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Fabrication and Mechanical Characterization of Pomegranate Peel Powder mixed Epoxy Composite

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Abstract: The ongoing research work focuses on utilizing pomegranate peels, which are food and agricultural waste, as a filler material to create innovative epoxy composites. Pomegranate peels, belonging to the Lythraceae family, are non-citrus fruit peel material. Through experimental analysis, the study examined how the addition of pomegranate peel particles (PPP) affects the mechanical properties (compressive, flexural and impact strength) of the resulting composites. Pomegranate peel powder particles and epoxy resin proportions of 60:40 were utilized to understand the impact on mechanical performance. The researchers also investigated the failure characteristics of the prepared samples. The findings revealed the different mechanical properties of the biocomposites. Additionally, the researchers conducted a morphological analysis of the composite surface using a SEM (scanning electron microscope). Present research indicates that PPP has the potential to be a valuable filler material for producing biocomposites, making them suitable for various applications such as general-purpose interior fitments and non-structural components.

Keywords: Pomegranate Peels, Composite, Fruit Waste, Mechanical Properties, SEM.

1. Introduction

In the last twenty years, there has been a notable global inclination towards using natural filler substances for producing composite materials. Natural fiber composites are increasingly seen as a feasible substitute for synthetic composites[1–2]. Due to their affordability, low weight, high durability, biodegradability, and advantageous characteristics, natural fibers are gaining increased utilization in the composites industry.[3,4,29]. With the escalating environmental issues and increasing global energy requirements, there is a rising emphasis on integrating natural fibers into diverse sectors.[5]. Because of the adverse effects of synthetic fibers in both production and disposal of end products, natural fibers are favored over them in engineering industries. Natural composites surpass manufactured composites in terms of their positive environmental impact[6-8]. They result in less reliance on nonrenewable resources, lower greenhouse gas emissions and increased energy restoration[9]. These increased environmental achievements are a key factor in improving the "Natural Fiber Composite" practice in the future. Natural fibers such as Bagasse, Pineapple, Ramie, Coir, Sisal, Bamboo, Banana and others are easily available and all the countries have focused on the development of “Natural Fiber Composite” to create value-added jobs[10]. Researching polymer composites with natural fibers is an important and pertinent field of study, given its potential to yield favorable mechanical properties[11-13]. Moreover, composites fabricated from natural fibers are eco-friendly and recyclable, rendering them well-suited for recovery and subsequent utilization[14-15].

The addition of fillers has proven to greatly enhance the wear resistance and mechanical properties of E-glass fiber[16]. Studies have compared different fillers, such as coconut shell, rice husk, and teakwood, in lignocellulosic flour/epoxy composites, revealing that higher filler content increases the stiffness of the composite, while the volume content of fillers affects its elasticity[17]. Various agricultural wastes, including bagasse, walnut shell powder and chicken feathers, have been utilized to develop composites using epoxy or polyester[18-20].

Annually, approximately 1.2 billion tons of food are wasted globally during the food life cycle, including fruits, fresh vegetables, dairy products, and bakery items. With population growth, the volume of FW is expected to increase further in the next 25 years. Currently, the predominant method of disposing of used waste is through landfill dumping. However, the rapid development of production, population growth, waste accumulation, and environmental pollution have created hazardous conditions for human life and contributed to global climate change. As a result, there is a need to reevaluate production and consumption models, including household waste management. This involves revising management approaches and exploring methods such as processing waste to obtain new materials and useful products (e.g., compost) and utilizing physical, chemical, and biological means to convert waste into fuel and energy. Some countries, like Sweden, have achieved significant success in this regard, with less than 1% of household waste being sent to landfills [21-24]. The production of bio-plastic from orange waste opens up exciting possibilities for creating innovative materials that have the potential to replace traditional plastics. Moreover, these bio-plastics are environmentally friendly biomaterials, presenting an excellent solution to the issues posed by fruit waste disposal and the need for its effective utilization[25]. Incorporating waste materials like Citrus limetta peel Powder into the production of Food Waste filler-based Epoxy Polymer composites not only decrease the reliance on petroleum-based Epoxy Polymer products but also enhance the potential for eco-friendly disposal of this fruit residue, thus promoting green manufacturing practices[26, 27].

