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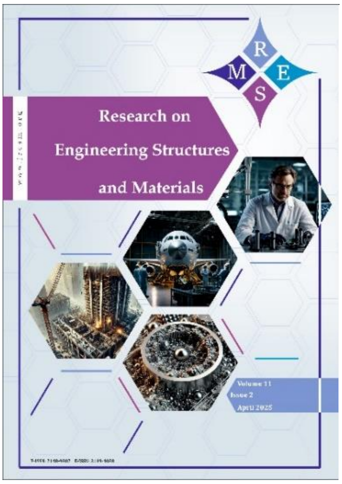

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Research Article

Fabrication and mechanical characterization of composite fiberboard utilizing dry lemon peel powder and epoxy resin

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Abstract

This research work is related to the manufacturing of a composite fiberboard using dry lemon peel powder and epoxy resin, which can be used as an alternate to the plywood or wood. The objective of this study is to assess the mechanical and microstructural properties of this novel composite fiberboard. To assess its strength and ability to absorb energy, different tests were performed on different specimens. To comprehend the morphology and filler particle distribution within the resin, the microstructure of the fabricated composite was also checked using a scanning electron microscope (SEM). As per the experimental findings, the composite's mechanical properties, such as hardness 22.45 (Vickers), tensile strength 14.7 MPa, flexural strength 27.9 MPa and impact strength 21.76 J/m^2, appeared promising with respect to the plywood. Additionally, perfect bonding was shown by the SEM study between the waste Dry Lemon Peel particles (DLPP) and the epoxy, contributing to improved mechanical properties.

1. Introduction

The agriculture products when used produce the waste in the form of peels or shells and most of the time; these wastes are either dumped in open places or burned to produce energy resulting in generation of dioxins [1]. Five billion tons of food is wasted worldwide each year during the food life cycle including fruits fresh, vegetables, dairy products, baked goods and so forth [2]. The volume of such waste is anticipated to rise over the next ten years as a result of the growing world population [3].

Lemon peels are also such an example of agricultural waste. The global lemon production typically falls within the range of 16 to 18 million metric tons annually, with India emerging as a prominent lemon-producing nation alongside Mexico, Argentina, and Spain. The quantity of waste peel generated from an individual lemon is subject to variation based on factors like lemon size and peel thickness. The lemon peel typically represents around 25% to 30% of the overall weight of the fruit. The remaining 70% to 75% constitutes the edible fruit pulp and juice.

The characteristics of lemon peel powder display variability influenced by factors including preparation methods, drying techniques and the specific attributes of the lemon peels utilized. The drying process is commonly employed to reduce moisture levels and enhance the shelf life of lemon peel powder. The Lemon peel powder emits a distinct citrusy fragrance akin to fresh lemon zest, with the strength of the aroma contingent on

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the freshness of the lemon peels and the processing approach. Also, the density of lemon peel powder is subject to change depending on particle size, compaction and moisture content, generally displaying a moderate density relative to other powders. Although not entirely water-soluble, lemon peel powder can disperse and impart its flavor and aroma when incorporated into liquids, exhibiting partial solubility in hot water or other solvents, subsequently releasing its components. Lemon peel powder is comparably soft to various synthetic materials, easily pulverized into a fine powder due to its low hardness. While not inherently brittle, extensive drying may render it fragile, necessitating caution to prevent excessive drying that could lead to brittleness and susceptibility to breakage.

