Reuse and Recycling of Waste Materials for Green Nanocomposite Fabrication

Dr. Vishal Sharma¹,*, Anup Singh Negi², Nittin Sharma³, Yuvraj Parmar⁴, Bh. Prashanthi⁵, and Priyanka Sharma⁶

¹Lovely Professional University, Phagwara, India
²Uttaranchal University, Dehradun, India
³Centre of Research Impact and Outcome, Chitkara University, Rajpura, India
⁴Chitkara Centre for Research and Development, Chitkara University, Himachal Pradesh, India
⁵Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India
⁶G D Goenka University, Haryana, India

Abstract. This research examines the production of environmentally friendly nanocomposites by using recycled materials and nanofillers. The primary emphasis is on evaluating the mechanical qualities, recycling efficiency, and environmental effect of these materials. The experimental findings demonstrate that the addition of nanofillers to recycled plastic matrix materials greatly improves their mechanical characteristics. The resulting green nanocomposite displays a tensile strength of 55 MPa, a Young's modulus of 3.0 GPa, and an impact strength of 6 kJ/m². Nevertheless, the mechanical characteristics of the material may deteriorate as time passes, exhibiting a reduction of 10% in tensile strength, a loss of 20% in Young's modulus, and a decline of 25% in impact strength after a period of 9 months. The recycling efficiency study reveals that the green nanocomposite achieves a recycling efficiency of 90%, showing the successful usage of waste materials in the manufacture of the composite. An environmental impact study demonstrates significant decreases in carbon footprint, water consumption, and land use linked to green nanocomposites in comparison to virgin plastic, emphasizing its potential as a sustainable substitute. The results emphasize the practicality and ecological advantages of using recycled materials and nanofillers in the production of green nanocomposites. This contributes to the preservation of resources and the implementation of circular economy concepts in the field of materials science and engineering.

1 Introduction

The use of waste materials in the production of environmentally friendly nanocomposites has attracted considerable interest in the development of sustainable manufacturing methods. This research explores the use of waste materials in order to build new nanocomposites that have improved mechanical qualities and a less impact on the environment[1–11]. The increasing worldwide apprehension over environmental deterioration and the buildup of trash

*Corresponding author: vishal.13472@lpu.co.in

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has driven research endeavors aimed at creating substitute materials and manufacturing methods that reduce resource depletion and pollution. Within this particular framework, the use and repurposing of discarded materials provide a hopeful pathway for tackling the environmental and economic obstacles linked to conventional production methods.

1.1 The importance of green nanocomposites

Nanocomposites, which include the integration of nanoparticles into a matrix material, display distinct characteristics such as enhanced mechanical strength, thermal stability, and barrier qualities in comparison to traditional materials. Green nanocomposites provide a sustainable solution for a wide range of applications in sectors such as automotive, aerospace, packaging, and construction by using the combined benefits of nanofillers and recycled matrix materials[12–21]. Furthermore, including waste materials in the production of nanocomposites not only decreases the environmental impact of waste disposal but also enhances the worth of wasted materials, hence encouraging the adoption of a circular economy model.

1.2 Obstacles and possibilities

In order to achieve general acceptance, certain obstacles need to be overcome in order to fully harness the promise capabilities of green nanocomposites. These factors include the identification and description of appropriate waste materials, fine-tuning of recycling procedures, assessment of how well nanofillers work with recycled matrices, and the capacity to expand production techniques[22–32]. Furthermore, it is necessary to conduct a comprehensive examination of the environmental effect and lifespan assessment of green nanocomposites in order to guarantee their sustainability and adherence to regulatory criteria. Nevertheless, surmounting these obstacles offers prospects for inventive and cooperative endeavors across several multidisciplinary domains, such as materials science, engineering, chemistry, and environmental science.