Composite materials made from waste agricultural materials or fruit peels are a promising area of research and development in the field of sustainable materials. They have become an increasingly important aspect of present day's materials because of their numerous advantages such as light weight, corrosion resistance etc [28]. These materials, often referred to as bio-composites, offer several advantages such as reduced environmental impact, utilization of waste materials, and potential biodegradability. Fruit peels, such as those from citrus fruits, can be dried, ground, and mixed with a suitable binder to form composites. These composites can be used for packaging materials, disposable cutlery, or even as additives in other composite materials.

Agricultural residues and fruit peels can also be used as raw materials for manufacturing particleboard and fiberboard. These engineered wood products find applications in furniture, construction, and interior design industries.

The specific process for creating composites from waste agricultural materials or fruit peels may vary depending on the desired properties and applications. Researchers and manufacturers are continually exploring new techniques and formulations to optimize the performance and sustainability of these materials.

Consequently, ongoing research aims to identify and utilize potential natural fiber materials as reinforcements in polymer composites to maximize the use of agricultural and food waste resources and address environmental concerns. Pomegranate peels are rich in cellulose, lignin, and other natural compounds. The specific composition may vary depending on factors such as the pomegranate variety and processing conditions.

Pomegranate peels are rich in antioxidants and have been found to have antibacterial and anti-inflammatory properties, making them an attractive material for various applications. Pomegranate is highly regarded worldwide for its exceptional nutritional value, being rich in fiber, protein, vitamin K, and medicinal properties. However, in juice processing industries, only the fruit is used, and the peel and seeds are discarded as waste. In India alone, during 2013-19, pomegranate was cultivated with an annual production of 3,135,190,000 kg and productivity of 13.70 Tones/ha, ultimately generating significant amounts of byproduct waste (approximately 40% of the fruit's weight). These pomegranate wastes are nutrient-rich, containing fibers, photochemical, and antioxidants, making them ideal candidates for efficient utilization as composites without harmful effects on the environment.

In this present study, Pomegranate Peel Powder will be extracted from discarded peels, and subsequently, it will be blended with epoxy in an appropriate ratio using the casting method to create a composite plate. The pomegranate peel powder particles will serve as the reinforcing agent in the composite. So the main objective of this study is to-

1. Perform various tests to assess its mechanical properties.
2. Additionally, a scanning electron microscope will be utilized to perform morphological analysis of the composite surfaces.

2. Materials and Methods

The research work will involve producing a composite fiberboard using pomegranate peel powder and epoxy involves several steps, including material preparation, mixing, molding and curing. After that different tests will be performed to determine the various mechanical properties of the produced fiberboard. The different steps involved are described as under-

2.1 Production of Particles from pomegranate peels

Uniform source conditions were maintained by collecting pomegranates from the local market in Delhi, India. The gathered pomegranate peels were stored in a refrigerator at approximately 15°C until they were ready for use. Subsequently, the peels were placed in ambient conditions to facilitate the drying process. Once completely dried, they were ground to obtain a powdered form.

Fig. 1: Different phases of production of pomegranate peel powder from the pomegranate

Figure 1 shows the different phases of the production of pomegranate peel powder from the pomegranate.

2.2 Fabrication of composite

Casting Pomegranate peel powder was developed into a composite using the casting method. Novolac resin epoxy was chosen for its excellent resistance to chemicals and high-temperature stability. To initiate the curing process, a hardener and accelerator were added during the fabrication of the composite plate. The curing was conducted at room temperature for the duration of 24 hours. Using a significant amount of filler resulted in decreased strength values when compared to high-performance composites. Reducing the filler content from 70% to 60% resulted in improved mechanical properties. The composite panel with a ratio of 60:40 groundnut shell particles to epoxy resin exhibited the highest tensile, bending, and impact strengths[26]. So keeping this in mind, a blend was created by combining 50% pomegranate peel powder and 50% epoxy resin by volume. The epoxy resin and hardener were mixed in a weight ratio of 10:1 and stirred thoroughly to prevent the formation of voids. This well-prepared mixture was poured onto a clean surface, maintaining the desired width, breadth, and thickness to form a composite with a cross-sectional area of 1x1.5 square feet. The composite was left to cure at room temperature for one day.