Particleboard made of polymeric composites is created by mixing a polymeric binder with filling materials using suitable conditions and proportions. Urea formaldehyde [4-5], phenol formaldehyde [6] polyethylene [7-8] and polyvinyl acetate [9-10] are the most widely used binders for fabrication of composite fiberboard from different types of agriculture waste powders. The anticipated outcome is that these binders could enhance the mechanical properties, fire and biodegradation resistance of composite materials. To reduce dependency on trees as a source of wood it is essential to assess agricultural residues which usually have a low calorific value for use as filler material in the manufacturing of commercial particleboard. Owing to the distinct cellulose structures in each particleboard manufactured from various agricultural residues have differing physical properties. Assessing agricultural residues to determine their specific characteristics is essential, as these traits may differ based on the geographical location where the plants were cultivated. Various plant fibers and agricultural residues, such as nutshell almond and walnut shell [11-13], peach nut shell [14] bamboo [15] cotton seed hulls [16] wood flour [17] rice husk and starch [18-19], Todo fir and sun flower, have been investigated as filling materials [20-21] and they all offer a diverse range of options. It was found that an increased proportion of coconut fiber adversely impacts both the mechanical strength and the increase in thickness [8]. Various ratios of walnut-almond shell particles [ranging from 0% to 100%] were examined with urea-formaldehyde as the binder. After thorough analysis, the study noted that adding walnut-almond particles notably enhanced the aqua-resistance of the panels. However, increasing the content of walnut-almond shells in the panels led to a decrease in flexural strength [14]. One of the researches outlines a method for producing fiberboard by integrating walnut shell powder particles into epoxy, with the objective of evaluating mechanical properties. After testing a tensile strength of 12.4 MPa, flexural strength of 19.1 MPa, compressive strength of 46.4 MPa and Charpy impact strength of 1.32 KJ/m^2 (notched) have been obtained which is within the acceptable range and comparable with the properties obtained for other fiberboards made from similar types of waste agriculture waste powders [22]. Despite the remarkable physical characteristics of nano and micro-structured materials traditional elasticity theories are unable to adequately explain their behavior. Use of size-dependent elasticity models which take into account the effects of their small scale is necessary to accurately analyze their mechanical responses. These models provide a more accurate understanding of the materials properties and behavior under different conditions by taking into account phenomena like surface effects and size effects that become significant at the nano and micro-scale [23-25]. Incorporating Citrus limetta peel Powder with Epoxy Polymer composites reduce dependency on petroleum-derived Epoxy Polymer products. The possible uses of an epoxy composite strengthened with citrus limetta peel powder include furniture and decorative pieces, as well as doors, tables, and shelves [26-27]. A composite material with remarkable mechanical qualities has been developed by combining pomegranate peel powder with epoxy. This composite exhibits significant potential for use in fields where high strength capacities are essential [28].

Adding lemon peel powder with epoxy resin in a certain ratio in a particular composite fiberboard can enhance the properties of composite fiberboard. Different observations are available which shows that adding graphene oxide [29], carbon nanotubes [30] and surface-modified graphene oxide [31] can enhance the mechanical properties of epoxy-based composite fiberboards. Additionally, the use of different binders in composite fabrication has been found to influence tribological properties and hardness, as observed in studies comparing emulsion and powder binders in epoxy resin composites [32]. Furthermore it's been observed that a composite made of epoxy and powdered lemon peel may exhibit enhanced mechanical strength and tribological performance making it a flexible material with a variety of applications in the automotive and aerospace industries. Polymer composites with natural fibers are a subject of research [33-34]. It has been noted that the strength of SiO_2-epoxy polymer nanocomposite material decreases less than that of unmodified material [35]. It was discovered that incorporating SiO_2 nanoparticles into the epoxy matrix increases the contact forces and energy absorption capabilities [36]. Epoxy composites show better tensile strength [up to 124 MPa], flexural strength (203 MPa) and lower carbon footprints than conventional petroleum-based alternatives. Epoxy has outstanding natural fiber adherence which improves the composites overall mechanical qualities [37].

The leftover lemon peel can be used to make composite fiberboard by drying and powdering it. This strategy fits into the larger idea of using agricultural waste or byproducts for the production of sustainable materials and processes. There are numerous advantages to using leftover lemon peel to make composite fiberboard such as:

- Environmental Sustainability: Recycling leftover lemon peels helps to manage waste in an environmentally friendly way and lowers pollution.
- Resource Efficiency: Their use leads to preservation of precious resources ultimately lowering the demand for virgin materials.
- Renewable and Biodegradable: Lemon peel is an environmentally friendly option since it is a renewable resource that breaks down naturally.
- High dietary fiber content especially insoluble fiber: Incorporating lemon peel powder into composite matrices improves the tensile strength due to its high dietary fiber content especially insoluble fiber makes it suitable for manufacturing the composite fiberboard [38].