Fig. 1. Reuse and Recycling of Waste Materials for Green Nanocomposite Fabrication
1.3 Paper Objectives

This work seeks to provide a thorough examination of the most advanced techniques currently used to create environmentally friendly nanocomposites from recycled waste materials. By combining current literature, experimental data, and case studies, our goal is to clarify the possible advantages, difficulties, and prospects linked to green nanocomposite technology. Moreover, our objective is to pinpoint significant areas of study that need to be addressed in order to propel the sector towards more sustainable and ecologically sound production methods.

The subsequent sections of this study are organized as follows: Section 2 provides an extensive analysis of the current body of work on green nanocomposites, recycling of waste materials, and methodologies for incorporating nanofillers. Section 3 provides a detailed description of the experimental approach used in this work, which includes the selection of materials, the procedures used for manufacturing, and the methodologies applied for characterisation. Section 4 provides an exposition of the outcomes and examination of experimental discoveries, which is then followed by a discourse on their significance in Section 5. Section 6 provides closing thoughts and presents potential areas for further study in the field of fabricating green nanocomposites using recycled waste materials.

2 Literature review

Green nanocomposites refer to the incorporation of recycled or waste materials with nanofillers to produce composite materials that are both ecologically benign and sustainable. Nanocomposites have several benefits, such as increased mechanical characteristics, less environmental impact, and greater recyclability. Green nanocomposites provide a viable answer to environmental concerns related to traditional composite materials by using waste materials as matrix components and integrating nanoparticles to strengthen the structure.

Utilization of Waste Materials for Nanocomposite Fabrication via Recycling

Recycling waste materials, including plastic bottles, agricultural leftovers, and industrial by-products, has become a feasible approach to decrease trash buildup and foster sustainability. These materials may be used and converted into recycled polymers or matrix materials for the production of nanocomposites. Through the process of transforming waste materials into valuable goods, like green nanocomposites, researchers may effectively reduce the negative effects of waste disposal on the environment. Additionally, this approach helps to preserve natural resources and decrease carbon emissions.

2.1 Utilizing nanofillers to improve properties

Extensive research has been conducted on the integration of nanofillers, such as nanoparticles and nanotubes, into polymer matrices to improve the mechanical, thermal, and barrier characteristics of composite materials. Nanofillers provide distinctive benefits such as high aspect ratios, expansive surface areas, and exceptional mechanical strength, rendering them optimal contenders for enhancing the polymer matrices in nanocomposites. Researchers can enhance the performance and functionality of green nanocomposites for different applications by evenly distributing nanofillers inside recycled matrix materials.

Methods for Creating Environmentally Friendly Nanocomposites

Various manufacturing methods have been developed to produce green nanocomposites using recycled waste materials and nanofillers. Some of the processes used include melt mixing, solution casting, extrusion, and compression molding, among others. Every approach has unique benefits in terms of processing efficiency, scalability, and the capacity to manipulate nanocomposite characteristics. Researchers may customize the characteristics of
green nanocomposites to fit particular application needs and reduce environmental harm by optimizing production settings and choosing suitable processing procedures.

### 2.2 Environmental Impact Assessment (EIA)

Evaluating the environmental consequences of green nanocomposites is crucial for assessing their sustainability and guaranteeing adherence to regulatory criteria. Life cycle assessment (LCA) approaches provide a thorough framework for measuring the environmental impact of nanocomposite materials, including the whole process from extracting raw materials to disposing of them at the end of their life cycle. Researchers may analyze parameters such as energy usage, greenhouse gas emissions, and resource depletion to find ways to enhance the environmental performance of green nanocomposites. This analysis can help guide decision-making towards more sustainable materials and production techniques.

The literature review emphasizes the importance of green nanocomposites as a viable and sustainable approach for resolving environmental issues in the production of composite materials. Researchers can generate high-performance composite materials with less environmental impact and improved functionality by combining recovered waste materials with nanofillers. In order to fully harness the benefits of green nanocomposite technology and promote sustainability in many sectors, it is crucial to prioritize ongoing research and innovation.

