 4-1 shows the tensile data of composites of pine-dust size ranging from 425 µm – 1000 µm.

% of Pine-dust	**Ultimate Load(KN)**	**Ultimate strength (Mpa)**	**Yield Load (KN)**	**Yield Strength (Mpa)**	**Elongation**	**% Elongation**
0	12.1	13.44	11.2	12.44	70	41.18
5	12.55	13.94	10.1	11.22	62.68	36.87
10	12.9	14.33	7.6	8.44	44.85	26.38
15	14.03	15.59	7.43	8.26	30.3	17.82
20	13.05	14.50	6.47	7.19	24.8	14.59
25	12.5	13.89	4.91	5.46	17.36	10.21
30	11.7	13.00	4.73	5.26	16.6	9.76

Table 4-1: Tensile Data of Composites of Pine-dust Size 425 µm – 1000 µm

The Table 4-1 shows the comprehensive set of calculated values based on loading vs elongation data of each composite having incorporated pine-dust size 425 µm – 1000 µm. These values sets a framework to analysis the tensile properties of composites and helps to compare it with recycled HDPE.

The following figures will further facilitate in-depth understanding the variation in tensile properties on varying proportion.

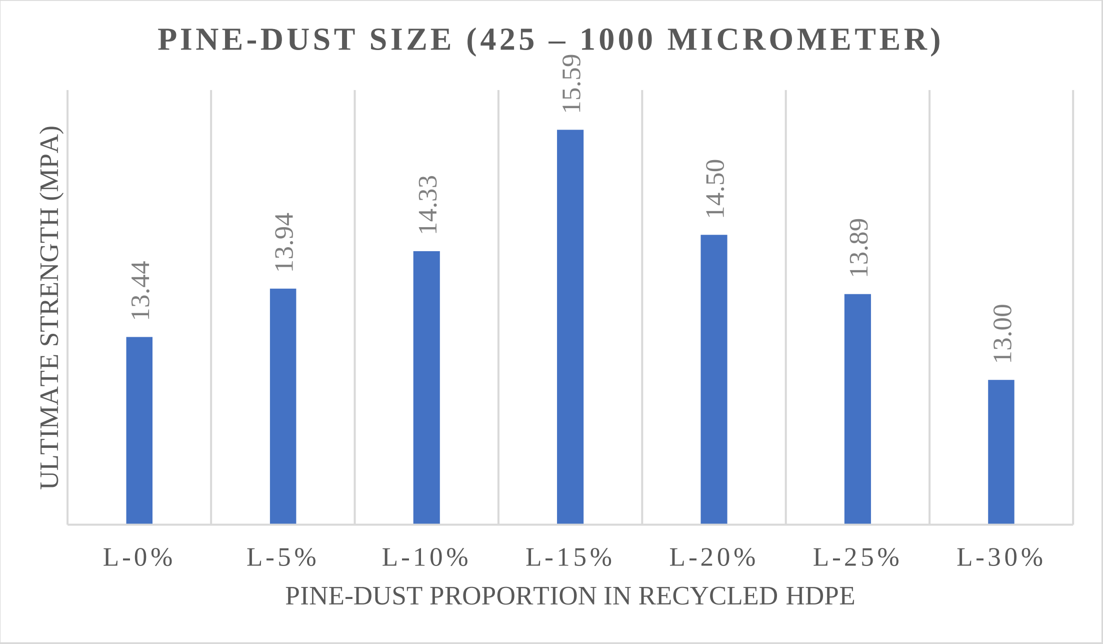

Figure 4-4: Ultimate Strength of Composites with Pine-dust Size 425 µm – 1000 µm

Shifting focus to the bar graph in Figure 4-4 depicting ultimate strengths of composites with the inclusion of pine-dust in the size range of 425 µm – 1000 µm, a compelling trend was observed. The graph demonstrates that the ultimate strength of these composites increases with the inclusion of pine-dust up to a 15% proportion. Beyond this point, there is a gradual decrease, yet it remains noteworthy that even at 20% and 25% inclusion, the ultimate strength remains higher than that of recycled HDPE with no pine-dust inclusion.

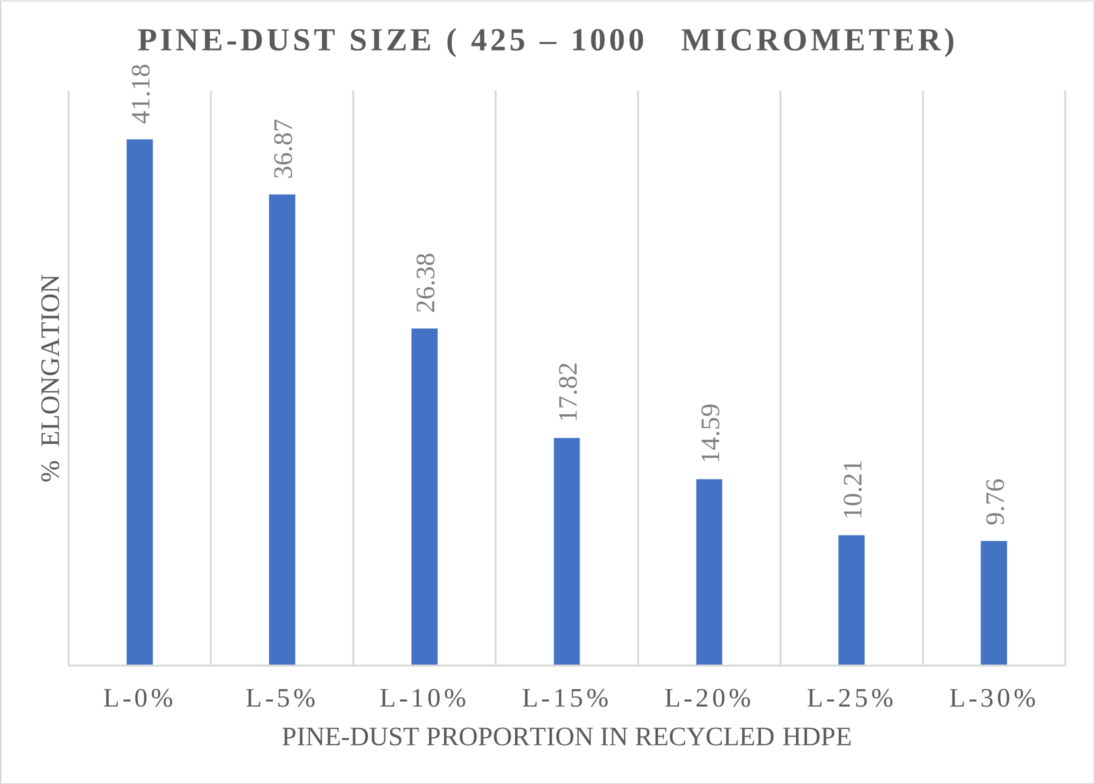

Figure 4-5: Percentage Elongation of Composites with Pine-dust Size 425 μm – 1000 μm

The bar graph in Figure 4-5 depicts the percentage elongation of composites with the inclusion of pine-dust in the size range of 425 μm – 1000 μm. As the proportion of pine-dust increases, there is a decrease trend in percentage elongation. This decline underscores that augmenting the pine-dust content within the composite material negatively influences its ductility, resulting in reduced elongation properties.

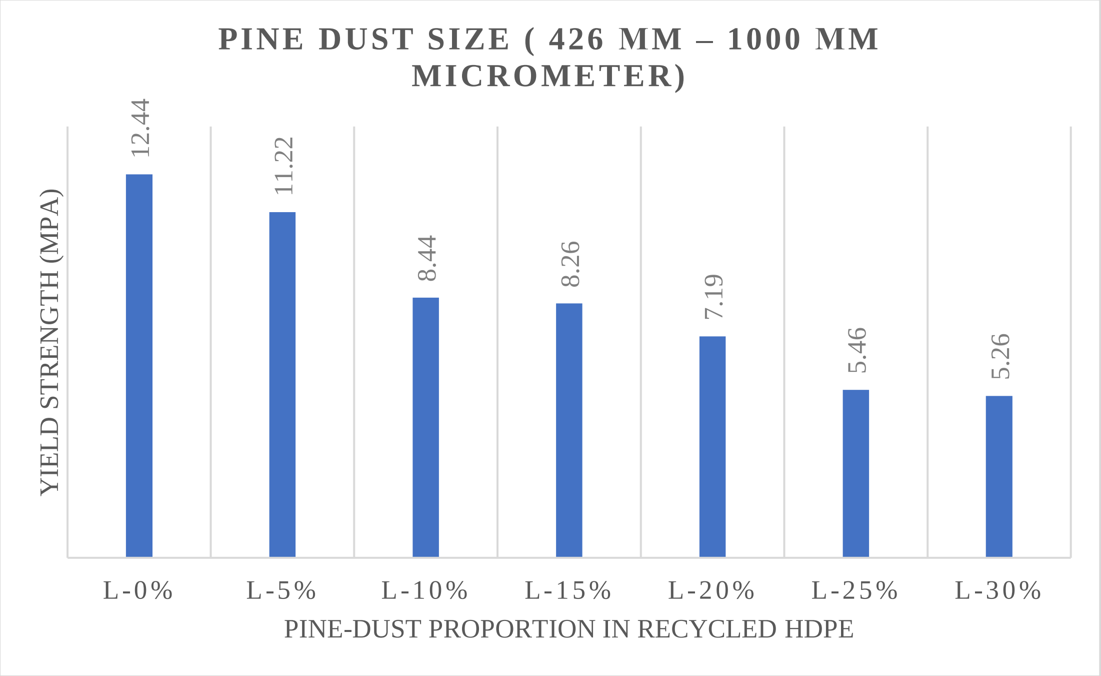

Figure 4-6: Yield Strength of Composites with Pine-dust Size 425 μm – 1000 μm

The bar graph in Figure 4-6 depicts the yield strength of composites with the inclusion of pine-dust in the size range of 425 µm – 1000 µm. As the proportion of pine-dust increases, there is a decrease trend in yield strength. This is due to the brittleness introduced by the higher concentration of rigid pine-dust particles.

The Table 4-2 shows the tensile data of composites of pine-dust size ranging from 212 µm – 425 µm.