So, the objectives of present research work are;

- To manufacture a fiberboard of Dry lemon Peel powder (DLPP) mixed with epoxy.
- To find out the mechanical strength of the fabricated fiberboard.
- To do SEM analysis of the fiberboard to describe its morphology.

2. Material and Methods

2.1. Materials

- Dry Lemon Peel Powder (DLPP): This fine powder is created by mechanically processing dried lemon peels.
- Epoxy Resin: Novolac Epoxy Resin (Araldite LY 556) with Aradur HY 951 as the hardener has been used as matrix for the fabrication of a robust and high-performing composite material.

2.2 Preparation of DLPP

The first step in creating DLPP is obtaining fresh clean lemon peels from nearby sources. Then in order to get rid of any contaminants they must be thoroughly cleaned and rinsed. After cleaning the peels are spread out evenly on trays and dried by either sun-drying for two to three days while covered with protective netting or roasting them for an entire day at 60°C. After being allowed to dry for a while the peels are manually cut into smaller pieces and then ground in a machine to a fine powder. To avoid thermal damage the grinding process is periodically stopped to allow for cooling. The ground powder is passed through a 200-mesh sieve to guarantee a constant particle size. Once collected the powder is stored in an airtight container that is sealed against moisture in a cool dry location. Because quality control methods are used the DLPP is of the highest quality and suitable for use in the manufacturing of composite fiberboards. Figure 1 shows the image of DLPP obtained from lemon waste.

Fig. 1. Dry Lemon Peel Powder (DLPP)

2.3 XRD Analysis of DLPP

Finding a materials crystallographic structure can be accomplished very successfully with X-ray diffraction (XRD) analysis. In many scientific domains such as geology chemistry physics and materials science it is extensively employed to examine the arrangement of atoms or molecules in a crystalline sample. A crystalline or powdered material is exposed to a monochromatic X-ray beam in an XRD experiment.

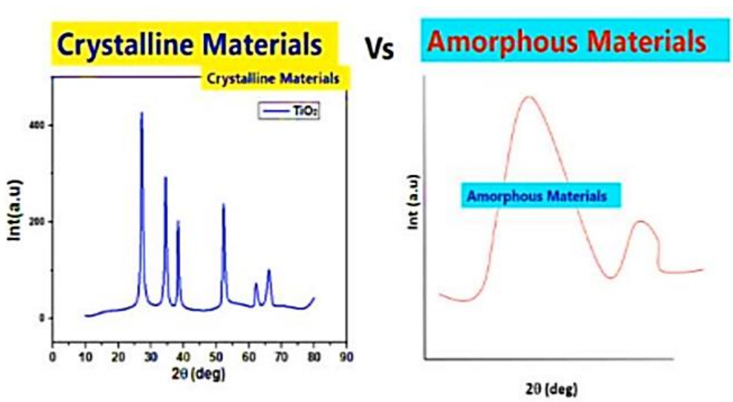

Fig. 2.Crystalline XRD and Amorphous XRD

The sample can be precisely rotated in the X-ray beam since it is mounted on a goniometer. The diffracted X-rays are collected by a detector that is positioned on the other side of the material. In order to obtain diffraction data, one typically rotates the sample and modifies the angle at which the detector and incident X-ray beam are positioned along a range of scattering angles. Usually, one uses a diffraction data visualization that shows the intensity as a function of the scattering angle (2θ). By analyzing the positions and intensities of the diffraction peaks one can determine the crystalline phases present in the sample along with several structural elements such as crystal orientation lattice parameters grain size and crystallographic defects. Figure 2 shows the graphs obtained after XRD analysis for Crystalline and Amorphous materials.

