International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Innovative and Cost-Effective Upcycling of Thermoset Plastic Waste for Sustainable Household Furniture Production

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Abstract

The current study aims to address the persistent challenge of recycling thermoset plastics, which are renowned for their inherent properties that render traditional recycling methods impractical. It proposes an innovative solution by repurposing thermoset plastics as reinforcing agents in non-critical load-bearing components of household furniture, thereby reducing reliance on new raw materials. The proposed approach involves customizing furniture designs to integrate upcycled thermoset plastics for reinforcement, departing from conventional recycling practices thereby, mitigating environmental impact and simultaneously offering a practical alternative to traditional recycling methods.

Through the integration of upcycled thermoset plastics into furniture production, this study demonstrates a tangible reduction in the demand for virgin plastic materials. This not only fosters environmental sustainability but also addresses the challenge of managing non-recyclable thermoset waste, contributing to a cleaner environment.

The innovative strategy outlined in this paper not only paves the way for a more eco-friendly and economically viable future in household furniture production but also presents additional ideology for sustainable material utilization and waste reduction, such as exploring composite options like plastic decking using upcycled thermoset plastic and sawdust.

Keywords: Recycle, Upcycled Thermoset Plastics, Household Furniture Production, Environmental Sustainability, Waste Management.

Introduction

The global thrust towards attaining sustainability for a greener and better tomorrow has brought to focus several methods and innovative measures for recycling and upcycling plastics. The goal of waste reduction and resource conservation is gaining more prominence in the current era throughout the industrial fronts. Despite the giant measures taken by the government and private firms across the world to recycle plastics, a recent report published by the Recycling Partnership (2024 [1]), states that in the United States a meagre percentage of 21% of recyclable waste is being recycled, while 3% gets lost at Materials Recovery Facilities (MRF's) and the remaining 76% is lost to the trash in homes. The contemporary world also faces the formidable challenge of recycling thermoset plastics. Unlike thermoplastics, thermoset plastics cannot be easily reprocessed or recycled due to their inherent properties [2]. The chemical nature of the thermoset matrix comprises a three-dimensional crosslink that impedes the process of re-melting by heat or solvent [3]. The difficulty of recycling thermosets is partly attributed to their impressive mechanical and thermal

durability [4] This includes epoxy, a typical thermoset plastic, which makes recycling the composite material [5]. Therefore, the traditional recycling methods fall short, prompting the exploration of alternative solutions.

This paper introduces a novel approach, diverting from conventional recycling, by repurposing thermoset plastics in household furniture production to address this challenge. The reduction in the usage of new raw materials for the production of plastic furniture or goods contributes significantly to the goal of sustainability, Especially, in the case of thermoset plastics, wherein a majority portion is left unrecycled and lost in the landfills [6]. This study proposes the use of thermoset plastics as reinforcing agents in the manufacturing of non-critical load-bearing household furniture such as coffee tables, chairs, stools, and stands. It also briefly sheds light on the characteristics of thermoset plastics along with highlighting the current challenges faced by industries in the process of recycling thermoset plastics. Furthermore, the paper discusses the proposed solutions and demonstrates the simple procedure of preparing a thermoset upcycled plastic chair.

Background

Several studies have investigated varying approaches to upcycle thermoset plastics while mitigating their adverse impacts on the environment. However, thermoset plastics present a prevalent and unique concern in the landscape of recycling plastics, due to their intrinsic properties and chemical characteristics that significantly set them apart from their thermoplastic counterparts [7] [8]. Oladele et al., (2023 [9]) conducted a review study on the modern trends in recycling thermoset plastic waste, the authors conclude that through the incorporation of innovative measures and approaches, these recycled wastes can be used as potential raw materials for product development. While thermoplastics can be recycled through melting and reshaping in multiple cycles without substantial degradation, thermoset plastics undergo an irreversible chemical reaction during curing, resulting in the formation of a three-dimensional network of cross-linked polymer chains. This distinctive molecular structure of thermos set plastics imparts impressive thermal stability, mechanical strength, and chemical resistance, making them indispensable in industries such as automotive, electronics, aerospace, and electrical. Nonetheless, it is these very characteristics that render them virtually non-recycle through conventional means, presenting a pressing and significant hurdle to the efforts of sustainable waste management.

Thermoset plastics comprise a wide range of materials, each customized to fulfill certain application demands and performance specifications. For instance, epoxy resins are well known for their exceptional mechanical strength, chemical resistance, and adhesion, which makes them perfect for application in composite materials, adhesives, and coatings [10]. Contrarily, polyurethanes show remarkable flexibility, and resilience to abrasion, thereby rendering them appropriate for use in a variety of applications, from coatings and sealants to foams and elastomers [11]. Vinyl ester resins, on the other hand, are an increasingly common choice for demanding applications in the infrastructure, chemical processing, and marine sectors due to their exceptional durability and resistance to corrosion [12]. Despite their diverse properties and wide-ranging applications, the non-recyclability of thermoset plastics poses a significant environmental challenge that demands innovative solutions [13].