% of Pine-dust	**Ultimate Load(KN)**	**Ultimate strength (Mpa)**	**Yield Load (KN)**	**Yield Strength (Mpa)**	**Elongation**	**% Elongation**
0	12.1	13.44	11.2	12.44	70	41.18
5	12.8	14.22	10.87	12.08	62.89	36.99
10	12.97	14.41	8.44	9.38	45.82	26.95
15	14.16	15.73	7.55	8.39	30.45	17.91
20	15.87	17.63	7.21	8.01	21	12.35
25	13.62	15.13	6.76	7.51	16.67	9.81
30	13	14.44	6.32	7.02	15.31	9.01

Table 4-2: Tensile Data of Composites of Pine-dust Size 212 μm - 425 μm

The Table 4-2 presents a comprehensive compilation of computed values derived from the loading vs elongation data for each composite incorporating pine-dust particles in the size range of 212 μm - 425 μm. These values establish a foundational framework for the detailed analysis of the tensile properties exhibited by these composites.

The subsequent figures have been included to enhance comprehension of the varying proportions and their influence on tensile properties.

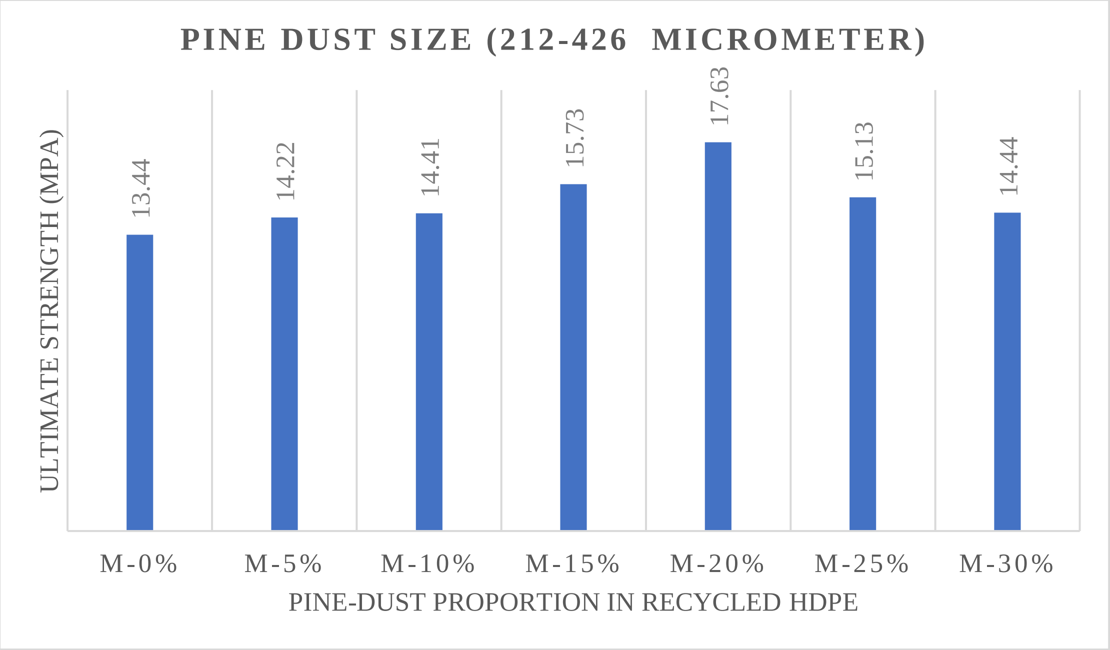

Figure 4-7: Ultimate Strength of Composites of Pine-dust Size 212 μm – 425 μm

The bar graph in Figure 4-7 illustrating ultimate strengths of composites with pine-dust in the size range of 212 μm – 425 μm, a notable trend emerged. Ultimate strength increased up to a 20% pine-dust inclusion, with 25% and 30% inclusions also surpassing the ultimate strength of recycled HDPE without pine-dust.

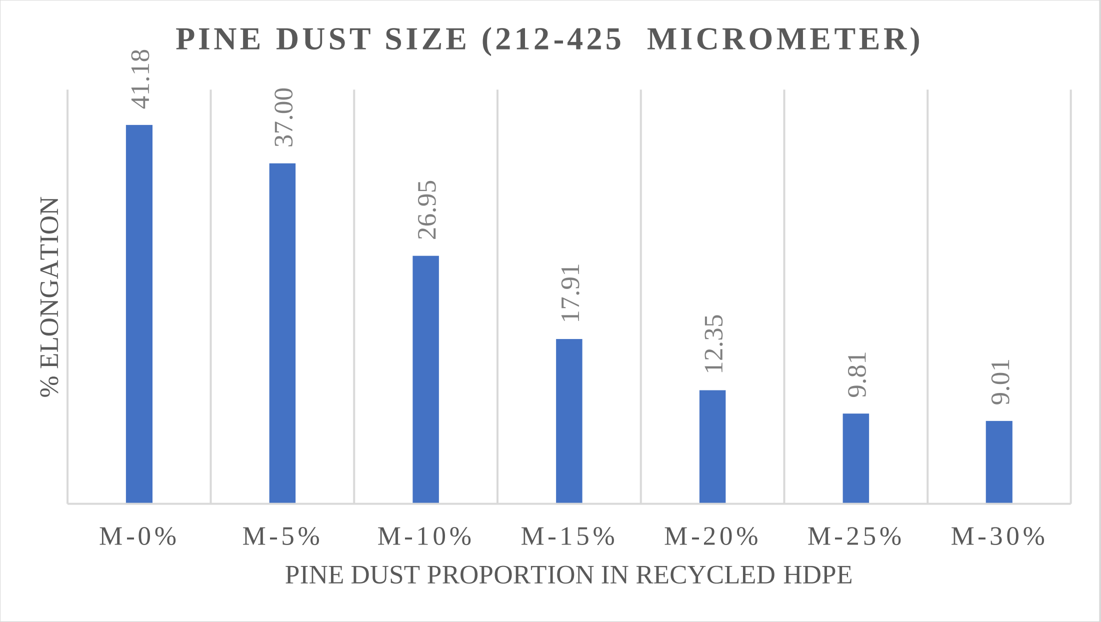

Figure 4-8: Percentage Elongation of Composites with Pine-dust Size 212 μm – 425 μm

The bar graph in Figure 4-8 depicts the percentage elongation of composites with the inclusion of pine-dust in the size range of 212 µm – 425 µm. As the proportion of pine-dust increases, there is a decrease trend in percentage elongation. This decline underscores that augmenting the pine-dust content within the composite material negatively influences its ductility, resulting in reduced elongation properties.

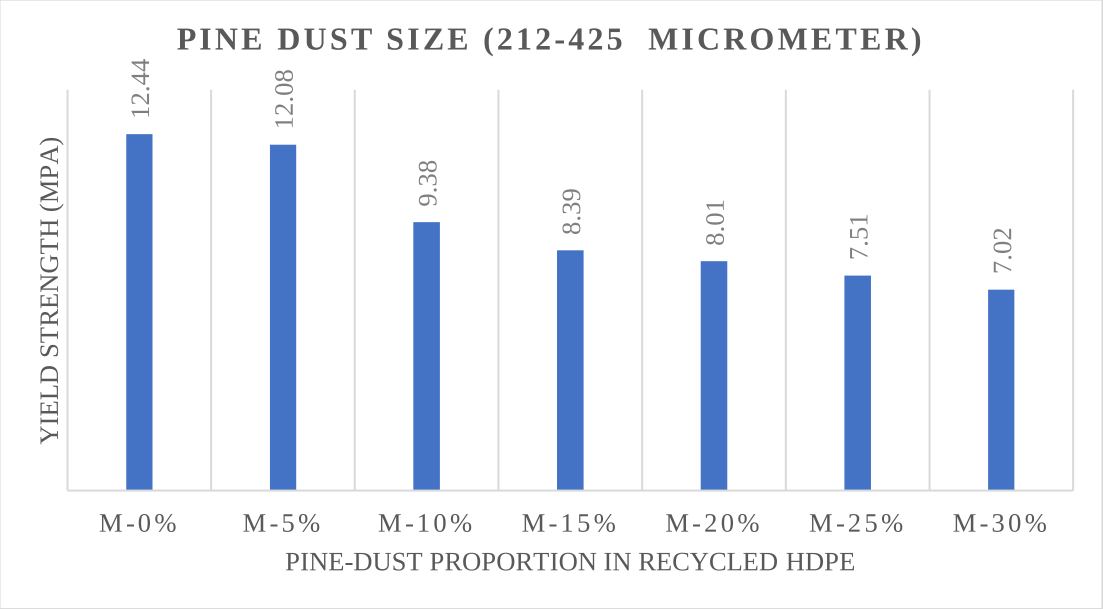

Figure 4-9: Yield Strength of Composites with Pine-dust Size 212 μm – 425 μm

The bar graph in Figure 4-9 depicts the yield strength of composites with the inclusion of pine-dust in the size range of 212 μm – 425 μm. As the proportion of pine-dust increases, there is a decrease trend in yield strength. This is due to the brittleness introduced by the higher concentration of rigid pine-dust particles.

% of Pine-dust	Ultimate Load(KN)	Ultimate strength (Mpa)	Yield Load (KN)	Yield Strength (Mpa)	Elongation	% Elongation
0	12.1	13.44	11.2	12.44	70	41.18
5	12.87	14.30	10.73	11.92	72.15	42.44
10	14.03	15.69	8.18	9.09	60.8	35.76
15	10	11.11	7.6	8.44	47.35	27.85
20	8.22	9.13	4.83	5.37	24.46	14.39
25	5.5	6.11	4.47	4.97	9.9	5.82
30	5.47	6.08	3.12	3.47	9.87	5.81

Table 4-3: Tensile Data of Composites of Pine-dust Size Less than 212 μm

The Table 4-3 shows the comprehensive set of calculated values based on loading vs elongation data of each composite having incorporated pine-dust size less than 212 μm. These values sets a framework to analysis the tensile properties of composites and helps to compare it with recycled HDPE.

The following figures will further facilitate in-depth understanding the variation in tensile properties on varying proportion.

