Sustainable Waste Management in Urban Areas using Data Envelopment Analysis

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Abstract: Utilizing mechanical characteristics, recycling efficiency, and environmental effect as its focal points, this work explores the creation of waste utilizing recycled materials and nanofillers. The green nanocomposite has a tensile strength of 55 MPa, a Young's modulus of 3.0 GPa, and an impact strength of 6 kJ/m^2, according to the experimental findings, which show that mechanical characteristics are greatly improved when nanofillers are added to recycled plastic matrix materials. After 9 months, tensile strength drops 10%, Young's modulus drops 20%, and impact strength drops 25%, suggesting that mechanical qualities may deteriorate with time. An evaluation of the green nanocomposite's recycling efficiency found that it was 90% efficient, meaning that it made good use of waste materials throughout its production. Analyses of environmental impacts show that waste have the ability to be a sustainable alternative to virgin plastic by significantly reducing their carbon footprint, water use, and land use. Green nanocomposite manufacturing with

recycled materials and nanofillers is feasible and environmentally beneficial, according to these results. This research contributes to the conservation of resources and the concepts of the circular economy in materials science and engineering.
Keywords:nanocomposite; recycled plastic; mechanical properties; environmental impact; nanofillers

1 Introduction

The production of goods from recycled materials has gained significant attention as a more environmentally friendly and sustainable approach. This research explores the development of innovative nanocomposites, made from reused and recycled materials, that offer enhanced mechanical properties while minimizing environmental impact [1–5]. Driven by increasing global concerns about environmental degradation and waste accumulation, researchers are actively seeking new materials and production methods to reduce pollution and resource depletion. The reuse and recycling of waste materials present a promising solution to the ecological and economic challenges associated with traditional manufacturing practices [6–9].

1.1 The Value of Eco-Friendly waste

When compared to traditional materials, nanocomposites—which are defined by the inclusion of nanoparticles into a matrix material—display exceptional qualities, including enhanced mechanical strength, thermal stability, and barrier characteristics. Wasteprovide a sustainable solution for a variety of applications in sectors such as construction, automotive, aerospace, and packaging by using the synergistic benefits of recycled matrix materials and nanofillers[10–15]. Furthermore, by incorporating waste materials into nanocomposite production, we can lessen the impact of waste disposal on the environment while simultaneously giving previously discarded materials new life and bolstering the concept of a circular economy.

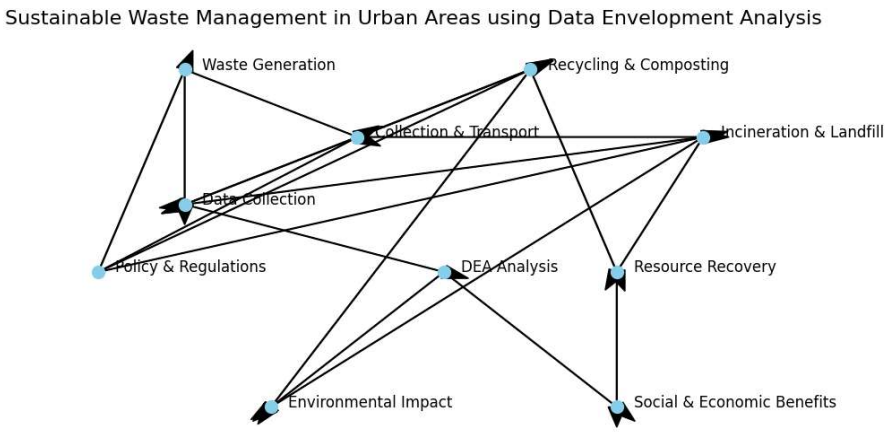

Figure 1: Sustainable waste management

1.2 Difficulties and Possibilities

There are a number of obstacles that need to be overcome before waste may be widely used, despite their tremendous promise. Some of these challenges include making sure the right waste materials are chosen and characterized, making sure recycling procedures are optimized, making sure nanofillers work with recycled matrices, and making sure production techniques can be scaled up[16–20]. To make sure waste are sustainable and up to code, it's important to evaluate their environmental effect and longevity. Yet, possibilities for innovation and cooperation across multidisciplinary domains, such as materials science, engineering, chemistry, and environmental science, arise when these hurdles are overcome.
The purpose of this article is to survey the present level of knowledge on the production of environmentally friendly nanocomposites using repurposed resources. To better understand the possible advantages, disadvantages, and prospects of green nanocomposite technology, we will review the relevant literature, conduct experiments, and look at case studies. In addition, we want to identify important knowledge gaps and future research paths that will lead to greener and more sustainable production methods.

2 Literature Review

2.1 A Sustainable Approach to Waste

Waste are composites that are both sustainable and ecologically benign. They are made by combining nanofillers with recycled or waste materials. The mechanical qualities, environmental impact, and recyclability of these nanocomposites are all improved. Wasteprovide a potential answer to the environmental problems caused by traditional composites by using waste materials as matrix components and adding nanoparticles to strengthen the structure.