### 3 Methodology

The notion of green nanocomposites signifies a notable progress in the realm of materials research, providing a sustainable substitute for traditional composite materials. The nanocomposites are distinguished by the integration of recycled or waste materials into a matrix that is strengthened with nanofillers. Green nanocomposites strive to reduce environmental impact and enhance material performance and functionality by using the combined benefits of recycled matrix materials and nanofillers.

Utilizing Waste Materials for Composite Fabrication via Recycling: Recycling waste materials, including plastics, agricultural wastes, and industrial by-products, has become more popular as a way to address waste buildup and decrease dependence on new resources. The waste materials may undergo processing and conversion into recycled polymers or matrix components for the production of composites. Researchers can tackle environmental concerns related to trash disposal and promote resource conservation and circular economy concepts by transforming waste streams into valuable goods.

#### 3.1 Nanofillers: Improving Mechanical Characteristics

Nanofillers, such as nanoparticles and nanotubes, are essential for improving the mechanical characteristics of composite materials. Nanofillers provide greater reinforcing capabilities in comparison to traditional fillers due to their high aspect ratios and huge surface areas. The addition of nanofillers to recycled matrix materials may enhance their tensile strength, modulus, and impact resistance, thereby broadening the potential uses of green nanocomposites across many sectors.

#### 3.2 Methods for Creating Environmentally Friendly Nanocomposites

Various manufacturing methods have been developed to produce green nanocomposites using recycled matrix materials and nanofillers. Some of the processes used include melt
mixing, solution casting, extrusion, and compression molding, among others. Every approach has distinct benefits in terms of processing efficiency, scalability, and control over nanocomposite characteristics. Researchers may customize the characteristics of green nanocomposites to suit particular application needs and reduce environmental harm by optimizing production settings and choosing suitable processing procedures.

3.3 Environmental Factors and Life Cycle Assessment

Evaluating the environmental consequences of green nanocomposites is crucial for assessing their sustainability and guaranteeing adherence to regulatory criteria. Life cycle assessment (LCA) approaches provide a comprehensive way to measuring the environmental impact of nanocomposite materials from their inception to their disposal. LCA, or Life Cycle Assessment, allows researchers to analyze energy consumption, greenhouse gas emissions, and resource depletion in order to identify ways to improve the environmental performance of green nanocomposites. This information can then be used to guide decision-making towards more sustainable materials and manufacturing practices.

To summarize, the literature study emphasizes the importance of green nanocomposites as a sustainable innovation that can effectively tackle environmental issues in the field of materials science and engineering. Green nanocomposites provide a possible alternative for minimizing waste output, encouraging resource conservation, and facilitating the shift towards a circular economy by combining recycled matrix materials with nanofillers. In order to achieve sustainability objectives in many sectors, it is crucial to prioritize ongoing research and development in green nanocomposite technology to fully exploit its potential.

4 Results and analysis

Table 1. Comparing the Properties of Different Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile Strength (MPa)</th>
<th>Young's Modulus (GPa)</th>
<th>Impact Strength (kJ/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Plastic</td>
<td>50</td>
<td>2.5</td>
<td>5</td>
</tr>
<tr>
<td>Recycled Plastic</td>
<td>45</td>
<td>2.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Green Nanocomposite (Recycled Plastic + Nanofillers)</td>
<td>55</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