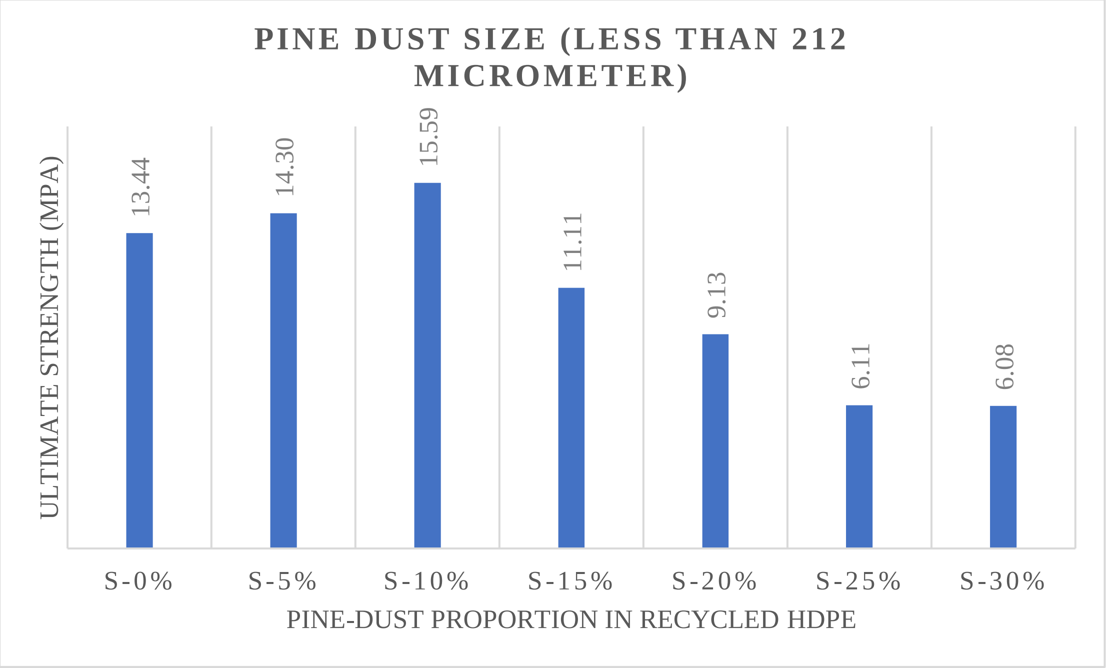

Figure 4-10: Ultimate Strength of Composites with Pine-dust Size less than 212 µm

In the bar graph Figure 4-10 for composite materials incorporating pine-dust particles smaller than 212 µm, the highest ultimate strength is evident at a 10% pine-dust inclusion, but beyond this threshold, there is a noticeable decline.

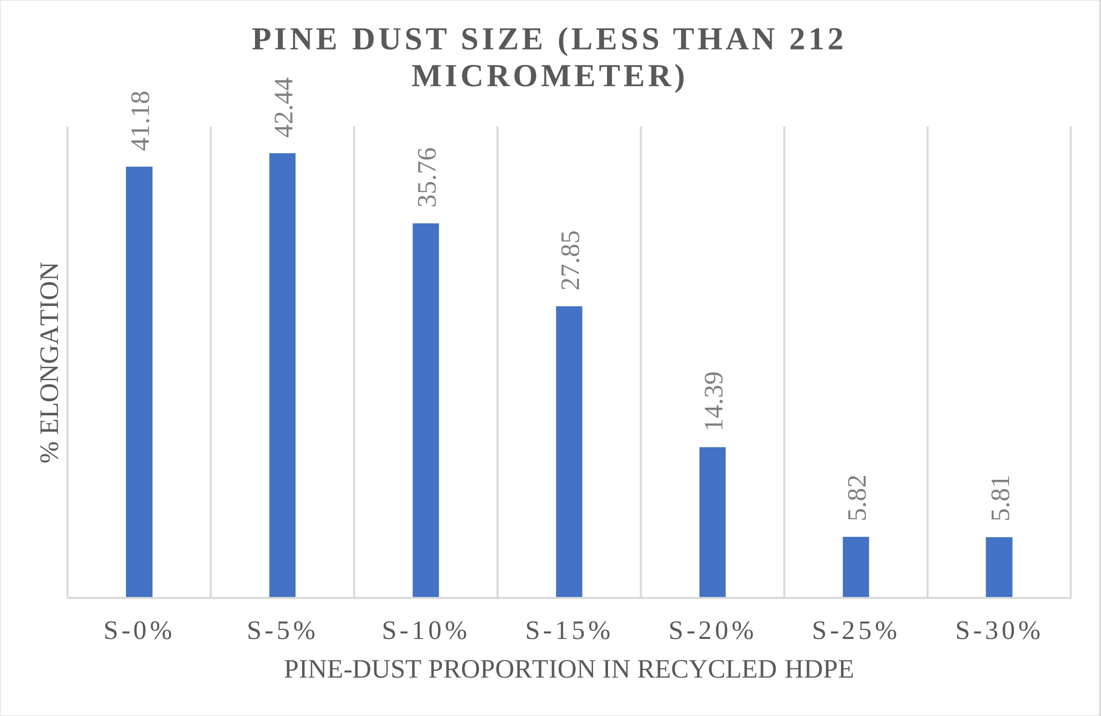

Figure 4-11: Percentage Elongation of Composites with Pine-dust Size Size less than 212 μm

The bar graph in Figure 4-11 depicts the percentage elongation of composites with the inclusion of pine-dust in the size range less than 212 μm. The percentage elongation slightly increased up to 5% inclusion of pine-dust in recycled HDPE, afterward it shows a decreasing trend. In addition, a similar elongation in 25% and 30 % inclusion of pine-dust was observed. This decline underscores that augmenting the pine-dust content within the composite material negatively influences its ductility, resulting in reduced elongation properties.

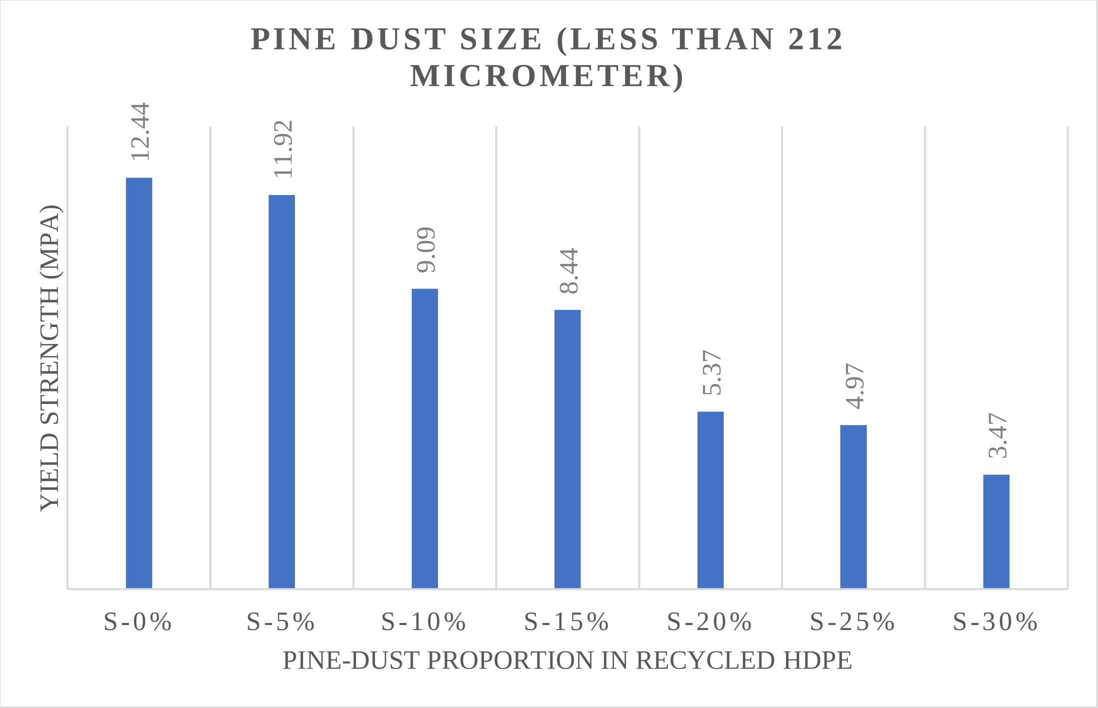

Figure 4-12: Yield Strength of Composites with Pine-dust Size Size less than 212 μm

The bar graph in Figure 4-12 depicts the yield strength of composites with the inclusion of pine-dust in the size less than 212 μm. As the proportion of pine-dust increases, there is a decrease trend in yield strength. The yield strength decreased slightly on inclusion of 5% of pine-dust in recycled HDPE but afterward shows a gradual decrement decreased This is due to the brittleness introduced by the higher concentration of rigid pine-dust particles.

4.3.3 Tensile Performance Comparison: Optimal Pine-dust Inclusion Composites

This section delves into a comparative analysis of the best composite materials derived from each of the three distinct pine-dust size ranges.

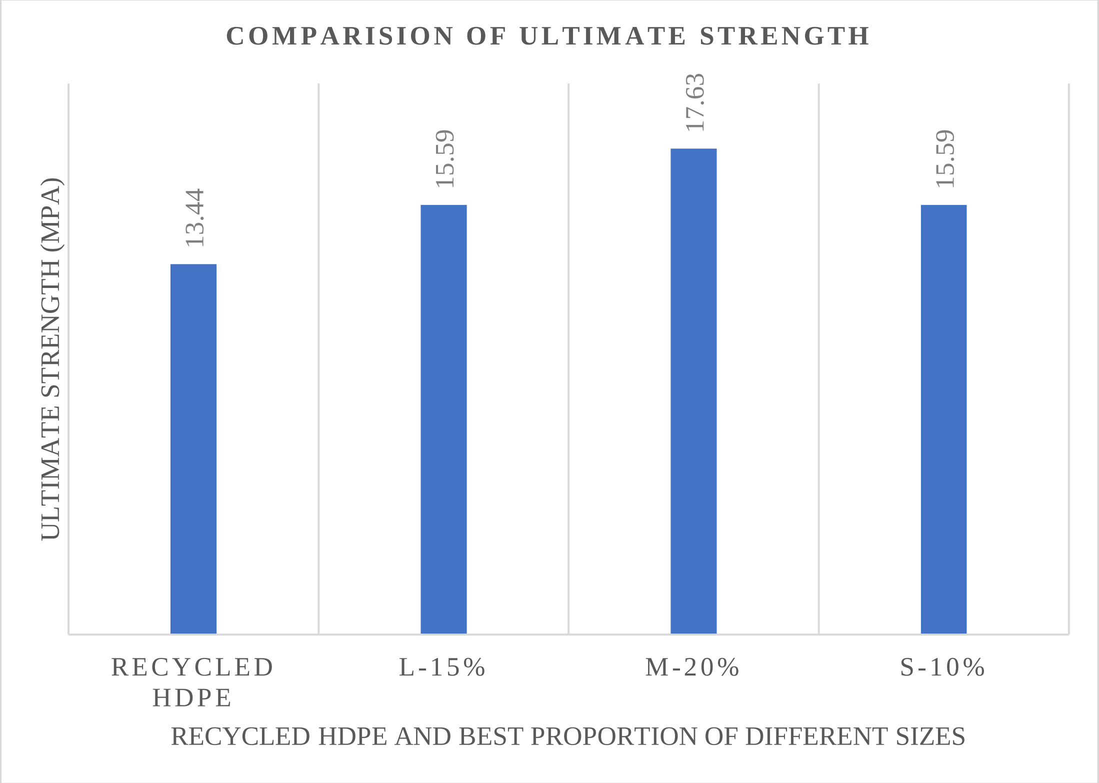

Figure 4-13: Comparison of Ultimate Strength of Recycled HDPE and Optimal Pine-dust Inclusion Composites of Three Different Ranges of Particle Size

