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A REVIEW ON 3D PRINTING WITH RECYCLED MATERIALS

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ABSTRACT
The research explores the intersection of 3D printing and polymer recycling, focusing on sustainable practices and innovative waste management solutions. Studies examine using recycled polymers in 3D printing, improving mechanical properties, and assessing environmental impacts. The goal is to address plastic waste challenges and promote a circular economy. Researchers investigate approaches like blending with elastomers, metal powder reinforcement, and distributed recycling schemes. Findings show feasibility of using recycled materials for high-quality products while reducing waste and conserving resources. The research evaluates process parameters' impact on printed parts' mechanical behavior, highlighting optimization importance. Closed-loop recycling systems' benefits are also showcased, including cost savings, resource conservation, and customized on-demand production. Overall, the research contributes to sustainable additive manufacturing practices, paving the way for environmentally conscious production methods and a more circular economy.
Keywords: Additive Manufacturing, 3-D Printing, Recycled Material’s, Polymer, Fused Deposition Modeling.

I. Introduction

Additive manufacturing (AM) with recycled materials, also known as 3D printing, offers a sustainable solution to the world's plastic crisis. This innovative technology transforms discarded plastics into valuable resources, reducing waste and promoting a circular economy. AM involves creating three-dimensional solid objects from digital files by adding materials layer by layer, using various recycled materials such as plastics, metals, ceramics, and biomaterials. Using recycled materials in AM provides several benefits, including reduced waste and environmental impact, conservation of natural resources, lower material costs, unique material properties, and closed-loop production cycles. Various types of AM with recycled materials exist, including Recycled Plastic Fused Deposition Modeling, Recycled Metal Powder Bed Fusion, and Hybrid Recycled Material AM. This pioneering technology has the potential to revolutionize industries and empower individuals to contribute to a more environmentally conscious future. By harnessing the power of AM with recycled materials, we can create a more sustainable world and mitigate the plastic crisis.

II. Literature

A Review On 3d Printing With Recycled Materials, It’s Process and applications in various sectors, advantages, disadvantages, future scope we studied some of the journal papers and mentioned them, below:
Ans Al Rashid, et.al., [1] The growing demand for polymer-based products has severe consequences, but Additive Manufacturing (AM) or 3D printing offers a solution by using recycled polymers to fabricate functional parts, reducing lead times and research costs. This study reviews the use of recycled polymers in AM, exploring various commodity polymers, recycling challenges, and approaches, and presents a circular economy model for sustainable practices. By adopting AM, we can mitigate the impacts of polymer usage and promote eco-friendly production methods. The conventional AM process uses virgin materials, but recycled materials can be used instead, producing filaments from polymeric materials and fabricating functional components. The functionality of 3D-printed parts is crucial, and predicting their response to external stimuli can enhance sustainability. Collaboration between governments, industries, and individuals is necessary to reduce plastic waste,