Fig 2: Finally Fabricated Composite Panel

2.3 Preparation of specimen

For the mechanical characterization of the fabricated composite panel, the following tests will be performed on the different specimens-

1. Compressive Strength Test
2. Three Point Bend Test
3. Impact Strength

Figure 3 shows the images of the specimens to be tested obtained from the fabricated composite plate and the finally prepared specimens.

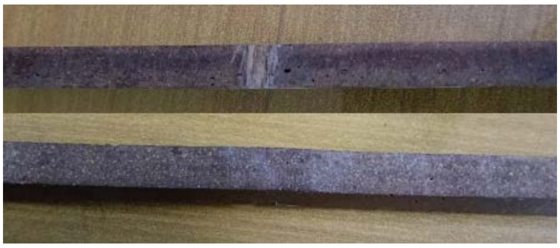

Fig 3: Test Specimen for Impact and 3PB Test

3. Results and Discussion

3.1 X-ray diffraction (XRD) analysis

X-Ray Diffraction (XRD) is a non-destructive analytical method used to study the atomic and molecular arrangement of crystalline materials. This technique involves exposing a sample to X-rays, which interact with the crystal lattice of the material, creating a diffraction pattern. XRD is mainly utilized to identify different phases or crystalline structures in a material and offers valuable insights into its composition and crystal arrangement. By determining the unit cell dimensions and symmetry, XRD helps in understanding the material's properties and behavior. Additionally, it can distinguish between crystalline and amorphous regions, providing information about the degree of crystallinity and the presence of any amorphous phases. In the case of the derived pomegranate peel powder, XRD was performed to analyze its phase or crystalline structures. Figure 4 shows the XRD pattern of the pomegranate peel powder.

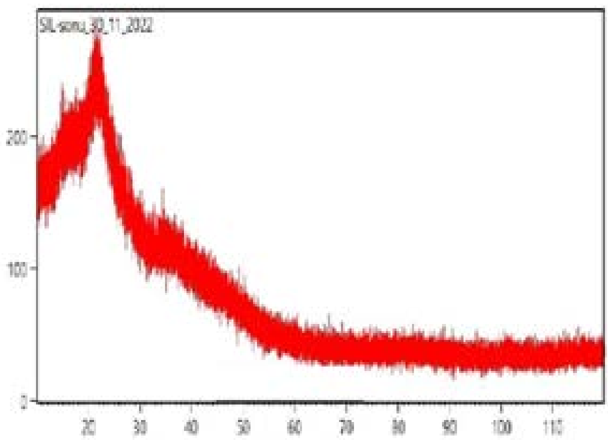

Fig 4: X-Ray Diffraction (XRD) image of Powder Sample

The X-ray pattern of pomegranate peel waste was analyzed using a Philips Analytical X-ray Diffractometer. To identify the crystal phases in the dried film, a sample with a thickness of approximately 107 mm was placed on the sample holder and scanned using the reflection method at an angle of 2θ over a range of 5° to 6° at a speed of 8°/min. The X-ray diffractogram of the pomegranate peel exhibited broad peaks at 2θ angles of 19.51° and 20.12°, indicating that the peels possess an amorphous nature. However, when the analysis was extended beyond 20°, no sharp peak was observed, which indicates the presence of a crystalline nature in the sample. Therefore, the sample exhibits characteristics that lie between being amorphous and crystalline.

3.2 Mechanical Characterisation

3.2.1 Compressive Strength Test

Figure 5 illustrates the procedure for the compression test. The test was carried out using a computerized universal testing machine, following the guidelines outlined in ASTM D695. A test specimen measuring 10x10x10 mm³ was positioned between the holders of the testing machine. Each sample underwent three tests, and the compressive strength was subsequently calculated.