The Figure 4-13 compares the ultimate strength of recycled HDPE and composite of each range of particle size exhibiting best ultimate strength. Across all the particle size ranges considered, the composites consistently outperform recycled HDPE in terms of ultimate strength. Among these outstanding composites, the M-20% composite stands out as the top performer, showcasing the highest ultimate strength among all tested materials. Additionally, it is noteworthy that the L-15% and S-10% composites shows identical ultimate strength values.

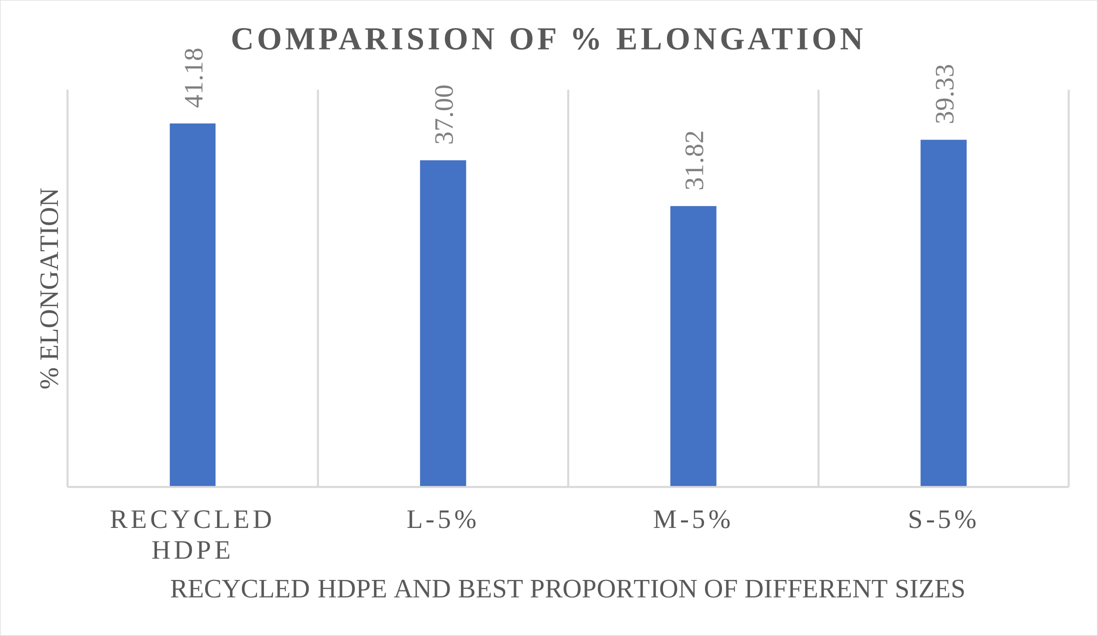

Figure 4-14: Comparison of % Elongation of Recycled HDPE and Optimal Pine-dust Inclusion Composites of Three Different Ranges of Particle Size

The Figure 4-14 compares the percentage elongation of recycled HDPE and composite of each range of particle size exhibiting highest percentage elongation. Across all the particle size ranges considered, the recycled HDPE consistently outperform best proportion of different sized composite in terms of percentage elongation, after which composite having 5 % inclusion of pine-dust size less than 212 µm resembled a comparable elongation.

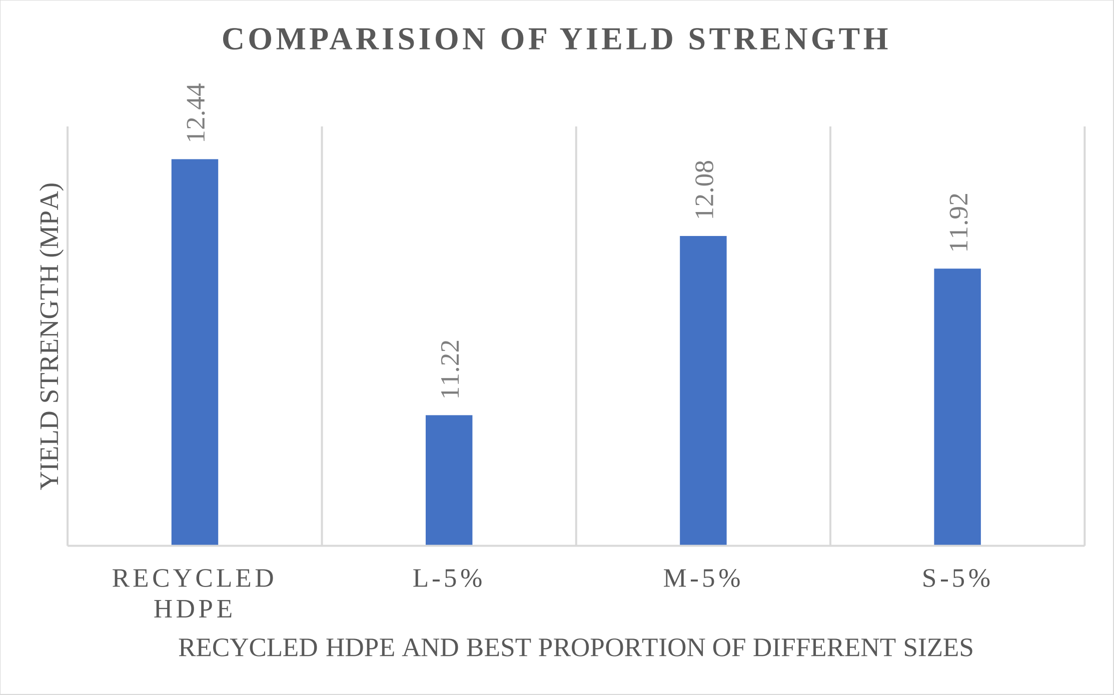

Figure 4-15: : Comparison of Yield Strength of Recycled HDPE and Optimal Pine-dust Inclusion Composites of Three Different Ranges of Particle Size

The Figure 4-15 compares the yield strength of recycled HDPE and composite of each range of particle size exhibiting best yield strength. Across all the particle size ranges considered, the recycled HDPE consistently outperform best proportion of different sized composite in terms of yield strength, after which composite having 5 % inclusion of pine-dust size range 212 µm – 425 µm resembled best yield strength among all composite.

4.3.4 Effect on Energy Absorption Characteristic

The raw data obtained from Charpy Impact Test were taken to analyze effect on energy absorption property of recycled HDPE on incorporating pine-dust of different sizes and proportions.

Size	**% of Pine-dust**	**Impact resistance (Joule)**
	0	2.00
425 µm-1000 µm	**5**	2.00
	10	4.00
	15	6.00
	20	4.00
	25	4.00

	30	1.00
212 µm- 425 µm	**5**	4.00
	10	5.00
	15	8.00
	20	8.00
	25	1.00
	30	1.00
Less than 212 µm	**5**	6.00
	10	10.00
	15	8.00
	20	6.00
	25	2.00
	30	1.00

Table 4-4: Energy Absorbed by Composite

The Table 4-4 shows the energy absorbed by composite of recycled HDPE incorporating pine-dust of different size range and proportion accordingly when untaken charpy impact test.

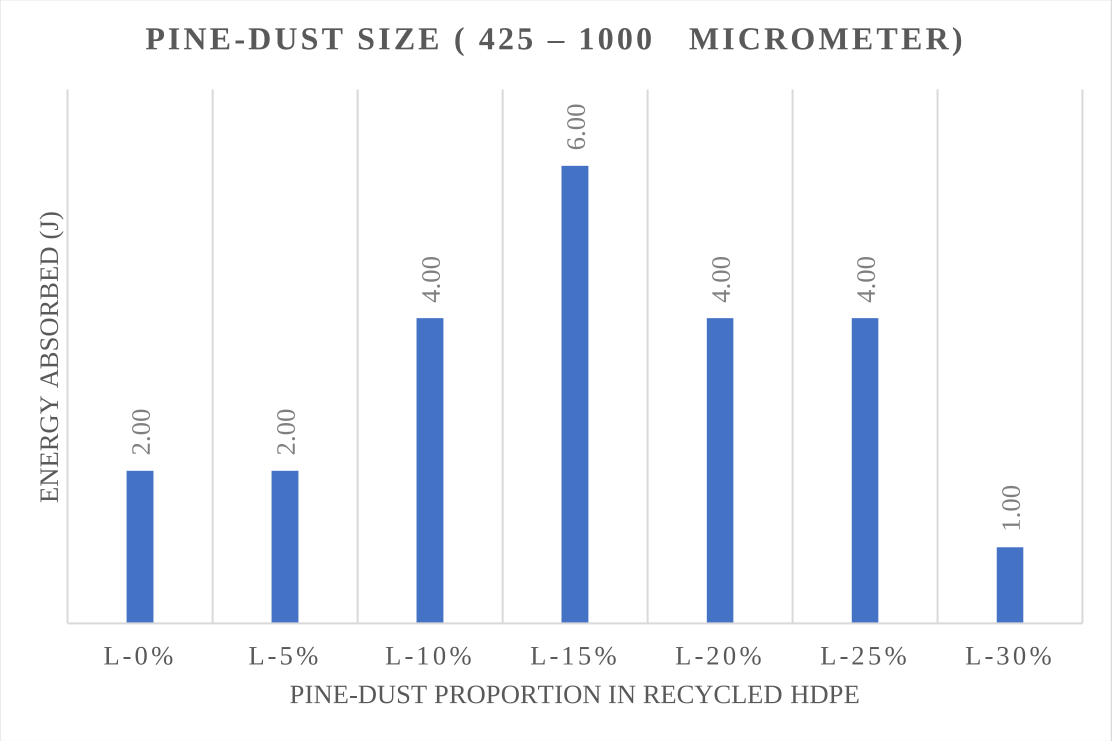

Figure 4-16: Energy Absorbed by composite of size 425 µm – 1000 µm

The Figure 4-16 shows the energy absorbed was maximum when the recycled HDPE incorporated by 15 % of pine-dust. The energy absorbed was uniform on incorporating 10%, 20% or 25% of pine-dust.