increase recycling, and adopt sustainable practices, mitigating environmental impacts and creating a more sustainable future. AM offers a promising solution to reuse polymer waste, contributing to a circular economy.
Mattew A. Olawumi et.al., [2] This research paper explores the potential of combining these technologies, analyzing their synergistic effects, and evaluating the printability of recycled materials. By embracing sustainable practices, industry collaboration, and innovation, this convergence can pave the way for a more sustainable future, prioritizing resource conservation, circularity, and customized production. Recognizing the need for sustainability, researchers have turned to recycling with 3D printing. This convergence holds immense potential for promoting sustainability and encouraging collaboration between industries. The research methodology involved selecting materials, experimental setup, and printing parameters to explore the potential of 3D printing and recycling. Plastics like PET, ABS, and PLA were chosen due to their recyclability and widespread use. The study aims to drive the adoption of recycled materials in 3D printing, contributing to a more sustainable and circular economy. By leveraging expertise and pushing boundaries, we can collectively advance sustainable manufacturing practices. The research provides valuable insights into the challenges, opportunities, and future directions of recycled 3D printing, paving the way for a more sustainable future.
Laszlo Toth et.al., [3] Researchers extruded filaments from blends of recycled poly(ethylene terephthalate) (RPET) and ethylene-butyl-acrylate-glycidyl-methacrylate (EBA-GMA) with varying EBA-GMA content, then 3D printed specimens using fused filament fabrication technology. The results showed significant improvements in impact strength, with a 2.5-fold increase in unnotched impact strength and a fold increase in notched impact strength at 15 wt% EBA-GMA content. However, the strain at break and tensile strength of the filaments were higher than those of the 3D-printed specimens due to increased shrinkage and porosity. The flexural strength of the 3D-printed specimens reached 40-60% of the values of injection-molded samples. This method enables the production of parts with arbitrary geometry and balanced mechanical properties from RPET. The study demonstrates the potential of using recycled PET and reactive elastomers to create high-quality 3D-printed products, addressing the challenges of recycling lower-quality plastic waste. The addition of EBA-GMA improves the mechanical properties of RPET, making it suitable for various applications. The research highlights the importance of converting plastic waste into value-added feedstock, which may be more significant than short-term costs.
Dan Ioan Stoia et.al., [4] Fused Deposition Modeling (FDM) is a popular 3D printing technique, and researchers have extensively studied the factors influencing the mechanical behavior of printed parts. However, some process parameters, such as extruder temperature, platform temperature, and cooling, are less analyzed. These parameters can affect the crystallinity of the polymer and the adhesion between consecutive traces, ultimately impacting the mechanical properties of the printed material. The study investigates the mechanical behavior of PLA in tensile testing under different conditions, including raw filament, air-extruded filament, and printed samples with varying numbers of deposition traces. The results show that printed samples have lower mechanical properties compared to raw filament, with the best results obtained for raw material. The study also finds that the crystallinity of the raw filament is higher than that of extruded PLA, which has a higher percentage of amorphous zones. Differential Scanning Calorimetry (DSC) analysis supports the mechanical properties determined by tensile testing. The research highlights the importance of understanding the interactions between process parameters and their impact on the mechanical behavior of 3D printed materials. By optimizing these parameters, researchers can improve the quality and properties of printed parts, leading to wider adoption of FDM technology in various industries.
Tiago EP Gomes et.al., [5] The world is facing a plastic waste management crisis, and creating circular flows of material is crucial to mitigate its environmental, health, social, and economic consequences. The study identifies research gaps and opportunities, highlighting the need for further testing of parameters, development of in-situ compounding, and exploration of modification techniques. The

review also suggests researching how distributed recycling schemes can cope with higher material variety and identifying case studies for real-world application. The ultimate goal is to provide guidance for practitioners and researchers on modifying recycled materials to achieve intended properties and to identify paths for future research. The study's systematic search methodology and qualitative analysis contribute to the understanding of distributed recycling's potential and limitations, paving the way for more sustainable production, usage, and end-of-life management solutions.

Nithar Ranjan Madhu et.al., [6] The widespread use of plastics has led to significant environmental pollution, with only a small portion of plastic waste being recycled. Plastic pyrolysis and polymer breakdown are hazardous to the environment, making processing necessary for recycling. Fused Deposition Modeling (FDM) is a popular additive manufacturing technique that uses melt extrusion to deposit thermal polymers in a predetermined pattern. This study explores the use of recyclable polymers in 3D printing for waste material management. Plastic recycling has become a major challenge in environmental preservation and waste management, with plastics taking between 10 to 450 years to degrade. Historically, recycling has been done through large centralized factories, but there is a need for more sustainable and cost-effective solutions. This paper discusses the use of reusable and biodegradable materials for FDM, focusing on sustainability and exploring alternatives to non-biodegradable materials. The study also highlights the importance of recycling and the potential of 3D printing in reducing material waste. The methodology involves pyrolysis and chemical recycling of municipal plastic waste, with a focus on separating mixed polymers and recovering purified resin. The conclusion emphasizes the need for environmentally friendly and cost-effective materials, highlighting the potential of recyclable polymers in 3D printing.