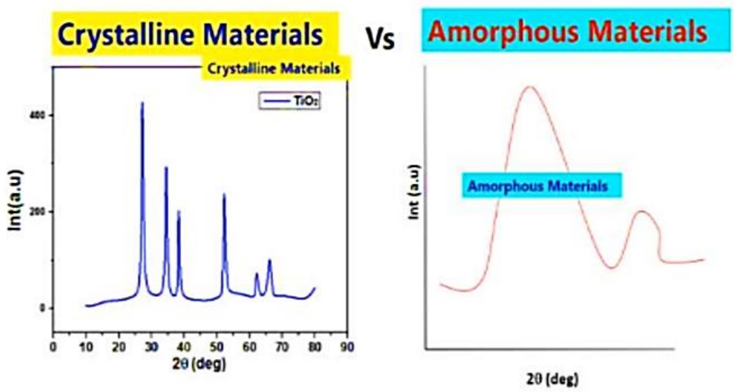

Fig. 2.Crystalline XRD and Amorphous XRD

Figure 3 shows the result of XRD Analysis of the DLPP. After analysis of the XRD Image, it has been observed that the DLPP is amorphous material. There are some impurity peaks in XRD which suggest the presence of unintended or foreign materials in the sample. This may be due to some dust or any other particle during generation of the peel powder. But in all they don't affect the overall nature of the powder particle.

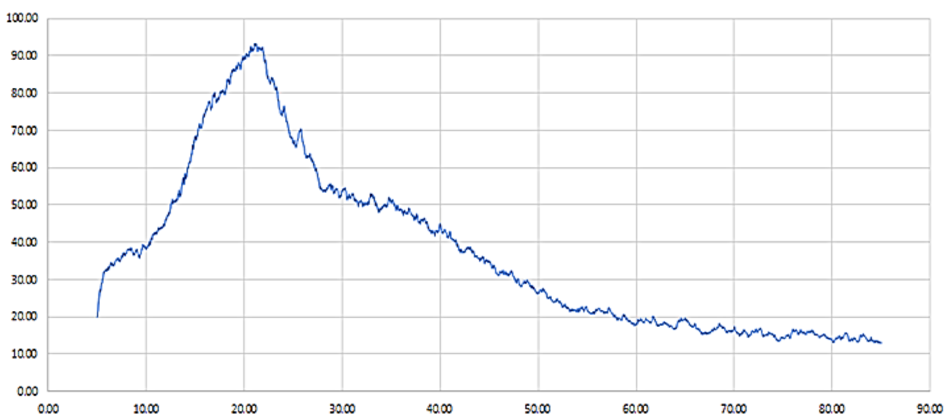

Fig. 3. XRD image of DLPP

2.4 Fabrication of Composite Fiberboard

Weighing the required materials is the first step in the fabrication process. The following number of materials have been selected for fabrication of composite fiberboard;

- 300 grams of DLPP,

- 700 grams of Novolac epoxy (Araldite LY 556),
- 210 grams of Aradur HY 951 hardener.

Mixture having ratio of 30 to 70 of the reinforcement particle and epoxy resin ensures the most appropriate ratio for achieving optimal curing and mechanical properties in the fiberboard [39-40]. Using a mechanical stirrer to ensure even dispersion 300 grams of DLPP are gradually added to 700 grams of epoxy resin (Araldite LY 556) at the start of the fabrication process. The mixture is then progressively stirred with 210 grams of Aradur HY 951 hardener until a homogenous blend is obtained. As shown in Figure 4, a rectangular mold is prepared for molding and curing and it is coated with a release agent to make it easier to remove the cured composite.

Fig. 4. Mold used for making the composite

After thoroughly mixing and degassing, the composite mixture is poured into the mold and leveled out. To guarantee full polymerization and improved mechanical properties, the mold is post-cured at 120°C for two hours after being left to cure at room temperature for 24 hours. Before mechanical testing, post-fabrication processing entails carefully removing the cured composite fiberboard from the mold. Figure 5 shows the finally fabricated Composite fiberboard.