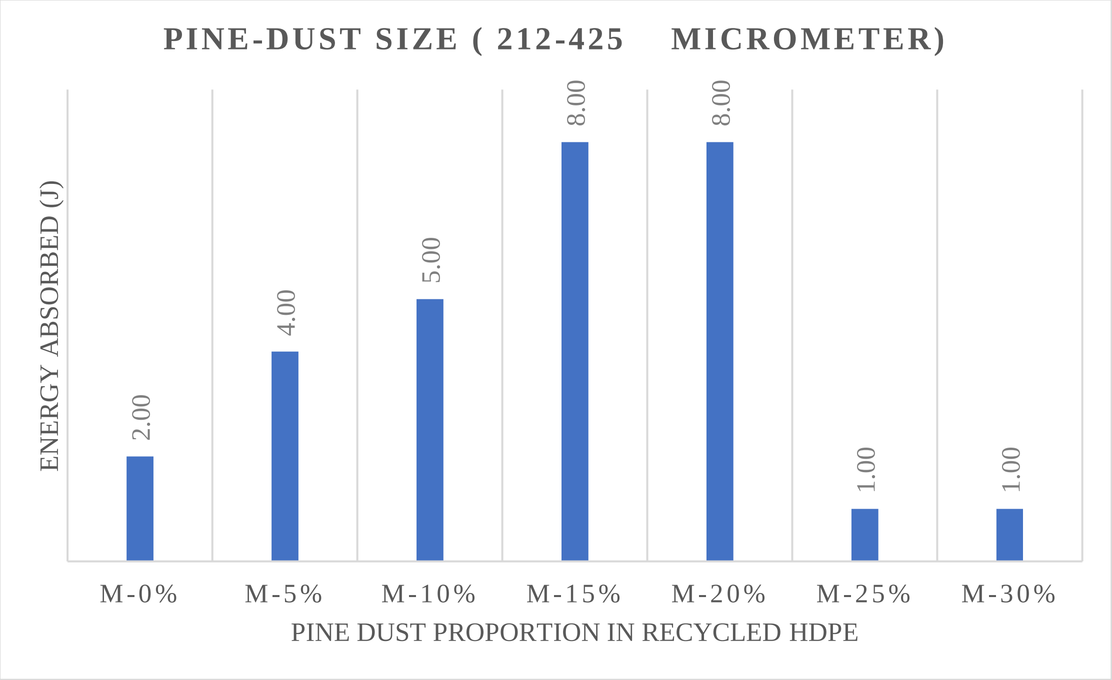

Figure 4-17: Energy Absorbed by composite of size 212 μm - 425 μm

The Figure 4-17 shows the energy absorption gradually increased up to 15% of pine-dust which is maximum for respective size of pine-dust after which it shows decreasing tendency.

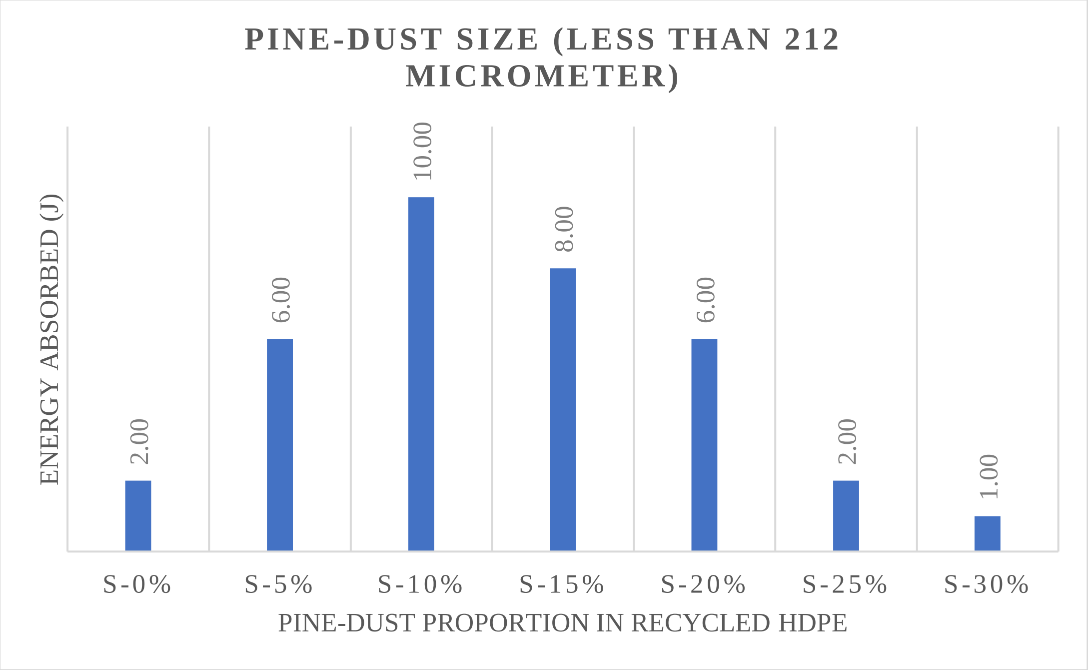

Figure 4-18: Energy Absorbed by composite of size less than 212 μm

The Figure 4-18 shows the energy absorption gradually increased up to 10% of pine-dust which is maximum for respective size of pine-dust after which it shows decreasing tendency.

4.3.5 Energy Absorption Comparison: Optimal Pine-dust Inclusion Composites of Different Ranges of Particle Size.

This section delves into a comparative analysis of the composite materials resembling best impact resistance from each of the three distinct pine-dust size ranges.

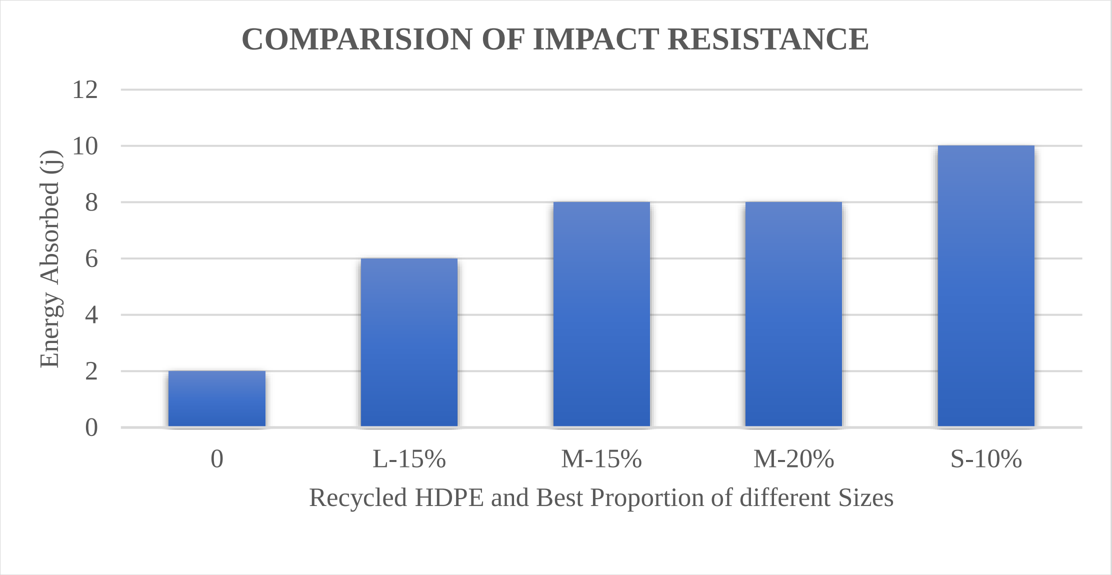

Figure 4-19: Comparison of Energy Absorption of Recycled HDPE and Optimal Pine-dust Inclusion Composites of Three Different Ranges of Particle Size

The Figure 4-19 compares the energy absorption of recycled HDPE and composite of each range of particle size exhibiting best. On all the sizes 15% inclusion resembles to have the higher energy absorption characteristic. Among the three-size ranges, S-10% have the highest energy absorption property after which M-15% and M-20% shows the second best. All composite that is been selected shows better energy absorption property than recycled HDPE alone.

4.4 **Effect on Morphology of the Composite**

A Stereo microscope with a total magnification of 100x optical and an additional 10x digital magnification was employed to examine the bond and dispersion of pine dust within the re cycled HDPE matrix.