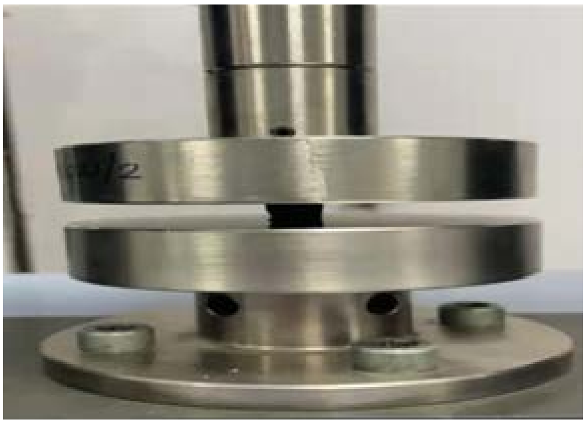

Fig. 5: Compression Test Set Up

The Graph shown in Figure 6 shows the Stress-Strain Curve for one of the composite plates under compressive strength testing. The three samples show very good compressive strength. The average strength of the composites comes out to be 58 N/mm^2.

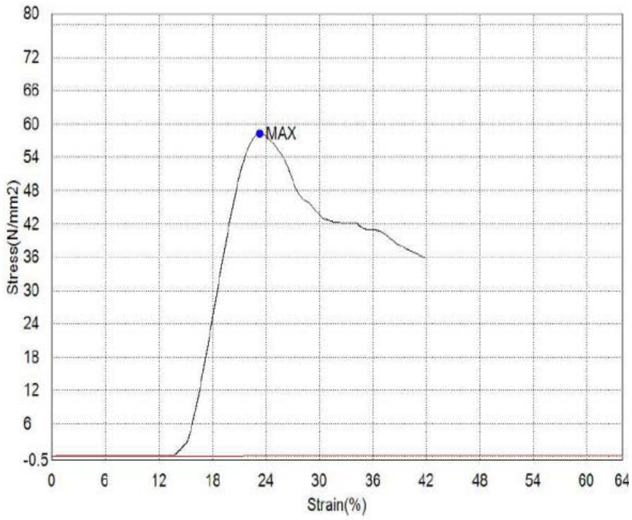

Fig 6: Stress-Strain curves for Compressive Testing

3.2.2 Flexural Strength Test (3PBT)

The test method evaluates the flexural properties of the composites following the guidelines of ASTM D790. Flexural test was conducted using a Universal Testing Machine, with a constant loading rate of 2 mm/min. The specimen was prepared with dimensions of 191×12 mm² and a depth of 12 mm. The setup for this experiment is shown in Figure 7.

The Graph shown below in Figure 8 shows the Force and Displacement relation for the Three Point Bending Test. An average Flexural Strength of 29.20 MPa has been obtained for the composite fabricated with pomegranate peel powder particles which is within the acceptable limit of 30 MPa (Generally, plywood used for construction and general purposes tends to have a flexural strength in the range of 25 to 50 MPa).

Fig 7: 3PBT Set Up

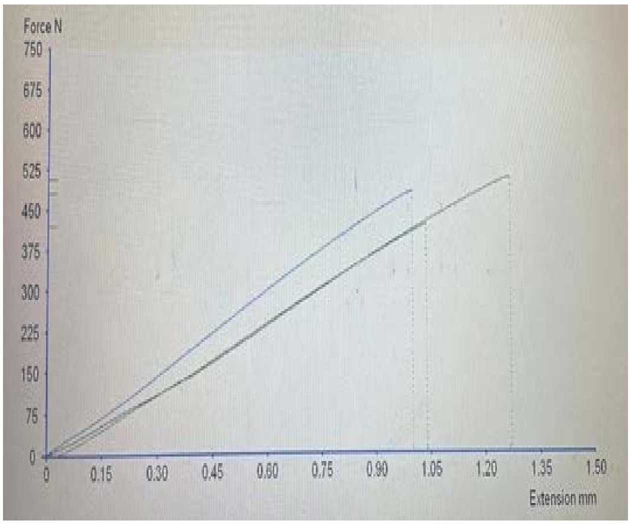

Fig 8: Graphical representation of 3PBT

3.2.3 Impact Test

The test method assesses the Izod impact strength of various composites following ASTM D256 standards.