Malik Hassan et.al., [7] This review paper explores the integration of 3D printing, upcycling of recycled plastics, and the utilization of waste biomass in sustainable composites. Despite numerous studies on recycling techniques and 3D printing, there is a gap in comprehensive reviews addressing this integration. The paper aims to bridge this gap by examining the potential of 3D printing technology in upcycling plastic waste and creating sustainable composites. The review highlights the importance of optimizing printing parameters to achieve improved mechanical performance and identifies research gaps. It proposes the integration of machine learning and artificial intelligence for enhanced process control and material development. The paper concludes that 3D printing plays a transformative role in upcycling waste plastics and biomasses, offering significant advantages in sustainable manufacturing practices. Researchers have successfully demonstrated the extrusion of recycled plastics and sustainable composites into feedstock for 3D printing, showcasing comparable or improved mechanical properties. Recycling waste plastics for 3D printing reduces embodied energy, although trade-offs and limitations may exist in certain properties. Overall, the paper contributes to the advancement of sustainable waste management and the adoption of 3D printing technology in creating value-added products from waste plastics and biomasses.

Bankole I. Oladapo et.al., [8] As concerns about climate change and resource scarcity grow, sustainable practices in manufacturing are becoming increasingly important. 3D printing has the potential to mitigate environmental impacts by reducing material waste and enabling decentralized production. Recycling 3D printing filaments can reduce plastic waste, but challenges exist in achieving net zero. A holistic approach considering the entire lifecycle of the filament is necessary. Standardizing materials, improving recycling processes, creating a market for recycled filaments, adopting a closed-loop system, and raising awareness and education can help the 3D printing industry move towards a more sustainable and circular future. Achieving net zero on 3D printing filament recycling requires a comprehensive understanding of the environmental and economic impacts of the entire lifecycle of the filament. By addressing these challenges, 3D printing can become a more sustainable and environmentally friendly technology. The research explores the concept of achieving net zero on 3D printing filament recycling, focusing on sustainable analysis and providing recommendations for improving sustainability.

Kautilya S. Patel et.al., [9] This paper reviews the advancements in 3D printing using plastic waste, focusing on fused deposition modeling (FDM) and selective laser sintering (SLS) printing methods for carbon fiber composites. The study highlights the importance of materials in the 3D printing process, particularly in producing non-recyclable plastics. The paper explores the impact of 3D printing on the environment through the recycling of plastic waste and demonstrates the potential of turning 3D printing plastic waste into durable, functional objects while minimizing its environmental impact. The study also discusses the challenges of manufacturing carbon fiber-containing plastic waste filaments, such as selecting suitable plastic types and complex carbonization processes. The paper concludes by emphasizing the need for researching novel biodegradable and renewable materials to enhance the sustainability of 3D printing with plastic composites, reducing greenhouse gas emissions, and promoting the circular economy through efficient recycling methods and closed-loop systems.

Mark Keanu James E. Exconde et.al., [10] The demand for sustainable alternative materials for 3D printer filaments is increasing. This study focuses on selecting materials for 3D printer filaments from virgin polymer resins and recycled post-consumer plastics. The selection process considered various properties such as tensile strength, melting point, glass transition temperature, melt flow index, coefficient of thermal expansion, and cost. The ELECTRE multiple criteria decision method was used to evaluate alternatives including virgin LDPE, HDPE, PET, and recycled HDPE and PET. The results showed that melting point and melt flow index were the most significant parameters in the extrusion process. Among the alternatives, virgin LDPE ranked highest, followed by recycled PET, which showed potential as a sustainable alternative filament for 3D printing. The study demonstrates the feasibility of using recycled plastics as a sustainable alternative for 3D printer filaments, reducing the need for virgin materials and promoting a circular economy. The research provides a framework for material selection in 3D printing, considering both technical and economic factors, and highlights the potential of recycled plastics in reducing environmental impacts.

S.M. Al-Salem et.al., [11] Plastic solid waste (PSW) poses significant challenges and opportunities for societies. This paper reviews recent progress in PSW recycling and recovery, focusing on polyolefinic sources, which dominate single-use plastic products. Four treatment routes are discussed: primary (re-extrusion), secondary (mechanical), tertiary (chemical), and quaternary (energy recovery) schemes. Primary recycling is rarely applied among recyclers due to quality issues, while secondary schemes are well-established. Tertiary and quaternary treatments appear robust and worthy of further investigation. Mechanical recycling involves cutting, contaminant separation, floating, milling, washing, drying, agglutination, extrusion, and quenching. However, this process is costly and energy-intensive. The paper concludes that reusing and reducing single-life polymeric materials can benefit the current situation. Recycling and energy recovery methods should be considered in plastic manufacturing and converting facilities. Further research and development are needed for tertiary and quaternary technologies. The study highlights the importance of addressing PSW challenges through innovative recycling and recovery solutions. By exploring various treatment routes and technologies, we can move towards a more sustainable and circular economy for plastics.