Fig. 5. Fabricated composite fiberboard

2.5 Mechanical Characterization

For the mechanical characterization of the fiberboard, specific tests mentioned below have been performed on specific samples obtained from it:

- Hardness test
- Tensile test
- Flexural test
- Impact test

2.5.1 Hardness Test

The resistance to surface wear indentation and scratches is referred to as hardness. It is a measure of the board's durability and strength, often influenced by the type of fibers, resins and bonding techniques used in its production. Hardness is crucial for applications where the fiberboard will face mechanical stress, such as in furniture, flooring or wall panels. The Vickers hardness test is performed on composites to evaluate their resistance to deformation and wear, which are critical indicators of their mechanical performance. By measuring the hardness, one can assess the effectiveness of the reinforcing materials within the composite matrix. This test also aids in quality control, guaranteeing consistency in production, and allows for the comparison of different composite formulations to identify the most effective combinations. The hardness has been measured using a Leitz Micro-hardness tester. For this test, a diamond indentater has been used which was operating under a load varying from 0.3 N to 3 N and forced throughout the material. Vickers Hardness Index (Hv) is computed by applying the subsequent formulas [41].

$$L = \frac{X + Y}{2} \tag{1}$$

$$H_v = 0.1889 \frac{F}{L^2} \tag{2}$$

Where, X is the horizontal length (mm), Y is the vertical length (mm), F is the applied load (N) and L is the diagonal of square impression (mm).

2.5.2 Tensile Test

Tensile strength refers to the maximum stress that the material can withstand while being stretched before fracture. This property is crucial for assessing the performance and durability of composite materials, particularly those reinforced with natural or synthetic fibers. The standard test procedure according to ASTM D638 has been applied for calculating the tensile strength for this research. Usually, flat specimens are used for the tensile test.

Fig. 6. UTM with Tensile Sample Loaded

The specimen geometries that are most frequently used are the flat specimens. Each Tensile testing sample has a Length of 250 mm, width of 25 mm and height of 10 mm. A Universal Testing Machine (UTM, Saumya Make) is used to conduct the tensile test. Cross head speed during the tests was 2 mm/min. Three composite samples have been tested and the average value has been obtained for analysis. The testing apparatus and the sample in loading condition are depicted in Figure 6.

2.5.3 Flexural Strength

The flexural strength is also known as the bending strength of a material. Flexural strength represents the higher stress-bearing capacity before fracture. This strength can be evaluated through a 3-point bending test. After fabrication of composite, the specimen has been prepared as per the ASTM D790 standard. To conduct the test, each specimen was placed on machine fixtures of UTM and load was applied constantly as shown in Figure 7. The length of specimen was 150 mm while the breadth 12.5 mm and height has been taken as 10 mm.

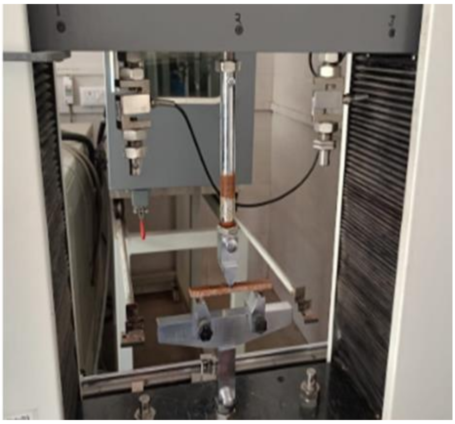

Fig. 7. Flexural test setup

The values of peak load are computed for each specimen from the load vs. deflection curve. The flexural strength for different specimen can be calculated using formula [42];

$$\sigma_{flex} = \frac{3Pl}{2bd^2} \quad (3)$$

Where, P stands for ultimate load (N), l stands for effective length (mm), b stands for breadth (mm) and d stands for height of the specimen(mm).