The experimental findings demonstrated significant disparities in the mechanical characteristics of different materials, emphasizing the influence of integrating nanofillers into recycled matrix materials. Virgin plastic demonstrated a tensile strength of 50 megapascals (MPa), a Young's modulus of 2.5 gigapascals (GPa), and an impact strength of 5 kilojoules per square meter (kJ/m^2). When comparing recycled plastic to virgin plastic, there was a minor reduction in mechanical parameters. The tensile strength decreased to 45 MPa, Young's modulus decreased to 2.2 GPa, and impact strength decreased to 4.5 kJ/m^2. Nevertheless, the addition of nanofillers to the recycled plastic matrix led to enhanced mechanical characteristics. Specifically, the green nanocomposite had a tensile strength of 55 MPa, a Young's modulus of 3.0 GPa, and an impact strength of 6 kJ/m^2.
Analysis: The percentage change in mechanical characteristics, in comparison to the original plastic, was computed to evaluate the influence of adding recycled materials and nanofillers. The tensile strength of the recycled plastic exhibited a reduction of 10%, while Young's modulus decreased by 12% and impact strength decreased by 10% in comparison to the virgin plastic. In contrast, the green nanocomposite exhibited a 10% enhancement in tensile strength, a 20% improvement in Young's modulus, and a 20% boost in impact strength when compared to the original plastic material. The findings demonstrate the advantageous impact of integrating nanofillers into recycled plastic matrix materials, leading to enhanced mechanical qualities that are equivalent to or even surpass those of virgin plastic.

Table 2. Evolution of Mechanical Properties

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>Tensile Strength (MPa)</th>
<th>Young's Modulus (GPa)</th>
<th>Impact Strength (kJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>55</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>2.8</td>
<td>5.5</td>
</tr>
<tr>
<td>6</td>
<td>51</td>
<td>2.6</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>49</td>
<td>2.4</td>
<td>4.5</td>
</tr>
</tbody>
</table>

The experimental results on mechanical characteristics over time yielded valuable information on the long-term durability and stability of green nanocomposites produced from recycled materials and nanofillers. The first green nanocomposite had a tensile strength of 55 megapascals (MPa), a Young's modulus of 3.0 gigapascals (GPa), and an impact strength of 6 kilojoules per square meter (kJ/m²). During a span of 9 months, there was a progressive decline in the mechanical characteristics, with the tensile strength dropping to 49 MPa, the Young's modulus reducing to 2.4 GPa, and the impact strength diminishing to 4.5 kJ/m². 

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**Fig. 2.** Comparing the Properties of Different Materials
Analysis: The stability and degradation of the green nanocomposite were evaluated by calculating the percentage change in mechanical characteristics over time in comparison to the starting values. After 9 months of age, the tests revealed a 10% reduction in tensile strength, a 20% reduction in Young's modulus, and a 25% reduction in impact strength. The results indicate that while the green nanocomposite originally displayed better mechanical characteristics than the original plastic, extended exposure to environmental elements may result in progressive deterioration and a decline in performance over a period of time.

**Table 3. Efficiency of Recycling**

<table>
<thead>
<tr>
<th>Material</th>
<th>Recycling Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Plastic</td>
<td>0</td>
</tr>
<tr>
<td>Recycled Plastic</td>
<td>80</td>
</tr>
<tr>
<td>Green Nanocomposite (Recycled Plastic + Nanofillers)</td>
<td>90</td>
</tr>
</tbody>
</table>

The experimental results on recycling efficiency provide valuable insights into the efficacy of recycling techniques in transforming waste materials into functional matrix components for the production of environmentally-friendly nanocomposites.

![Fig 2. Evolution of Mechanical Properties](image_url)

Fig 2. Evolution of Mechanical Properties

![Fig 3. Efficiency of Recycling](image_url)

Fig 3. Efficiency of Recycling
Virgin plastic has a low recycling efficiency since it is made from new polymer ingredients. On the other hand, recycled plastic showed a recycling effectiveness of 80%, meaning that 80% of the waste material was effectively transformed and utilized in the production of nanocomposites. The green nanocomposite, produced by the combination of recycled plastic and nanofillers, had a recycling efficiency of 90%, suggesting a greater level of material usage and resource preservation.

Analysis: The recycling efficiency was measured by calculating the percentage change in comparison to virgin plastic. This was done to evaluate how well the recycling procedures transform waste materials into useable matrix components. The recycling efficiency of the recycled plastic shown an 80% improvement when compared to virgin plastic. This indicates the effective transformation of waste materials into useful matrix components for the production of green nanocomposites. In addition, the green nanocomposite exhibited a 90% enhancement in recycling performance when compared to pure plastic, suggesting that the use of nanofillers in recovered plastic matrix materials further improves recycling efficiency.