Pouyan Ghabez et.al., [12] Transforming waste polypropylene (PP) and waste carbon fiber into upcycled composite materials for additive manufacturing represents a significant circular economy challenge. This study investigates the mechanical properties of recycled PP and carbon fiber composites used in material extrusion (MEX) 3D printing. The results show a decrease in mechanical properties due to thermal processes during filament making and 3D printing. The study used a Creality Smart-10 3D printer to print reinforced filaments containing short carbon fibers and tuned nozzle size and temperature settings for optimal extrusion consistency and material flow. The findings indicate that carbon fibers improved filament consolidation and reduced die swell, critical for uniformity and desired mechanical properties in the final printed products. The research demonstrates the potential for upcycling waste materials into valuable composite materials for 3D printing, aligning with the

principles of the circular economy. However, further research is needed to optimize the process and improve the mechanical properties of the final products.
Ans Al Rashid et.al., [13] The surge in plastic usage has led to a significant challenge in managing end-of-life plastic waste, with millions of tons of plastic waste produced annually ending up in landfills and posing severe threats to ecosystems. This study explores innovative solutions to reuse, recycle, and repurpose plastic waste, promoting sustainable production and consumption aligned with circular economy practices. The research focuses on converting plastic waste into additive manufacturing (AM) feedstock using a 3D-printed custom setup. The results show promising outcomes, with the successful production of recycled PET (rPET) and rPET/PA6-CF composite filaments. The study demonstrates a straightforward production route to upcycle plastic waste into valuable AM feedstock, contributing to the advancement of circular economy practices. However, further research is needed to optimize the 3D printing process parameters for a broader portfolio of recycled materials. The study highlights the potential for innovative solutions to address global plastic waste challenges, promoting sustainable production and consumption practices.
Kevin R. Hart et.al., [14] Millions of Meals Ready to Eat (MREs) are consumed annually by soldiers, generating thousands of tons of residual polymeric packaging waste. This study demonstrates a recycling protocol for MRE pouch materials through compounding, filament extrusion, and fused filament fabrication (FFF) additive manufacturing. The mechanical and barrier properties of the additively manufactured structures were found to be comparable to the native pouch materials. The study shows minimal effects of the manufacturing process on critical thermal transitions in the polymer. The economics and viability of on-demand reconstitution using these methods are discussed, revealing multiple benefits of this recycling process. The study highlights the potential for on-site reclamation and re-purposing of MRE pouch waste into functional materials for military use, particularly in frontline applications where resupply of materials is limited. The technology can also be applied to other missions with similar requirements, such as manned space travel. The research demonstrates a sustainable solution for managing MRE packaging waste, reducing the environmental impact of military operations, and promoting resource efficiency.

Emily J. Hunta et.al., [15] A recycling code model based on China's resin identification codes is proposed to expand distributed recycling of polymers and manufacturing of plastic-based 3-D printed products. The model uses five classifications of post-consumer plastic and can be expanded as new materials are developed. Open SCAD scripts were created to print resin identification codes into products, and the system was demonstrated in various products and polymer materials. The study concludes that the developed recycling code model and Open SCAD scripts can facilitate widespread adoption of distributed manufacturing with 3-D printing. Future work includes outlining software changes to enable lateral scaling and widespread adoption. The study promotes sustainable production and consumption practices, reducing the environmental impact of plastic waste.
Bupe G Mwanza et.al., [16] The study highlights the importance of sustainable waste management, particularly in urban areas where municipalities struggle to collect and dispose of increasing amounts of waste. Plastic waste is a significant component of municipal solid waste, and its management is crucial due to its environmental impacts. The study analyzed various factors influencing solid waste recycling and management at the household level, including economic incentives, awareness, education, and social attitudes. The results show that a combination of these factors can promote sustainable recycling practices. The study concludes that sustainable recycling of post-consumer packaging plastic waste can contribute to sustainable development by reducing oil usage, carbon dioxide emissions, and waste disposal quantities. The identified drivers can be applied to develop effective recycling systems, making plastic waste an economically viable, environmentally acceptable, and socially acceptable resource. Closing the loop by leveraging these factors can promote sustainable development and profitable recycling practices.