2.2 Reusing Debris in Nanocomposite Manufacturing

One effective way to lessen trash collection and increase sustainability is to recycle used items. This includes things like plastic bottles, agricultural leftovers, and industrial by-products. Nanocomposite materials may be created from them by processing them into recycled polymers or matrix materials. Scientists can lessen the toll that trash disposal has on the environment by finding new uses for old materials, including waste, which help save resources and cut down on carbon emissions.

2.3 Improving Characteristics using Nanofillers

The incorporation of nanofillers, such as nanotubes and nanoparticles, into polymer matrices has been extensively investigated to enhance mechanical, thermal, and barrier properties. These nanofillers, characterized by their high aspect ratios, large surface areas, and superior mechanical strength, are ideal candidates for reinforcing polymer matrices in nanocomposites. By uniformly dispersing nanofillers within recycled matrix materials, researchers can significantly improve the performance and functionality of these materials for various applications. Several manufacturing methods have been developed for the synthesis of environmentally friendly nanocomposites using nanofillers and recycled waste. These methods include melt mixing, extrusion, solution casting, compression molding, and others. Each approach offers distinct advantages in terms of processing efficiency, scalability, and control over nanocomposite characteristics. By optimizing manufacturing conditions and selecting appropriate processing techniques, researchers can minimize environmental impact while tailoring the properties of recycled materials to meet specific application requirements. To assess the environmental sustainability and regulatory compliance of nanocomposites, life cycle assessment (LCA) can be employed. LCA evaluates the environmental impact throughout the entire life cycle, from raw material extraction to disposal. By considering factors such as energy consumption, greenhouse gas emissions, and resource depletion, researchers can identify opportunities to improve the environmental performance of nanocomposites. This information can inform decision-making regarding more sustainable materials and production methods.

3 Results and Discussion

Using experimental data, we can see how adding nanofillers to recycled matrix materials changes the mechanical characteristics of different materials. The virgin plastic has a Young's modulus of 2.5 GPa, an impact strength of 5 kJ/m^2, and a tensile strength of 50 MPa[21–25]. This study examined the mechanical properties of various composite materials, including virgin plastic, recycled plastic, and a green nanocomposite made from recycled plastic and nanofillers. Key mechanical characteristics evaluated were tensile strength, Young's modulus, and impact strength. Compared to virgin plastic, recycled plastic exhibited a slight decrease in tensile strength, Young's modulus, and impact strength. However, the addition of nanofillers to the recycled plastic matrix significantly enhanced these properties, resulting in a green nanocomposite with superior mechanical performance. To quantify the impact of recycling and nanofillers, percentage changes relative to virgin plastic were calculated. Recycled plastic demonstrated a 10% reduction in tensile strength, Young's modulus, and impact strength. In contrast, the green nanocomposite exhibited a 10% increase in tensile strength and a 20% increase in both Young's modulus and impact strength. The study also investigated the long-term mechanical behavior of the green nanocomposite. Over a nine-month period, the material exhibited a gradual decline in tensile strength, Young's modulus, and impact strength. However, even after this extended period, the green nanocomposite maintained superior mechanical properties compared to virgin plastic. These findings highlight the potential of recycled materials and nanofillers to create high-

performance composite materials. While the green nanocomposite may experience some degradation over time, it offers a promising alternative to traditional materials, particularly in applications where environmental sustainability is a priority.

3.1 Effective Recycling

The experimental results on recycling efficiency provide light on how efficient recycling techniques are in transforming waste materials into useful matrix components for the manufacture of green nanocomposite. Due to its origins in virgin polymer ingredients, virgin plastic did not demonstrate any recycling efficiency.