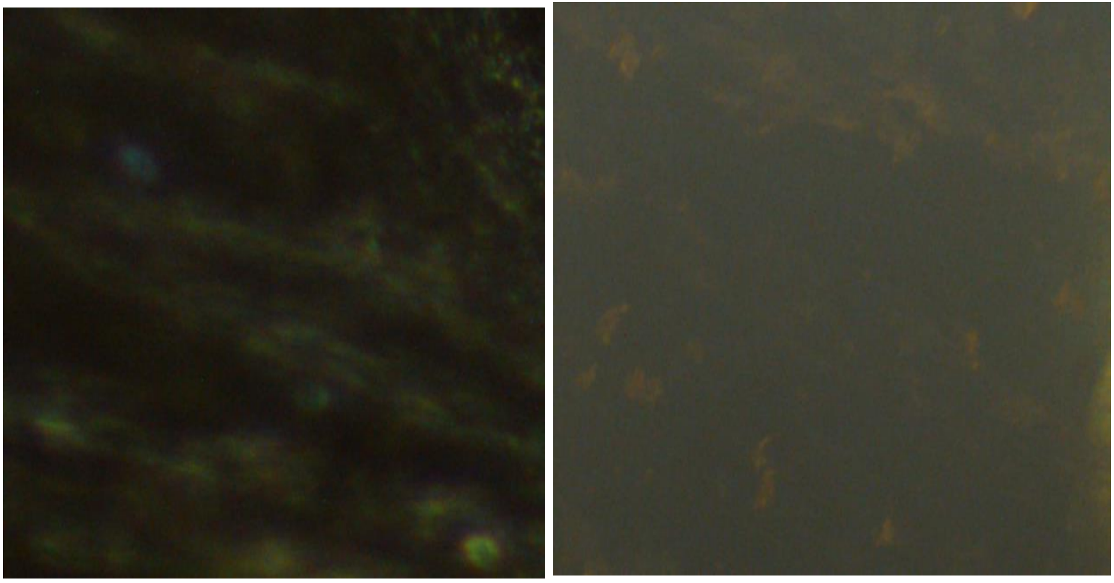

Figure 4-21: Recycled HDPE and Composite with 5% inclusion of pine dust of size range 212 µm- 425 µm

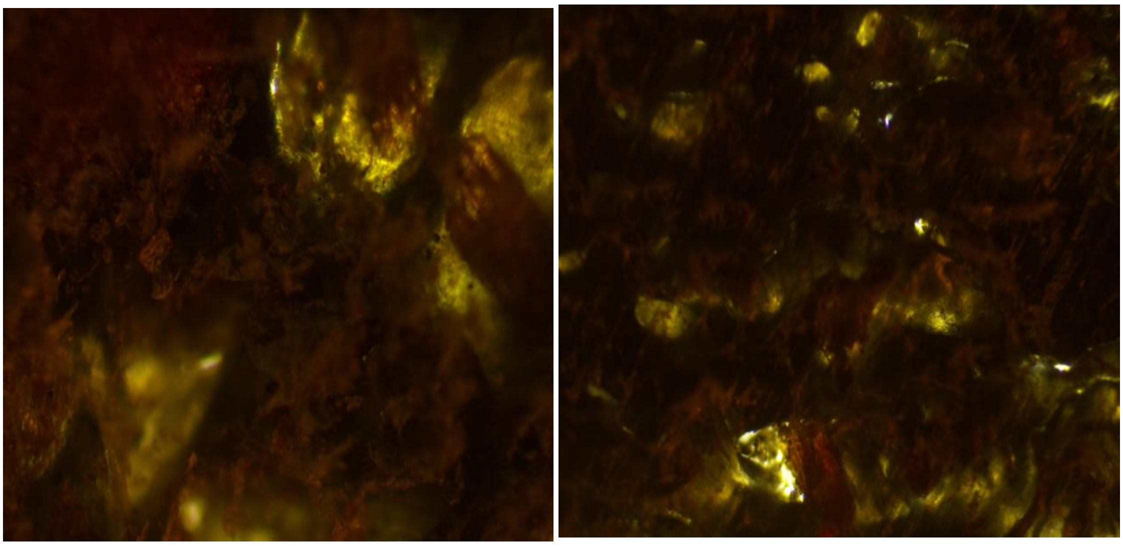

Figure 4-20: Composite with 10% inclusion of pine dust of size range size range less than 212 µm and and 15 % inclusion of size range 425 µm - 1000 µm

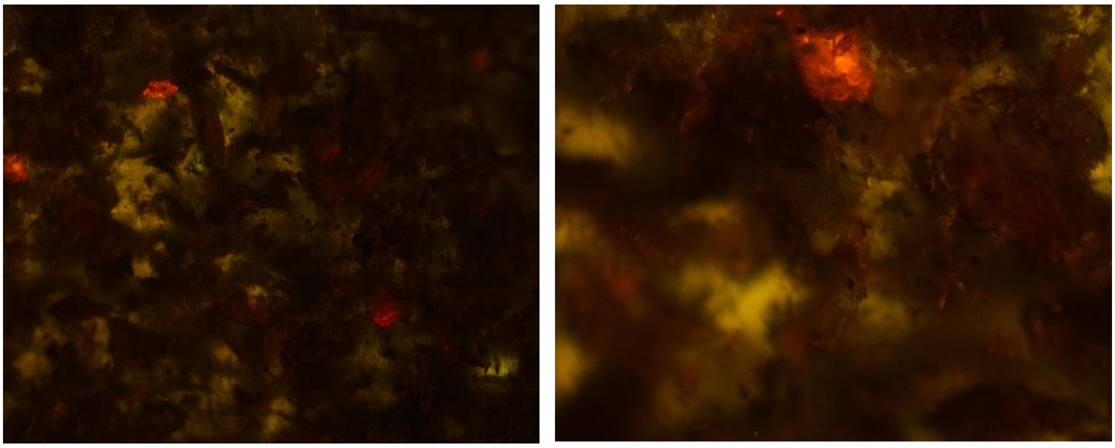

Figure 4-23: Composite with 20% inclusion of pine dust of size range 212 μm-425 μm and 15% inclusion of size range less than 212 μm

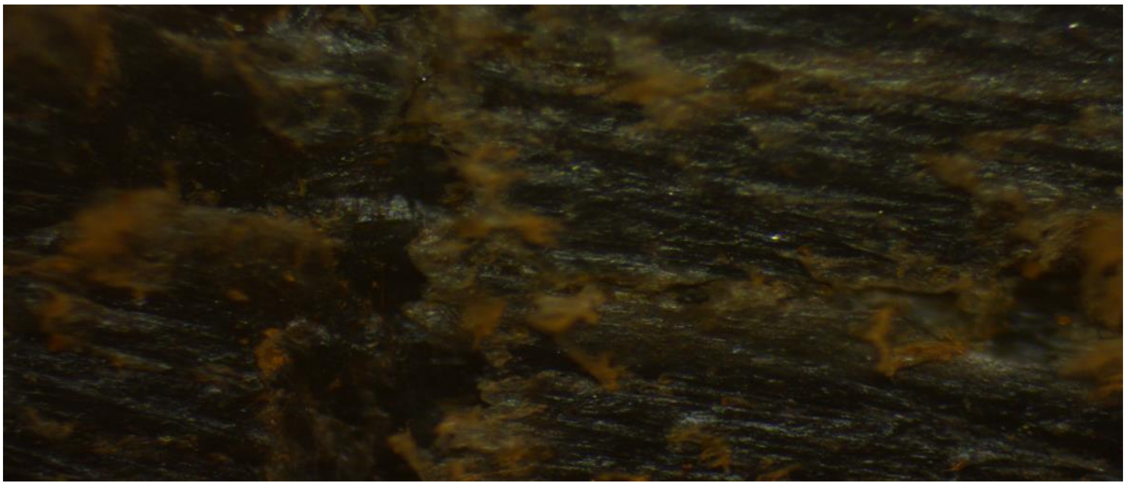

Figure 4-22: Composite with 25% inclusion of pine dust of size range less than 212 μm

The careful examination of morphology through the lens of a stereoscopy microscope has yielded profound insights into the complex dynamics governing the interaction between pine dust and recycled HDPE.

In the initial stages of our analysis, we observed a consistent dispersion of pine dust particles throughout the recycled HDPE matrix. This even distribution highlighted a seamless integration between the two components, enhancing the structural robustness.

Consequently, the composite exhibited a significant improvement in its ultimate strength, confirming the capacity to reinforce recycled HDPE.

However, a noteworthy transformation became apparent as the proportion of pine dust was increased. With the incremental addition of pine dust, a distinct agglomeration phenomenon emerged, giving rise to clusters or conglomerates within the composite. These aggregations, albeit visually evident, were indicative of a less homogeneous dispersion of pine dust particles within the matrix. As a result, there was a noticeable and significant reduction in the ultimate strength of the composite material. This decline in mechanical performance emphasized the importance of preserving a consistent dispersion of pine dust within the recycled HDPE matrix.

Furthermore, a specific focus on the size of pine dust particles, particularly those measuring less than 212 µm , revealed a critical finding. Within this size range, the agglomeration of pine dust was more apparent, exacerbating the adverse effects on ultimate strength. The presence of smaller particles appeared to exacerbate the clustering phenomenon, leading to a pronounced and drastic reduction in the overall structural integrity of the composite material.

4.5 **Water Absorption Test:**

The raw data collected from the water absorption test were analyzed to assess how the incorporation of pine-dust of varying sizes and proportions affects the water absorption characteristics of recycled HDPE.

Size	% of Pine-dust	Dry Weight (gm)	Weight Weight(gm)	Difference	% of Water absorption
	0	103.121	106.342	3.221	3.124
425 µm-1000 µm	**5**	87.564	90.575	3.011	3.439
	10	93.377	96.754	3.377	3.617
	15	97.094	100.681	3.587	3.694
	20	94.941	98.539	3.598	3.790
	25	107.717	111.84	4.123	3.828
	30	98.346	102.332	3.986	4.053
212 µm-425 µm	**5**	91.580	94.82	3.240	3.538
	10	95.390	98.797	3.407	3.572
	15	106.738	110.758	4.020	3.766
	20	89.621	93.104	3.483	3.886
	25	101.141	105.159	4.018	3.973
	30	92.995	97.003	4.008	4.310
Less than 212 µm	**5**	107.349	110.98	3.631	3.382
	10	86.580	89.7	3.120	3.604

	15	92.026	95.436	3.410	3.705
	20	96.432	100.329	3.897	4.041
	25	96.515	100.547	4.032	4.178
	30	98.532	102.774	4.242	4.557

Table 4-5: Water Absorption Test

The water absorption analysis as shown in Table 4-5 resembles the fact that increasing in proportion of pine-dust in recycled HDPE increases in water absorption characteristic of composite. As well as decreasing in size of composite also leads to increase in water absorption characteristic of composite.