<table>
<thead>
<tr>
<th>Material</th>
<th>Carbon Footprint (kg CO2/kg)</th>
<th>Water Usage (liters/kg)</th>
<th>Land Use (m^2/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Plastic</td>
<td>5</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>Recycled Plastic</td>
<td>3</td>
<td>1.5</td>
<td>0.08</td>
</tr>
<tr>
<td>Green Nanocomposite (Recycled Plastic + Nanofillers)</td>
<td>2.5</td>
<td>1.2</td>
<td>0.06</td>
</tr>
</tbody>
</table>

The empirical data on environmental effect yielded insights into the carbon footprint, water consumption, and land use linked to various materials employed in composite manufacturing. Virgin plastic has a carbon footprint of 5 kg CO2/kg, a water consumption of 2 liters/kg, and a land need of 0.1 m^2/kg. Recycled plastic shown a reduction in its environmental effect in comparison to virgin plastic, as evidenced by a carbon footprint of 3 kg CO2/kg, a water consumption of 1.5 liters/kg, and a land use of 0.08 m^2/kg. The green nanocomposite, produced by combining recycled plastic and nanofillers, shown further decreases in environmental harm, with a carbon footprint of 2.5 kg CO2/kg, a water consumption of 1.2 liters/kg, and a land use of 0.06 m^2/kg.
Fig 4. Comparative Analysis of Environmental Impact

Analysis: The efficiency of using recycled materials and nanofillers in lowering the environmental footprint was evaluated by calculating the percentage change in environmental impact relative to virgin plastic. The use of recycled plastic resulted in a significant reduction of 40% in carbon footprint, a 25% drop in water consumption, and a 20% decrease in land utilization when compared to virgin plastic. In addition, the green nanocomposite exhibited further decreases in its environmental effect, including a 50% drop in carbon footprint, a 40% decrease in water consumption, and a 40% decrease in land use compared to virgin plastic. The results emphasize the considerable environmental advantages of using recycled materials and nanofillers in composite manufacturing, resulting in significant decreases in carbon emissions, water consumption, and land use.

5 Conclusion

This research article has examined the creation of environmentally-friendly nanocomposites via the use of recycled materials and nanofillers. The main areas of investigation are mechanical qualities, durability, recycling effectiveness, and environmental consequences. The findings indicate that the addition of nanofillers to recycled matrix materials may greatly increase the mechanical characteristics of composite materials, leading to enhanced tensile strength, Young's modulus, and impact resistance in comparison to virgin plastic. Nevertheless, the mechanical characteristics of green nanocomposites may deteriorate with time as a result of environmental influences, underscoring the need of continuous monitoring and upkeep to guarantee sustained performance.

Furthermore, the recycling efficacy of waste materials for the production of green nanocomposites was determined to be quite high, with recycled plastic exhibiting a recycling efficacy of 80% and the green nanocomposite obtaining a recycling efficacy of 90%. This demonstrates the practicality of using waste materials as matrix components for creating composites, thereby supporting the ideas of resource conservation and circular economy.

In addition, the environmental impact evaluation showed substantial decreases in carbon footprint, water consumption, and land use linked to green nanocomposites in comparison to virgin plastic. Green nanocomposites provide an environmentally friendly alternative to traditional composite materials by using recycled materials and nanofillers. This helps reduce...
the negative impact of plastic waste on the environment and promotes environmental sustainability.

To summarize, this study emphasizes the capacity of green nanocomposites to serve as a viable and environmentally friendly solution for tackling the environmental issues in the field of materials science and engineering. In order to advance the use of green nanocomposites in various industries and promote sustainability, it is crucial to conduct further research and development to enhance fabrication techniques, increase durability and stability, and minimize environmental impact.

References

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