2.5.4 Impact Strength

The Izod impact strength refers to its ability to absorb energy during impact and is a crucial for applications requiring durability and resistance to sudden forces. The Izod impact strength test as per ASTM 256 is used to evaluate the impact resistance of materials like metals, composites and polymers.

To determine the Impact strength of the composite fiberboard fabricated for this research, three specimens each having length of 50 mm and cross section area of 10x10 mm^2 have been cut from the main fiberboard sheet. Figure 8 shows the test setup for the impact test.

Fig. 8. Izod Impact test setup

2.6 SEM Analysis

Small portions of the composite are cut and coated with gold using sputtering to enhance conductivity. These coated samples are then analyzed using a scanning electron microscope to study how dry lemon peel powder (DLPP) is distributed within the epoxy matrix and to determine the bonding interfaces between the filler and the matrix.

3. Results and Discussion

3.1 Hardness Test

To measure Vickers hardness numbers Leitz Micro-hardness testing machine has been employed. Vickers hardness for the composite material is 22.45. According to this hardness value the mechanical properties of the composite are greatly enhanced when lemon peel powder is added to the epoxy resin matrix as a reinforcing agent. It also shows that the material is reasonably resistant to deformation and indentation under load.

3.2 Tensile Test

The tensile test was conducted in this study on three specimens obtained from composite fiberboard composed of epoxy resin and powdered dry lemon peel in accordance with ASTM D638 standard on a UTM, (Saumya Make). The test findings show that the fiberboard has an average tensile strength of 14.7 MPa.

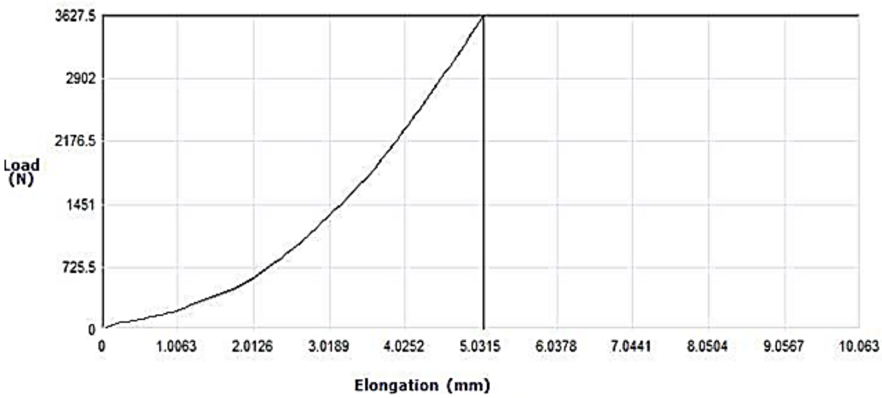

Fig. 9. Load versus deformation curve for tensile test

The Figure 9 shows a curve for Tensile Test of one of the test specimens. The materials elastic behavior wherein the deformation increases at a constant rate as the load is applied is first indicated by the curves non-linear increase. The curve peaks as the load increases at about 5.0315 mm of elongation or roughly 3627.5 N which is the highest load the material can bear before failing. The curve ends at this peak indicating that the specimen has either failed or has reached its breaking point due to significant plastic deformation. Its mechanical characteristics and behavior under tensile stress are highlighted by this curve which shows the materials ability to support increasing loads up to a critical point. DLPP have low tensile strength as compared to synthetic fibers. It has been observed that the composite fiberboard fails due to failure of the filler before the binding agent. As the filler has low strength as compared to that of the epoxy.

3.3 Flexural Test

Dry lemon peel powder and epoxy resin were mixed to create the specimens which were then molded and allowed to cure under carefully monitored circumstances. The three different specimens of the composite fiberboard were subjected to the flexural strength test in accordance with ASTM D790. The UTM (Saumya Make) with a three-point bending configuration was used to conduct the flexural strength tests. Dry lemon peel powder can effectively reinforce epoxy resin as evidenced by the composite fiberboard's average flexural strength of 27.9 MPa.