The impact test was conducted using an Impact Testing Machine and V-notched specimens. The specimens had dimensions of 63.5 mm length, 10 mm width, and 10 mm thickness, with a notch depth of 2.54 mm and a notch angle of 45 degrees. During the Izod test, the specimen was held in a cantilever beam orientation (typically vertical) and securely clamped with the center line of the notch aligned with the top of the clamping surface. The pendulum was released to strike the specimen, and the energy absorbed by the specimen was directly recorded on the scale. Three samples for each composition were tested, and the mean value was taken as the impact strength of the composite material being evaluated. The test revealed that the composite possesses average impact strength of 21.2 KJ/m^2. This result indicates the material's ability to withstand impact forces and absorb energy without fracturing or breaking. A higher impact strength value signifies a greater resistance to impacts, making the composite suitable for applications that involve potential mechanical shocks or dynamic loads. The promising impact test result highlights the material's potential for use in various industries, where durability and impact resistance are critical factors.

The different mechanical properties observed after testing are shown below in table 1–

Table 1- Results for different tests

S. N.	Test	Observations
1	Compressive Strength	58 N/mm^2
2	Three Point Bend Test (Flexural Strength)	29.20 MPa
3	Impact Strength	21.2 KJ/m^2

3.3 Scanning Electron Microscope (SEM) Analysis

The sample of the fabricated composite panel has also been tested to detect the distribution and bonding of the pomegranate peel powder and epoxy. The two images shown in Figure 9 show the bonding and voids formation in the composite sample. From the images, it is clear that the bonding of the pomegranate peel particles is normal and the voids formation is very less, which ultimately results in better mechanical properties for the composite structure.

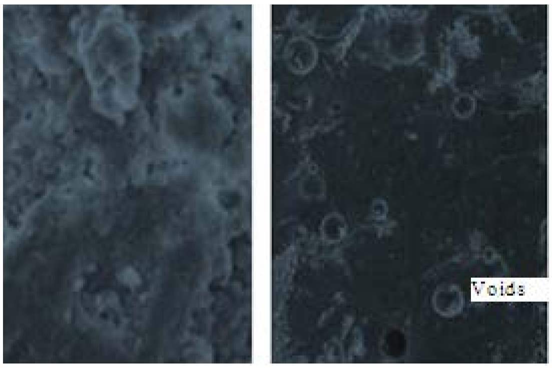

Fig 9: SEM Image a) Bonding of Epoxy and Pomegranate peel powder b) Fewer Voids in composite

4. Conclusion

In conclusion, this research paper explored the development of a novel composite material by incorporating pomegranate peel powder into epoxy. The investigation aimed to assess the mechanical properties of the composite through various tests. The results obtained were highly promising, revealing impressive performance characteristics.

- The XRD analysis of the pomegranate peel powder exhibits characteristics that lie between being amorphous and crystalline.
- The compressive strength of the composite reached 58 N/mm2, indicating its ability to withstand significant compressive forces without failure.
- The Flexural Strength of 29.20 MPa demonstrated the composite's capacity to resist bending stresses, making it suitable for applications requiring load-bearing capabilities.
- Furthermore, the impact strength of 21.2 KJ/m^2 showcased the composite's remarkable ability to absorb energy during impacts, which is crucial in scenarios where resilience against sudden loads is essential.
- The SEM analysis provided valuable insights into the microstructure of the composite, revealing a normal bonding pattern between pomegranate peel particles and epoxy. Additionally, the minimal void formation observed in the SEM analysis contributed to the improved mechanical properties of the composite, enhancing its overall strength and durability.

Based on these compelling results, it can be concluded that the incorporation of pomegranate peel powder into epoxy has led to the creation of a composite material with superior mechanical properties. This composite shows great promise for potential applications in areas where high strength, impact resistance and load-bearing capabilities are crucial. The research findings open new avenues for the utilization of agricultural waste materials like pomegranate peel in the development of sustainable and high-performance composites

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Nomenclature

PPP	Pomegranate Peel Powder
XRD	X-Ray Diffraction
SEM	Scanning Electron Microscope
ASTM	American Society for testing and Materials
3PBT	Three Point Bending

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