Since thermoset plastics have an irreversible curing process and a cross-linked molecular structure, traditional recycling techniques like mechanical recycling and pyrolysis have shown to be generally unsuccessful. Polymers that are thermoset cannot be melted or moulded without degrading, therefore mechanical recycling—which entails grinding and melting discarded plastic to create new products—is

not an option for thermoset plastics [14]. Because thermoset plastics are resistant to disintegration and have a high temperature stability, pyrolysis—which is heating plastic trash to high temperatures without oxygen—faces comparable difficulties when working with them to break down polymer chains into smaller molecules [15]. Although it is still in its nascent stages and needs additional resources and study, chemical recycling—which entails dissolving plastic trash into its component monomers or other chemical compounds for reuse—holds promise for some thermoset polymers [16].

In addition to filling up landfills, thermoset plastic waste can have substantial negative effects on the environment by releasing greenhouse gases during disposal, possibly leaking hazardous chemicals, and contaminating soil and water ecosystems [17]. Thermoset plastics are not readily flammable and may produce hazardous byproducts when heated to high temperatures, in contrast to thermoplastics, which may be burned to recover energy or pyrolyzed to create fuel [18]. Extended-term ecological consequences are a pressing concern because of their extended degradation time and resistance to biological degradation, which further increases their environmental persistence [19]. Therefore, tackling the negative effects of thermoset plastic waste on the environment calls for all-encompassing strategies that put an emphasis on prevention, reduction, and sustainable management techniques [20].

Methodology

Proposed Solution and Key Findings

In response to the multifaceted challenges posed by thermoset plastic recycling, an innovative and integrated approach is proposed to repurpose these materials in the production of household furniture. This approach involves leveraging advances in material science, design optimization, and manufacturing innovation to develop novel techniques for incorporating upcycled thermoset plastics into furniture components. By carefully selecting suitable thermoset plastic waste streams, processing them to remove impurities, and integrating them into household furniture designs as reinforcing agents, this solution aims to maximize resource efficiency, minimize environmental impact, and enhance product performance. Along with the substantial reduction of reliance on new raw materials, this approach addresses critical sustainability challenges in terms of material cost savings, waste diversion, energy efficiency, and product durability, underscoring its potential.

An important aspect of the proposed solution is ensuring the compatibility and performance of upcycled thermoset plastics in furniture applications. This involves conducting comprehensive material testing and analysis to assess factors such as mechanical strength, durability, fire resistance, and chemical stability. By evaluating the properties of both the thermoset plastics and the furniture components, the potential challenges and opportunities for optimization can be identified. Moreover, studying the long-term performance and environmental impact of furniture made with upcycled thermoset plastics is essential for validating the sustainability and viability of the proposed solution. Through iterative experimentation, modelling, and validation, the design and manufacturing processes to achieve optimal outcomes in terms of performance, durability, and environmental impact can be iteratively refined.

Procedure to Prepare a Thermoset Upcycled Plastic Chair

The procedure for preparing a thermoset upcycled plastic chair involves a series of meticulous steps aimed at integrating reclaimed thermoset plastics into the furniture design. Suitable thermoset plastic waste is identified, collected, and processed to remove contaminants and prepare it for incorporation into the chair structure. Primarily, thermoset plastic waste must be collected and sorted according to size and shape,

following which without the usage of any chemical procedures, these wastes must be crushed mechanically into small and uniform shapes, while ensuring that no toxic gases are emitted. These crushed pieces must then be fed into a grinder machine, possibly an automatic conveyor system and the ground powder must be collected from the outlet of the grinder without spillage.

Next, the chair design is carefully modified to accommodate the addition of thermoset plastic reinforcements, ensuring compatibility with existing manufacturing processes and product specifications. This may entail adjustments to the geometry, composition, and assembly methods of the chair components to optimize performance, aesthetics, and sustainability. The ground thermoset plastic powder can be combined with a binding agent in a mould hopper and mixed with thermoplastic virgin material in equal proportions. It can be used effectively to enhance the bearing capacity of household furniture. Subsequently, the upcycled thermoset plastics are seamlessly integrated into the chair assembly, enhancing its structural integrity, durability, and environmental credentials. Through rigorous testing, validation, and quality control measures, manufacturers can ensure that the finished products meet or exceed industry standards for safety, performance, and sustainability.

Conclusion

In conclusion, this paper offers a promising innovative approach to the challenge of thermoset plastic recycling. The repurposing of these non-recyclable materials in household furniture production, not only mitigates the environmental impact of thermoset plastic waste but also promotes resource conservation and sustainability. Through collaboration between industries and researchers, this approach can be further refined and scaled up to realize its full potential in addressing the broader issue of plastic waste management. By harnessing the collective commitment, the way towards a more sustainable and circular economy can be paved, where waste becomes a valuable resource rather than a burden. In the future, there are several avenues for expanding and refining the use of upcycled thermoset plastics in various applications. Beyond household furniture, composite materials incorporating thermoset plastics could be explored for use in decking, construction materials, automotive components, and more. Additionally, continued research and development efforts are needed to optimize recycling processes, identify new

sources of thermoset plastic waste, and explore innovative manufacturing techniques. By leveraging advances in materials science, engineering, and sustainability, new opportunities for waste reduction, resource conservation, and environmental stewardship can be ventured.

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