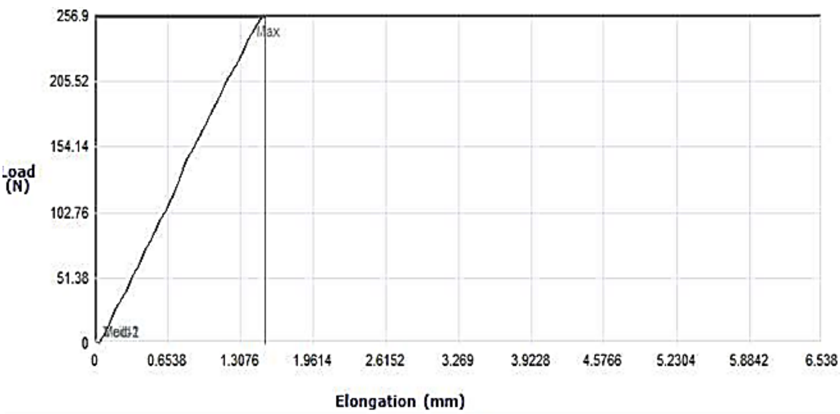

Fig. 10. Load versus deformation curve for flexural test

The graph shown in Figure 10 illustrates the results of a flexural test performed on one of the specimens obtained from a composite fiberboard made from dry lemon peel powder and epoxy resin. The curve begins with a linear region where the load increases proportionally with elongation, indicating the elastic behavior of the material. This means that as the load is applied, the material deforms at a constant rate. The linear portion continues up to a point labeled "Max," where the maximum load of approximately 256.9 N is reached and the corresponding elongation is around 1.9614 mm.

Beyond this maximum load point, the curve sharply declines, indicating the failure of the material. The sharp drop suggests that the composite fiberboard has reached its flexural strength limit and can no longer sustain the applied load, leading to a sudden failure. This graph demonstrates the material's ability to withstand increasing loads up to a certain point, after which it fails. The linear elastic region provides insight into the material's stiffness, while the peak point represents its flexural strength. It has been found that the brittleness of the epoxy which permits little plastic deformation prior to failure is the reason why the composite fails under flexural loading. Thus it abruptly breaks under flexural stress following a specific load.

3.4 Impact Strength

The method used to evaluate the impact resistance of the composites made of dry lemon peel powder and epoxy resin was the Izod impact strength test which is carried out in accordance with ASTM D256. The notched specimen was subjected to a sudden force during the test using a pendulum and the energy the specimen absorbed up until fracture was measured. After three distinct samples were tested, the average impact strength was found to be 21.7 J/m. The toughness and durability of the material are indicated by this value which shows its resistance to impact forces. It is important for applications where the material may be subjected to sudden or dynamic loads that the results suggest the composite material has a moderate level of impact resistance. From the test it has been observed that the failure of the material is due to the low toughness of DLPP because dry or powdered natural fibers possesses low strength-to-weight ratios compared to synthetic fibers, making the composite less resistant to impact forces.

3.5 SEM Analysis

The composite made up of Dry lemon peel powder and epoxy was subjected to scanning electron microscopy (SEM) using Leo 435 VP equipment. The micro graphs of the composite are shown in Figure 11. Micrographs unequivocally demonstrate that a strong bond between the reinforcement and matrix is achieved in the absence of debonding, fiber chipping out and crack formation.