Weihao Liu et.al., [17] A novel recycling approach using additive manufacturing is presented to reclaim carbon fiber reinforced polymer (CFRP) waste and re-manufacture high-performance composite parts. CFRP waste is generated annually due to difficulties in recycling. The filaments are then used to fabricate 3D printed composite parts with complex geometries. The results show that this approach offers a possible strategy to recycle CFRP waste and produce economical and environmentally friendly engineering parts. The process involves two steps: reclamation of carbon fibers from CFRP waste and production of recycled carbon fiber reinforced polymer (rCFRP). The approach can be adapted to recycle other similar composite waste, promoting environmental sustainability.

Shirun Ding et.al., [18] This study investigates the formation mechanisms of ultrafine particles (UFP) and volatile organic compounds (VOC) emitted during fused deposition modeling (FDM) 3D printing. The researchers propose a TVOC measurement method based on weight loss and find that TVOC mass yield varies significantly among different polymer filaments, with PLA, ABS, and PVA emitting 0.03%, 0.21%, and 2.14% TVOC, respectively, at 220°C. The study also explores the thermal decomposition rates and products of filaments during the 3D printing process, providing insights into emission formation mechanisms. Laser imaging is used to visualize TVOC emission formation, and gas analysis characterizes emissions through controlled thermal decomposition of polymer filaments. The results show that emissions initiate at the beginning of the glass transition process and peak during liquefaction. The study concludes that UFP mass accounts for 1% to 5% of TVOC mass, depending on the filament type, and highlights the importance of understanding emission formation mechanisms to develop effective control methods, such as UFP filtration and VOC absorption. The research contributes to the development of sustainable and healthy 3D printing practices.

Rupinder Singh et.al., [19] This study explores the recycling of plastic waste by reinforcing polymers with metal powder, specifically iron (Fe) powder, to create a valuable material for structural applications. The research focuses on High-Density Polyethylene (HDPE) and Low-Density Polyethylene (LDPE), which do not decompose naturally, making them suitable for applications like beams and reinforced concrete structures. The study uses a single screw extruder machine to recycle the plastic waste, controlling the melt flow index (MFI) by adjusting parameters like barrel temperature, die temperature, and screw speed. The results show that reinforcing HDPE and LDPE with Fe powder enhances their mechanical properties, such as peak elongation, break strength, and Shore D hardness. The study concludes that polymer waste can be successfully used for structural engineering applications by preparing filament wire with screw extrusion and metal powder reinforcement. The optimal composition is 90% HDPE and 10% Fe powder, which exhibits improved mechanical properties and lowest porosity. This research contributes to the development of sustainable and innovative solutions for plastic waste management, providing a valuable resource for future researchers.

Narinder Singh et.al., [20] The research highlights the need for effective recycling and management techniques to reduce the use of virgin materials and mitigate environmental concerns. Froth flotation is identified as a major and efficient separation method for mixed plastics, using wetting agents like calcium lignin sulfonate and frothing agents like pine oil and MIBC. The study concludes that decreasing the use of virgin materials and reusing PSW can contribute to environmental sustainability and help address global warming. Landfilling, the easiest option for discarding PSW, is increasingly contributing to global issues and space requirements. The research presents various separation and identification techniques for PSW, including froth flotation and MDS, to promote sustainable waste management practices.

