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Literature Review on Evaluation of Mechanical Properties of Walnut Shell Powder-Reinforced Epoxy Composites

Autade Pravin Jotiram[1], Dr. Digambar.D.Date[2], A.Z.Patel[3], U.J.Jadhao[4]
[1] Research Scholar, TPCT's College of Engineering Osmanabad, Maharashta, India
[2,3,4] TPCT's College of Engineering Osmanabad, Maharashta, India

Abstract:

The incorporation of natural fillers such as walnut shell powder, pistachio shell powder, coconut shell powder, and other bio-based materials into epoxy composites has been extensively studied for their effects on mechanical and thermal properties. Researchers have reported that walnut shell powder enhances hardness, stiffness, and modulus while influencing tensile and flexural strengths depending on its content and particle size. Studies indicate that optimal filler concentrations (typically around 5-15 wt%) lead to significant improvements in tensile, flexural, and compression strengths, though excessive filler content can cause agglomeration and void formation, reducing mechanical performance. The surface treatment of fillers, such as NaOH modification, further enhances mechanical properties.

Keywords: Walnut shell powder, epoxy composites, natural fillers, etc.

1. Introduction

The development of sustainable, lightweight, and high-performance materials has gained significant attention in recent years due to the increasing demand for environmentally friendly alternatives in industrial applications. Polymer composites reinforced with natural fillers have emerged as promising candidates for reducing environmental impact while maintaining or enhancing material performance. These composites provide a unique opportunity to utilize renewable resources, minimize waste, and create value-added products.

Walnut shell powder (WSP), an agro-industrial byproduct obtained from the processing of walnuts, represents a potential reinforcement material due to its unique properties. It is lightweight, hard, and composed primarily of lignin, cellulose, and hemicellulose, which contribute to its mechanical strength. Despite these advantages, the use of walnut shell powder in polymer composites remains underexplored, particularly at the nano scale, where the reduced particle size offers the potential for improved surface area, better dispersion, and enhanced interfacial bonding within the polymer matrix.

This study proposes to investigate the mechanical properties of epoxy composites reinforced with nano walnut shell powder. By fabricating and testing these composites, the research aims to explore their feasibility as sustainable alternatives to conventional materials and contribute to the development of high-performance, eco-friendly composites for a variety of applications. The findings of this study will provide insights into the benefits of utilizing nano-sized natural fillers and promote the broader adoption of bio-based materials in industries such as automotive, construction, and consumer goods.

2. Literature Review:

Natural fillers, such as coconut shell powder, rice husk, and almond shell powder, have been extensively studied for use in polymer composites. These fillers improve the mechanical, thermal, and biodegradability properties of polymers. However, walnut shell powder, despite its hardness and lignocellulosic composition, has been less explored, especially in its nano form. Existing studies have demonstrated that reducing filler particle size to the nano scale can significantly enhance the surface area, improve interfacial bonding, and consequently, the composite's overall properties. This research aims to address the gap by focusing on nano walnut shell powder as a reinforcement in epoxy composites.

Various researchers have explored the influence of natural fillers such as walnut shell powder and other bio-based materials on the mechanical properties of epoxy composites. Talikoti (2023) investigated epoxy composites reinforced with walnut shell powder, finding that adding 5 wt% improved tensile, flexural, and compression strengths by 10.4%, 17.6%, and 42%, respectively. Similarly, Shejkar (2023) observed that the addition of walnut shell particulates (WSP) enhanced hardness and compressive strength, with smaller particle sizes (50 microns) yielding better mechanical properties than larger ones (75 and 100 microns). Ahmad (2023) reported that the inclusion of pistachio shell powder improved impact strength, while walnut shell powder initially reduced it before increasing with higher weight ratios. Additionally, walnut shell and pistachio shell fillers increased hardness and flexural strength, albeit with minor increases in thermal conductivity and water absorption.

Mittal et al. (2023) noted that walnut shell particles enhanced stiffness and hardness but decreased tensile and flexural strength, with 35 wt% being the optimal filler amount. Lata (2023) found that walnut shell (WNS) improved tensile and compression modulus but reduced tensile and compressive strength, with 5 wt% WNS demonstrating uniform distribution and lower water absorption. Ranakot (2023) studied walnut shell powder-filled glass fiber-reinforced vinyl ester composites, reporting tensile strength improvements of 10.4% and 13.3% at 5 wt% and 10 wt% WNP, respectively, though higher loadings led to agglomeration and reduced performance. Nitin (2023) observed that increasing walnut particle content from 10% to 20% reduced ultimate tensile strength but increased elongation, while modulus of elasticity remained largely unaffected.

Shejkar (2023) further examined the effects of filler content and surface modification on epoxy/WSP composites, finding that increasing WSP content reduced density but increased voids and water absorption. Compressive strength, hardness, and tensile and flexural moduli improved with increasing WSP, peaking at 10 wt% before declining. Alkali treatment with 2-mole NaOH enhanced all properties, whereas 4-mole NaOH slightly degraded them. Thakur (2023) conducted three-point bending tests on epoxy composites with varying WSP weight fractions, demonstrating close agreement with theoretical predictions. Salasinska (2023) determined that adding walnut shell waste filler increased stiffness and hardness while reducing tensile strength and impact resistance, with higher filler content leading to better thermal stability at elevated temperatures.