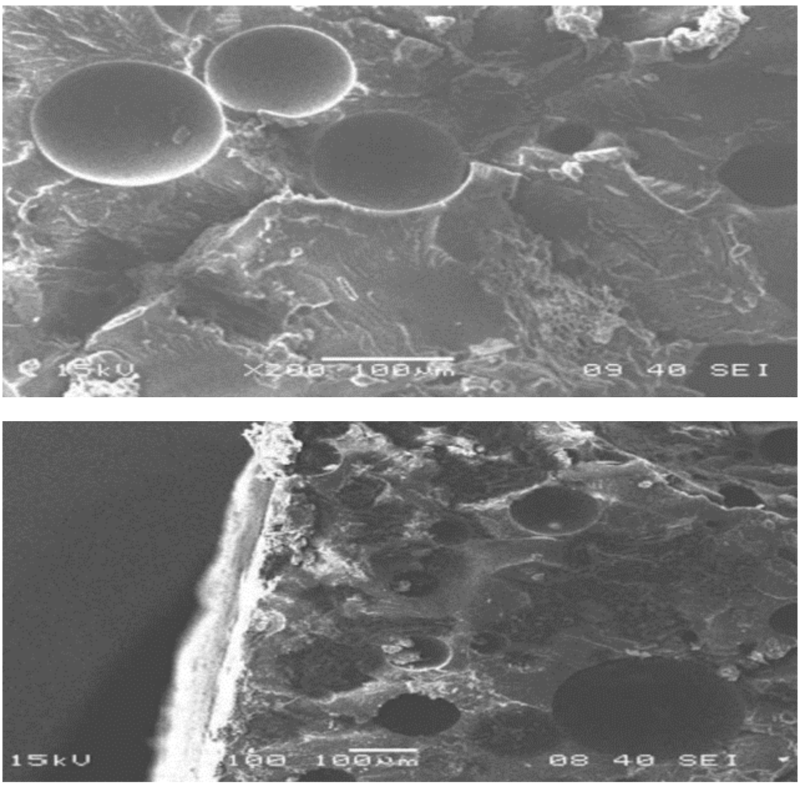

Fig. 11. Micro graphs of the composite

4. Conclusions

The investigation into the mechanical properties of composite materials reinforced with dry lemon peel powder and epoxy resin matrix has yielded significant insights. Based on the various tests and analyses conducted, the following conclusions can be drawn:

- The Vickers hardness number for the composite material was found to be 22.45. As a result, the composites mechanical qualities are greatly improved by the addition of lemon peel powder increasing its resistance to deformation and indentation under load as are comparable to that of plywood or wood.
- The fiberboard has a mean tensile strength of 14.7 MPa according to the results of the tensile test. The tensile strength of present research composite are comparatively higher than that of the properties of plywood or the walnut shell-epoxy composite fiberboard, which has the tensile strength 12.4 MPa Also the tensile performance of this composite could be improved by strengthening the bond adding toughness to the resin or using better filler materials.
- The fiberboard exhibited a mean flexural strength of 27.9 MPa during the flexural strength test. The flexural strength of present research composite are comparatively higher than that of the properties of the walnut shell-epoxy composite fiberboard, whose flexural strength has been previously noted as 19.1 MPa. The flexural strength can be enhanced by fillers like fibers such as carbon or glass fibers. Additionally adding nano-materials to the epoxy matrix like carbon nanotubes (CNTs) or nano-clays can also improve the flexural strength.
- From Impact testing it has been found that the composite fiberboard has mean impact strength of 21.7 J/m2. This value indicates moderate impact resistance, suggesting that the material is suitable for applications involving sudden or dynamic loads. It may be possible to increase the composites resilience to impact loading by strengthening the fiber-matrix bond optimizing the filler treatment or adding additional reinforcing materials.
- An examination using scanning electron microscopy (SEM) demonstrated a robust connection between the epoxy resin matrix and the reinforcement made of dry lemon peel powder. The absence of debonding, fiber chipping out and crack formation in the micrographs underscores the effectiveness of the lemon peel powder as a reinforcing agent.

Therefore, it has been found that the composite material with dry lemon peel powder and epoxy resin has improved mechanical strength such as tensile, flexural strength, hardness and moderate impact resistance. The strong interfacial bonding observed in the SEM analysis further validates the potential of lemon peel powder as a viable reinforcement in composite materials. These findings suggest promising applications for this environmentally friendly composite in various industries where mechanical robustness and sustainability are paramount.

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