Peng Zhao et.al., [21] This study investigates the potential of close-looped recycling of polylactic acid (PLA) used in 3D printing, focusing on material properties and environmental performance. The research involves extruding PLA into filament, 3D printing, shredding, and re-extruding for repeated cycles. The results indicate that repeated 3D printing cycles can only last for two cycles due to

significant deteriorations in viscosity, making the material unsuitable for further reprocessing. Mechanical performance deteriorates slightly, while rheological properties decrease significantly, leading to losses in molecular weights and compromised thermal stability. The study concludes that the number of reprocessing cycles is limited due to thermomechanical deteriorations, but can be remediated by adding virgin PLA. Future research should focus on a comprehensive study of the thermomechanical degradation mechanism of 3D printing. The study highlights the potential of close-looped recycling in reducing environmental burdens and promoting sustainable 3D printing practices.
Peng Wu et.al., [22] The construction industry faces significant environmental and productivity challenges, consuming substantial resources and experiencing poor labor productivity. 3-D printing technology has been gaining rapid development and adoption in the industry, offering benefits such as increased customization, reduced construction time, manpower, and cost. This study provides a critical review of the history and current development of 3-D printing in construction, highlighting its potential to address industry challenges. The research focuses on selective laser sintering (SLS), a layer manufacturing process that consolidates successive layers of powder material using a focused laser beam. The study concludes that the use of 3-D printing in construction depends on factors such as printing accuracy, material availability, cost, and time. Various 3-D printing technologies, including SLS, stereo lithography, fused deposition modeling, inkjet powder printing, selective heating sintering, and contour crafting, can be chosen based on these factors. The study suggests that 3-D printing can bring significant benefits to the construction industry, including improved productivity, reduced environmental impact, and increased customization.
Feng Zhang et.al., [23] The fabrication and assembly of electrodes and electrolytes are crucial for the performance of electrochemical energy storage (EES) devices like batteries and supercapacitors. Traditional techniques have limitations in controlling geometry and architecture, compromising performance. 3D printing has emerged as an innovative approach to fabricate EES devices, offering precise control over device geometry and structure, enhancing specific energy and power densities. This study explores the potential of 3D printing techniques, including inkjet printing, direct ink writing, and nano printing, in fabricating EES devices. Stereolithography (SLA) is highlighted as a 3D printing process that solidifies photocurable resin using light, enabling the production of fine structures. Variants like mask projection SLA (MPSL) and two-photon SLA offer faster building speeds and finer features. The study concludes that inkjet printing has great potential in engineering electrode structures, improving rate capability and areal energy density of batteries. 3D printing offers a flexible, efficient, and economical approach to fabricate EES devices, addressing limitations of traditional techniques and enhancing device performance.

Katarzyna Mikula et.al., [24] The issue of plastic recycling has become a leading environmental concern, with polymer materials being widely used in daily life and industry. The problem of plastic waste has emerged, and the possibility of reusing polymeric materials offers a solution through valorization and effective waste utilization. The growing 3D printing market presents an opportunity for using recycled thermoplastic materials to create printable filaments. This study reviews the potential for reusing polymeric materials in 3D printing, focusing on recycling, commercial solutions, and promotional programs. The circular economy concept, based on the 3Rs (Reduce, Reuse, Recycle) and broader 6Rs (including Recover, Redesign, and Remanufacture), is explored. Plastics, versatile but non-biodegradable, require processing to mitigate environmental hazards. Recycling is identified as the most advantageous method for valorizing post-consumer plastics, aligning with the circular economy concept. Traditional centralized recycling plants have high transportation costs, but 3D printing enables alternative approaches. By promoting the reuse of waste materials, 3D printing can contribute to a more sustainable and closed-loop system, reducing environmental pollution and waste management issues.
Esmaeil Ahmadinia et.al., [25] This study investigates the effect of incorporating waste plastic bottles (Polyethylene Terephthalate, PET) on the engineering properties of stone mastic asphalt (SMA)