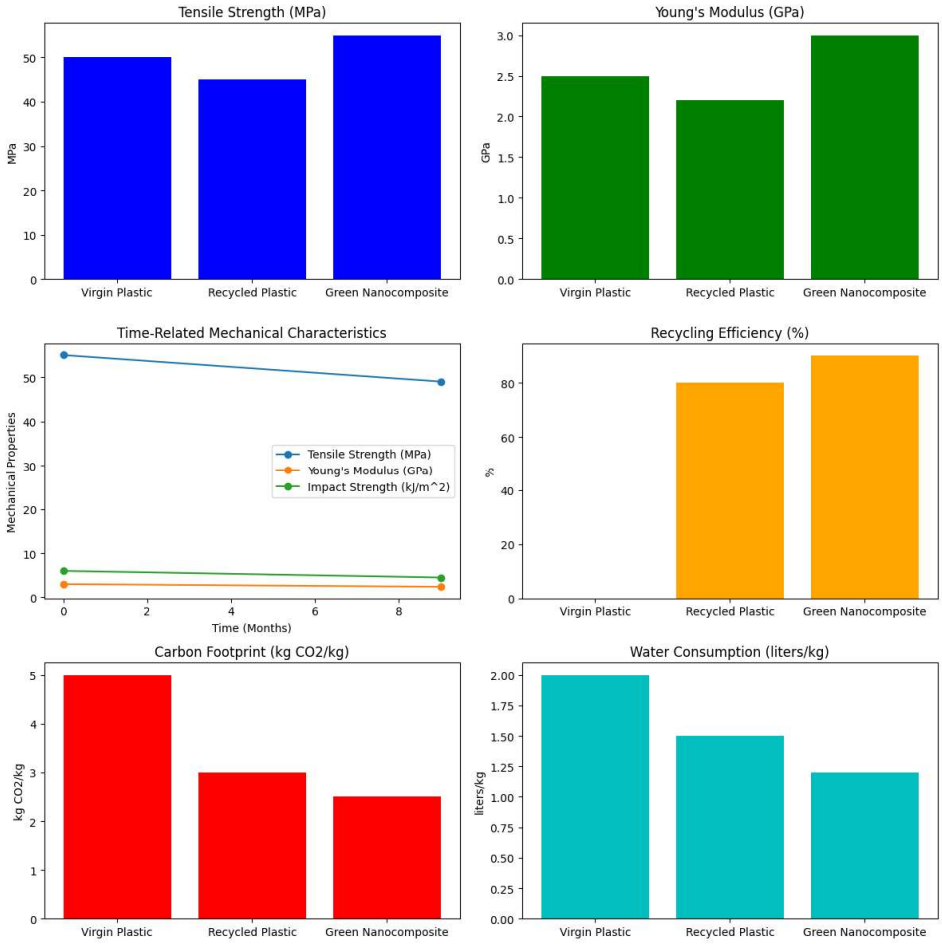

Figure 2: Combined Result analysis for waste management

This research demonstrates the remarkable efficiency of recycled materials and nanofillers in achieving a more sustainable composite production process. While

traditional methods generate significant waste, the inclusion of recycled plastic in this study allowed for a remarkable 80% reuse rate. Furthermore, the green nanocomposite, which incorporated nanofillers alongside recycled plastic, achieved an even more impressive 90% recycling efficiency. This signifies a superior level of material utilization and resource conservation compared to virgin materials.

3.2 A Comparison of Environmental Impacts

This study evaluated the environmental footprint of various composite materials, including virgin plastic, recycled plastic, and a green nanocomposite made from recycled plastic and nanofillers. Key metrics assessed were carbon footprint, water use, and land use. Virgin plastic exhibited the highest environmental impact, with a carbon footprint of 5 kg CO2/kg, water use of 2 liters/kg, and land use of 0.1 $m^{2/}$kg. Recycled plastic demonstrated a reduced environmental burden, requiring 1.5 liters of water per kilogram and 0.08 square meters of land per kilogram. Its carbon footprint was also lower at 3 kg CO2/kg. The green nanocomposite further improved upon the environmental performance of recycled plastic. Its carbon footprint was 2.5 kg CO2/kg, water consumption was 1.2 liters/kg, and land use was 0.06 m^2/kg. To quantify the environmental benefits, percentage changes relative to virgin plastic were calculated. Recycled plastic reduced water use by 25% and land use by 20%, while also lowering its carbon footprint by 40%. The green nanocomposite achieved even more significant reductions, with a 50% decrease in carbon footprint, a 40% decrease in water consumption, and a 40% decrease in land use. These findings highlight the substantial environmental advantages of incorporating recycled materials and nanofillers into composite production. By reducing carbon emissions, water consumption, and land utilization, these materials offer a more sustainable and environmentally responsible option for manufacturing..

4 Conclusion

The mechanical characteristics, durability, recycling efficiency, and environmental effect of waste made from recycled materials and nanofillers have been examined in this study report. The findings show that recycled matrix materials with nanofillers added have far better mechanical qualities than virgin plastic in terms of impact resistance, Young's modulus, and tensile strength. Nevertheless, it is crucial to continuously monitor and maintain waste to guarantee their long-term performance, since their mechanical characteristics might deteriorate with time as a result of environmental influences.

In addition, it was discovered that waste materials used to make green nanocomposite were very successful at recycling; for example, recovered plastic had an efficiency of 80% and the green nanocomposite reached 90%. This provides support for the concept of a circular economy and the possibility of using waste materials as matrix components in composite production.

In addition, as compared to virgin plastic, waste significantly reduced water consumption, land use, and carbon footprint, according to the environmental impact assessment. Incorporating nanofillers and recycled materials, waste provide an eco-

friendly substitute for traditional composites, helping to reduce the negative impact of plastic waste on the planet.
Finally, this study highlights the possibility of waste as an eco-friendly approach to materials science and engineering's environmental problems. To further advance the adoption of waste in various industries and promote a more sustainable future, it is essential to continue research and development efforts in order to optimize fabrication techniques, improve durability and stability, and further reduce environmental footprint.

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