Gairola (2023) investigated the mechanical and wear performance of banana fiber/walnut powder-based epoxy composites, noting that tensile, flexural, and impact strengths peaked at 15 wt% WNP, with sliding velocity and fiber content being key wear performance factors. Dhima (2023) studied jute-basal hybrid epoxy composites, finding that walnut shell filler improved mechanical properties compared to unfilled composites. Singh (2023) observed that walnut particles increased bio-composite stiffness but reduced ultimate strength while enhancing hardness. Chandramohan (2023) demonstrated that incorporating walnut shell and coconut shell fibers in hybrid polymer composites improved tensile, flexural, shear, and impact strengths.

Other studies focused on different natural fillers. Somashekhar et al. (2023) found that combining coconut shell powder and tamarind shell powder in epoxy increased tensile properties by 50%, with an optimal composition of 50% coconut shell powder, 5% tamarind shell powder, and 45% epoxy resin. Babu (2023) analyzed tamarind, date seed, and prawn shell powders with Arundo Donax L. leaf in epoxy, highlighting their superior mechanical properties compared to synthetic fibers. Shakuntala (2023) investigated wood apple shell filler, which improved tensile and flexural strengths, wear resistance, and viscoelastic stiffness, with DMA testing validating its thermal stability.

Dayal (2023) developed a bio-composite using walnut shell powder, coir, and jute fiber, finding specimen 1 to exhibit the best flexural strength (7.60 MPa), impact strength (154.9 J/m), and Rockwell hardness (72 on the R scale). Another study by Somashekhar (2023) explored coconut shell powder-epoxy composites, evaluating tensile strength, flexural properties, and hydrophilic behavior. Al-Obaidi (2023) reported that adding 5 wt% of pistachio shell particles (size <63 μm) improved impact strength (75%), tensile strength (56%), and flexural strength (87.7%), while 15 wt% (63-120 μm) increased hardness by 28%. Srivastava (2023) fabricated coconut shell powder-reinforced epoxy composites and found them advantageous in reducing density and cost while improving the strength-to-weight ratio. Lastly, Baig (2023) demonstrated that adding groundnut shell powder significantly enhanced the mechanical properties of banana fiber-reinforced epoxy-based bio-composites.

3. Literature Gap

Despite extensive research on natural fillers in polymer composites, certain gaps remain:

- Limited studies exist on the use of walnut shell powder as a reinforcement material, especially in its nano scale form.
- The influence of nano walnut shell powder on the mechanical properties of epoxy composites has not been comprehensively investigated.
- There is insufficient understanding of the interfacial bonding mechanisms between nano walnut shell powder and epoxy resin.
- Most studies on natural fillers focus on macroscopic or micro-scale fillers, neglecting the potential benefits of nano-scale fillers in terms of enhanced mechanical and thermal performance.
- Comparisons between nano walnut shell powder and other nano natural fillers in terms of their performance and cost-effectiveness are scarce

4. Objectives The primary objectives of this research are as follows:

- To synthesize nano walnut shell powder through suitable mechanical and chemical methods.
- To fabricate epoxy composites reinforced with varying weight percentages of nano walnut shell powder.
- To evaluate the mechanical properties of the composites, including tensile strength, flexural strength, impact resistance, and hardness.

5. Research Methodology

5.1 Materials Procurement:

- Epoxy resin and hardener will be procured from a commercial supplier.
- Walnut shells will be collected and cleaned to remove impurities.

5.2 Preparation of Nano Walnut Shell Powder:

- Walnut shells will be crushed and ground into fine powder using a ball mill.
- The fine powder will be further reduced to nano scale using high-energy ball milling and characterized using particle size analysis (e.g., dynamic light scattering).

5.3 Composite Fabrication:

- Epoxy resin will be mixed with varying weight percentages (e.g., 1%, 3%, 5%, and 7%) of nano walnut shell powder.
- The mixture will be thoroughly stirred and degassed to remove air bubbles.
- The composites will be molded using compression molding or casting methods and cured under specified conditions.

5.4 Mechanical Testing:

- **Tensile Strength:** ASTM D638 standard will be followed.
- **Flexural Strength:** ASTM D790 standard will be used.
- **Impact Resistance:** Charpy impact tests will be performed as per ASTM D256.
- **Hardness:** Shore D hardness testing will be conducted.

6. Expected Outcomes

- Enhanced mechanical properties of epoxy composites reinforced with nano walnut shell powder.
- Improved interfacial bonding due to the nano-scale size of the filler particles.
- Identification of the optimum weight percentage of nano walnut shell powder for achieving the best mechanical performance.

7. Significance of the Study: This research contributes to the growing field of sustainable materials by utilizing a renewable, low-cost, and abundant agricultural byproduct. The findings could pave the way for eco-friendly composite materials with potential applications in automotive, construction, and consumer goods industries. Moreover, the use of nano walnut shell powder can add value to walnut processing waste, aligning with the principles of a circular economy.

8. Conclusion:

This research aims to explore the mechanical performance of epoxy composites reinforced with nano walnut shell powder, contributing to the development of sustainable materials. By utilizing a natural filler in its nano form, the study seeks to achieve superior composite properties and establish the potential of nano walnut shell powder as a viable reinforcement in polymer matrices.

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