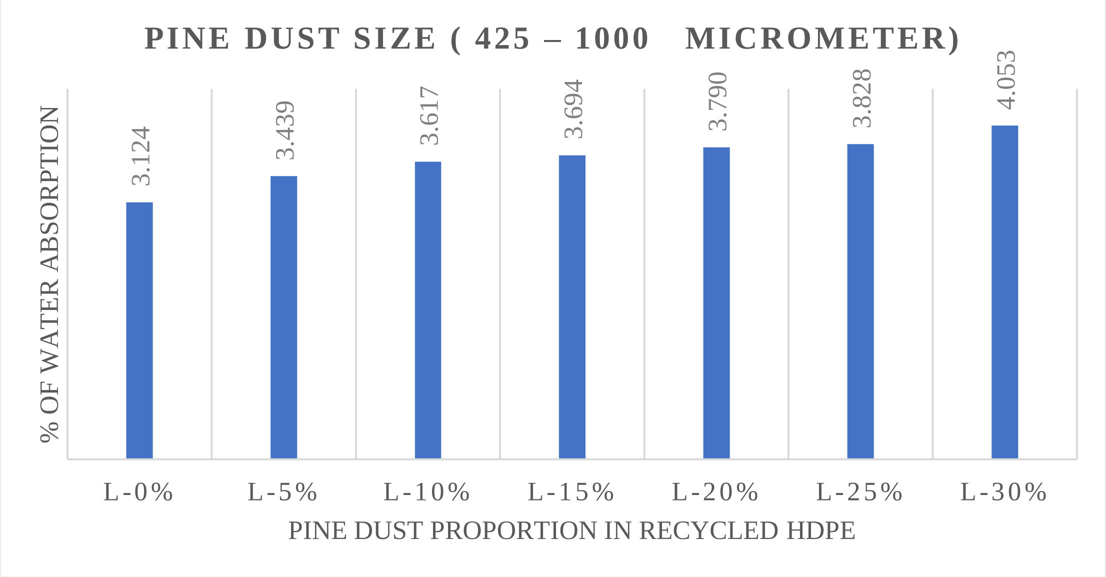

Figure 4-24: Percentage of Water Absorption of Composites with Pine-dust Size Size 425 µm - 1000 µm

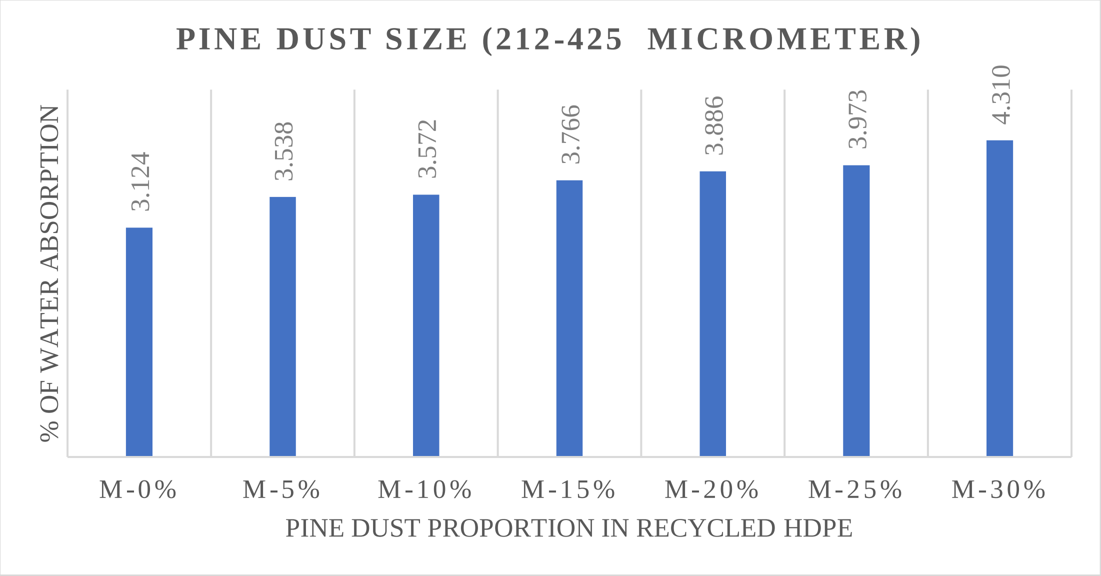

Figure 4-25: Percentage of Water Absorption of Composites with Pine-dust Size Size 212 μm - 425 μm

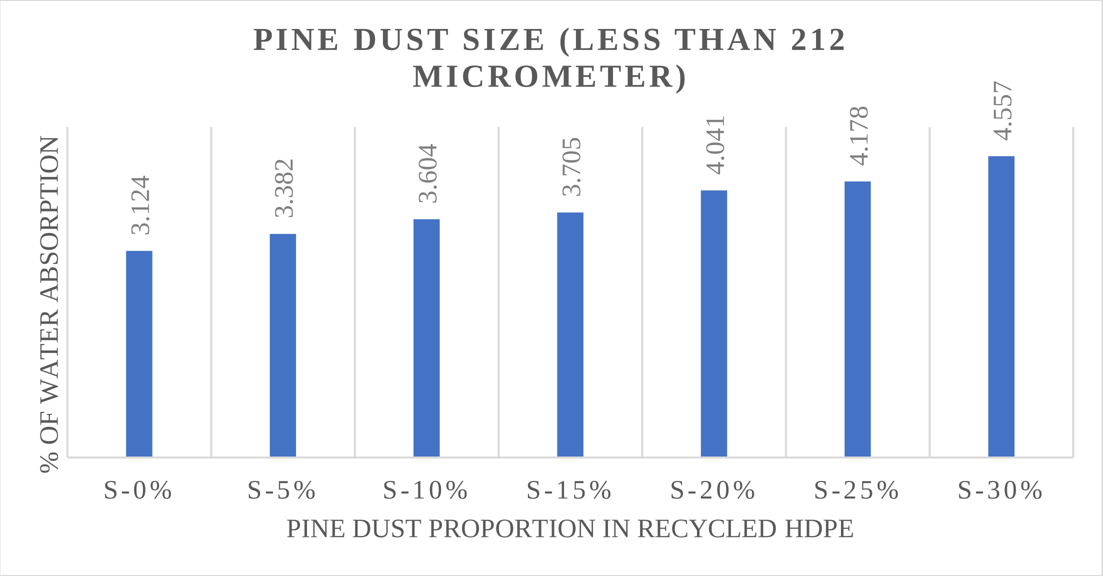

Figure 4-26: Percentage of Water Absorption of Composites with Pine-dust Size Less than 212 μm

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 **Conclusions**

The incorporation of pine-dust into recycled HDPE composites demonstrated valuable insight, pine-dust, a natural filler, enhance the mechanical characteristics when incorporated with recycled HDPE. Visual Inspection revealed that the alignment of pine-dust particles within the composite was random, and their distribution was denser in the central area. Despite some minor irregularities, the bonding between natural fibers (NFs) and recycled HDPE was deemed excellent, underlining the potential for robust composite materials.

When analyzing the effect of pine dust on tensile properties, tensile testing unveiled that while an increase in pine dust proportion enhanced ultimate load up, in all sizes of pine dust, similar trend is observed, ultimate strength increased to a certain proportion then shows decreasing trend. Comparative analysis demonstrated that composites consistently outperformed pure recycled HDPE in ultimate strength. Among the entire specimen composite with pine dust in the size range of 212 µm - 425 µm and inclusion proportion 20% exhibit highest ultimate strength. Still many specimen beats the ultimate strength of recycled HDPE, thus, incorporating pine dust with recycled HDPE enhance ultimate strength of composite.

In terms of elongation properties, an inverse relationship was noted as the proportion of pine dust increased. The ductility of the composite material decreased with higher pine dust content, resulting in reduced elongation properties. The maximum percentage elongation of 41.18 % was observed in recycled HDPE whereas in the recycled HDPE composite with inclusion of pine dust in size range of 212 µm - 425 µm by 30% proportion the elongation percentage was decreased up to 5.81 %.

In the Charpy Impact testing phase of study, the energy absorption properties of recycled HDPE composites incorporating pine dust of varying sizes and proportions were examined; it was observed that 15% inclusion consistently displayed the highest energy absorption characteristics. The top-performing specimens showed an energy absorption of 8 Joules, significantly surpassing the energy absorption of 2 Joules exhibited by pure recycled HDPE. These results emphasize the potential of incorporating pine dust into recycled HDPE composites to enhance their energy absorption properties.

The examination of the composite morphology involving pine dust and recycled HDPE, conducted through stereoscopy microscopy, has provided valuable insights into their complex interactions. Initially, the uniform dispersion of pine dust particles within the recycled HDPE matrix displayed amalgamation blend, resulting in a significant improvement in ultimate strength and confirming its potential to reinforce recycled HDPE. However, as the proportion of pine dust increased, an apparent agglomeration phenomenon occurred, leading to the formation of clusters within the composite and subsequent reductions in ultimate strength. This underscores the paramount importance of maintaining a consistent distribution of pine dust within the recycled HDPE matrix. Additionally, the scrutiny of smaller pine dust particles, especially those measuring less than 212 μm, accentuated the agglomeration effect, intensifying the decline in ultimate strength and compromising the overall structural integrity of the composite material.

The water absorption tests indicated that an increase in the proportion of pine dust in recycled HDPE led to a corresponding increase in the water absorption characteristics of the composite. Additionally, decreasing the size of the composite also contributed to higher water absorption characteristics. These findings provide valuable insights into the interplay between pine dust size, proportion, and the mechanical and water absorption properties of the composite materials.

5.2 **Recommendation**

i. Adjust the proportion of pine dust in recycled HDPE composites to suit specific application needs and optimize mechanical performance.
ii. Consider alternative processing methods to prevent agglomeration and maintain uniform pine dust distribution in recycled HDPE composites.
iii. Perform extended durability studies to assess the long-term performance of these composites under diverse environmental conditions, including moisture, UV exposure, and temperature variations.
iv. Utilize Scanning Electron Microscopy (SEM) for in-depth morphological analysis to enhance understanding of the composite's microstructure and surface characteristics.

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ANNEX-A LOADING VS ELONGATION OF M-20% COMPOSITE

Elongation	Loading	Elongation	Loading	Elongation	Loading
0.03	2731.00	1.80	7464.01	3.62	10271.17
0.07	2915.97	1.84	7594.58	3.68	10303.82
0.13	3057.42	1.90	7659.86	3.72	10358.22
0.16	3166.22	1.94	7779.54	3.77	10401.74
0.20	3296.79	1.98	7855.71	3.81	10445.26
0.25	3459.99	2.03	7986.27	3.86	10488.78
0.29	3590.56	2.07	8062.44	3.92	10554.07
0.34	3742.89	2.13	8149.48	3.97	10597.59
0.39	3884.33	2.17	8225.64	4.01	10641.11
0.43	4025.78	2.22	8367.09	4.06	10717.27
0.48	4167.22	2.27	8410.61	4.10	10760.80
0.51	4265.15	2.31	8552.06	4.15	10815.20
0.57	4439.24	2.37	8606.46	4.21	10836.96
0.62	4569.80	2.42	8737.03	4.25	10826.08
0.66	4700.37	2.46	8791.43	4.29	10782.56
0.70	4820.05	2.51	8867.59	4.35	10847.84
0.75	4928.86	2.55	8987.28	4.39	10967.53
0.80	5037.66	2.60	9063.44	4.44	11043.69
0.84	5168.23	2.65	9128.72	4.49	11119.85
0.89	5277.03	2.70	9172.25	4.53	11185.14
0.93	5418.48	2.74	9183.13	4.59	11250.42
0.98	5527.29	2.80	9281.05	4.63	11293.94
1.03	5657.85	2.84	9335.45	4.68	11163.37
1.07	5755.77	2.88	9411.62	4.73	11272.18
1.12	5875.46	2.92	9466.02	4.79	11359.22
1.16	5984.26	2.96	9531.30	4.83	11435.39
1.20	6093.07	3.02	9607.47	4.88	11489.79
1.25	6190.99	3.05	9650.99	4.93	11544.19
1.30	6310.68	3.08	9650.99	4.97	11631.24
1.34	6408.60	3.13	9738.03	5.02	11674.76
1.39	6528.29	3.18	9825.08	5.07	11740.04
1.43	6626.21	3.23	9890.36	5.11	11794.44
1.48	6745.90	3.28	9955.64	5.16	11837.97
1.53	6854.70	3.33	10020.92	5.21	11903.25
1.57	6963.51	3.37	10042.68	5.26	11946.77
1.62	7061.43	3.42	10075.33	5.31	11990.29
1.66	7170.24	3.48	10118.85	5.36	12044.69
1.71	7279.04	3.52	10151.49	5.41	12099.10
1.76	7366.09	3.57	10195.01	5.46	12142.62

Elongation	**Loading**	**Elongation**	**Loading**	**Elongation**	**Loading**
5.50	12186.14	7.37	13600.60	9.24	14492.80
5.55	12251.42	7.42	13633.24	9.29	14514.56
5.60	12273.18	7.47	13655.00	9.33	14525.44
5.64	12338.47	7.52	13698.53	9.38	14536.32
5.70	12371.11	7.57	13720.29	9.42	14558.09
5.74	12425.51	7.61	13720.29	9.48	14568.97
5.79	12469.03	7.66	13763.81	9.52	14590.73
5.83	12501.67	7.71	13785.57	9.57	14623.37
5.88	12556.08	7.75	13807.33	9.62	14612.49
5.94	12599.60	7.80	13839.97	9.68	14623.37
5.98	12621.36	7.84	13861.73	9.72	14645.13
6.03	12664.88	7.90	13883.49	9.77	14656.01
6.08	12697.52	7.95	13916.14	9.81	14677.77
6.13	12751.92	7.99	13937.90	9.86	14721.29
6.18	12773.69	8.04	13970.54	9.91	14710.41
6.23	12817.21	8.08	13992.30	9.96	14743.05
6.27	12849.85	8.14	14003.18	10.00	14743.05
6.32	12904.25	8.18	14046.70	10.05	14764.81
6.37	12947.77	8.23	14057.58	10.09	14797.46
6.41	12969.54	8.28	14079.34	10.15	14808.34
6.46	13002.18	8.34	14090.22	10.20	14819.22
6.50	13067.46	8.38	14122.87	10.24	14819.22
6.55	13078.34	8.43	14155.51	10.29	14819.22
6.61	13121.86	8.47	14177.27	10.34	14840.98
6.65	13143.62	8.52	14177.27	10.39	14873.62
6.70	13176.26	8.57	14220.79	10.44	14884.50
6.75	13208.91	8.62	14253.43	10.48	14906.26
6.80	13252.43	8.66	14253.43	10.53	14895.38
6.85	13285.07	8.71	14264.31	10.58	14906.26
6.90	13306.83	8.75	14286.07	10.62	14938.90
6.94	13339.47	8.81	14307.83	10.67	14949.78
6.99	13361.23	8.85	14373.12	10.71	14960.66
7.04	13415.63	8.90	14373.12	10.76	14960.66
7.09	13448.28	8.95	14362.24	10.81	14982.42
7.13	13459.16	9.01	14384.00	10.86	15004.18
7.18	13480.92	9.05	14427.52	10.91	14993.30
7.23	13513.56	9.10	14438.40	10.95	15036.83
7.28	13546.20	9.14	14460.16	11.01	15015.06
7.33	13578.84	9.19	14460.16	11.05	15047.71

Elongation	Loading	Elongation	Loading	Elongation	Loading
11.10	15069.47	12.95	15395.88	14.82	15559.09
11.15	15069.47	13.01	15428.52	14.86	15580.85
11.19	15091.23	13.06	15406.76	14.91	15580.85
11.25	15102.11	13.10	15417.64	14.96	15591.73
11.30	15112.99	13.15	15428.52	15.01	15580.85
11.34	15134.75	13.19	15439.40	15.06	15602.61
11.39	15123.87	13.25	15428.52	15.10	15602.61
11.43	15134.75	13.29	15450.28	15.15	15602.61
11.49	15156.51	13.34	15428.52	15.20	15602.61
11.53	15156.51	13.39	15450.28	15.25	15613.49
11.57	15178.27	13.43	15450.28	15.29	15635.25
11.62	15189.15	13.49	15461.17	15.34	15635.25
11.68	15178.27	13.53	15461.17	15.39	15646.13
11.73	15200.03	13.57	15482.93	15.43	15646.13
11.77	15210.91	13.62	15461.17	15.49	15657.01
11.82	15221.79	13.66	15461.17	15.53	15657.01
11.86	15221.79	13.72	15472.05	15.58	15667.89
11.92	15232.68	13.77	15482.93	15.63	15689.66
11.96	15243.55	13.81	15493.81	15.68	15678.77
12.01	15254.44	13.86	15482.93	15.73	15689.66
12.05	15276.20	13.91	15504.69	15.77	15678.77
12.10	15265.32	13.96	15482.93	15.82	15689.66
12.15	15276.20	14.01	15493.81	15.86	15711.42
12.20	15297.96	14.05	15515.57	15.92	15700.54
12.24	15297.96	14.10	15515.57	15.96	15722.30
12.29	15319.72	14.15	15504.69	16.01	15722.30
12.34	15297.96	14.20	15515.57	16.05	15722.30
12.39	15330.60	14.24	15515.57	16.10	15711.42
12.43	15330.60	14.28	15526.45	16.16	15733.18
12.48	15330.60	14.34	15537.33	16.20	15744.06
12.53	15352.36	14.39	15537.33	16.25	15744.06
12.58	15363.24	14.43	15526.45	16.29	15744.06
12.63	15374.12	14.48	15526.45	16.35	15744.06
12.67	15374.12	14.53	15537.33	16.39	15744.06
12.72	15385.00	14.58	15526.45	16.44	15754.94
12.76	15385.00	14.62	15537.33	16.48	15754.94
12.82	15406.76	14.67	15548.21	16.53	15754.94
12.86	15395.88	14.72	15559.09	16.58	15765.82
12.91	15406.76	14.76	15559.09	16.63	15754.94

Elongation	Loading
16.68	15776.70
16.72	15776.70
16.77	15787.58
16.82	15765.82
16.87	15776.70
16.91	15787.58
16.96	15787.58
17.01	15787.58
17.06	15798.46
17.10	15809.34
17.15	15809.34
17.19	15798.46
17.25	15809.34
17.29	15820.22
17.34	15820.22
17.38	15820.22
17.42	15820.22
17.48	15809.34
17.53	15809.34
17.57	15809.34
17.62	15809.34
17.68	15820.22
17.72	15820.22
17.76	15831.10
17.81	15809.34
17.85	15820.22
17.91	15820.22
17.95	15831.10
18.00	15831.10
18.05	15831.10
18.09	15841.98
18.15	15831.10
18.19	15831.10
18.23	15831.10
18.28	15841.98
18.34	15841.98
18.38	15831.10
18.43	15852.86
18.47	15852.86
18.52	15841.98
18.57	15831.10
18.61	15841.98
18.66	15841.98
18.71	15841.98
18.75	15831.10
18.81	15841.98
18.85	15852.86
18.90	15841.98
18.94	15841.98
18.99	15852.86
19.04	15841.98
19.09	15852.86
19.14	15852.86
19.18	15852.86
19.24	15852.86
19.28	15852.86
19.32	15841.98
19.37	15874.62
19.42	15852.86
19.47	15863.74
19.52	15852.86
19.56	15852.86
19.61	15852.86
19.65	15852.86
19.71	15852.86
19.76	15841.98
19.80	15852.86
19.85	15841.98
19.90	15852.86
19.95	15852.86
19.99	15852.86
20.04	15863.74
20.08	15852.86
20.13	15852.86
20.18	15841.98
20.22	15841.98
20.27	15852.86
20.30	15841.98
20.34	15841.98
20.39	15831.10
20.44	15852.86
20.48	15841.98
20.53	15841.98
20.57	15831.10
20.62	15841.98
20.66	15841.98
20.70	15831.10
20.75	15841.98
20.80	15841.98
20.84	15831.10
20.88	15831.10
20.92	15820.22
20.97	15820.22

ANNEX-B PHOTOS

Raw Material Collection

Figure 8-1: Pine Dust Collected From Local Furniture Industry

Sample Processing

Figure 8-2: Solar Heating and Home Seiving

Figure 8-3: Pine Dust Sizing

Figure 8-4: Post-Heating

Sampling

Figure 8-5: Sampling

Sample Processing

Figure 8-6: Sample Processing

Figure 8-7: Cooling and Extraction

Sample Building

Figure 8-8: Specimen Processing

Figure 8-9: Tensile Test Specimen

Mechanical Testing

Figure 8-10: Tensile Testing

Water Absorption Test

Figure 8-11: Water Absorption Testing

Fabrication of Recycled High Density Polyethylene composite with Natural Filler Pine-dust: Effect of Morphological Structure on Mechanical Properties

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