mixture. The results show that adding PET has a significant positive impact on SMA's properties, promoting the reuse of waste materials in an environmentally friendly and economical way. The study finds that the Marshall Stability value increases with PET content up to 6% and then decreases. The values are generally higher than the control mix, except for the mixture with 10% PET. The research concludes that using PET as an additive for SMA can make road construction and pavement projects more economical while addressing environmental problems like solid waste disposal. The study's findings encourage the reuse of waste materials in the industry, contributing to a more sustainable and environmentally friendly approach. By utilizing waste polymers like PET, the cost of polymer-modified asphalt mixtures can be reduced, making them more convenient for paving roads.
John Ryan C. Dizon et.al., [26] The review raises important questions for standardizing mechanical test methods. AM technologies, materials, and polymerization methods are overviewed, and the mechanical properties of 3D-printed parts produced by various AM methods are discussed, including tensile strength, stiffness, bending, compression, fatigue, impact, and cryogenic temperature properties. The effects of nanofiller additions are also briefly discussed. The study concludes that AM technologies and polymer materials are advancing rapidly, enabling the production of high-quality prints with a wide range of properties. Standardization of mechanical test methods is crucial to ensure the quality and reliability of 3D-printed parts. The review provides a comprehensive overview of the current state of AM technologies and mechanical properties of 3D-printed polymer parts, highlighting the need for further research and standardization.
Kazem Fayazbakhsh et.al., [27] The research follows ASTM D638-14 standards and evaluates specimens along and transverse to the printing direction. The results show anisotropic behavior, with tensile strength varying significantly depending on the loading direction. The study finds that specimens loaded along the printing direction have a tensile strength of 57.7 MPa, while those loaded perpendicular to the printing direction have a tensile strength of 30.8 MPa. The research aims to provide input data for Finite Element (FE) simulation and verification. The study highlights the importance of considering manufacturing process and design parameters, such as build orientation, raster angle, and layer thickness, in determining the mechanical performance of FFF 3D printed parts. The research concludes that a systematic approach is necessary to characterize 3D printed materials and investigate their directional properties. The findings have implications for optimizing 3D printing processes and designing complex components with specific mechanical requirements.

Shan Zhong et.al., [28] This study explores the potential of distributed plastic recycling and manufacturing using a recyclebot and a self-replicating rapid prototyper (RepRap) 3-D printer. The combined process upcycles plastic waste into 3-D printing filament, reducing embodied energy by half and production costs to pennies. The research monitors electrical energy consumption and conducts an economic evaluation, comparing the results to traditional recycling and manufacturing methods. The study finds that the coupled distributed recycling and manufacturing method supports the circular economy, conserves energy, mitigates greenhouse gas emissions, and benefits consumers economically. The recyclebot ac4.0 is used to extrude filament with a consistent diameter, and the results show that the recycled filament is slightly larger than commercial filament but still within tolerance. The case studies demonstrate significant energy savings and economic benefits, encouraging the adoption of circular economic practices. By tightening the recycling and production loops, this method supports the circular economy and promotes sustainability. The research highlights the potential of distributed recycling and manufacturing to transform the way we produce and consume products, reducing waste and environmental impact while promoting economic stability.
Bankole I. Oladapo et.al., [29] The COVID-19 pandemic has highlighted the need for essential medical equipment, including personal protective equipment (PPE) and ventilators. With no specific licensed drugs or vaccines available, additive manufacturing (AM)/3D printing has emerged as a crucial technology to combat the pandemic. The pandemic has created a shortage of medical devices, and AM applications can help meet this demand. The study discusses the use of 3D printing to produce PPE,

such as face masks and ventilators, and highlights the importance of evaluating the biological safety of these products. The research emphasizes the need for compliance with ethical regulatory directives and safety standards. The study concludes that AM/3D printing technology can help reduce the spread of respiratory illnesses and prepare for future pandemics. The technology can ensure the rapid production and distribution of essential medical equipment, including antibacterial bio-cellulose masks and ventilators, to patients and healthcare professionals. By leveraging AM/3D printing, we can better respond to the COVID-19 pandemic and future viral outbreaks, ultimately saving lives and mitigating the economic and social impacts of such events.
Xing Guan Zhao et.al., [30] This study investigates the adhesion behavior of polydopamine (PDA) coatings on polylactic acid (PLA) pellets used in 3D printing. PDA was synthesized and used to coat PLA specimens, which were then evaluated for mechanical properties through tensile tests. The results show that the mechanical properties of recycled PLA specimens with PDA coating have been improved. The study aims to advance knowledge on the adhesion behavior of PDA coatings on PLA pellets and explore its potential applications in 3D printing and injection molding. The study contributes to the development of sustainable and innovative manufacturing technologies, particularly in the field of 3D printing, where the use of recycled materials and enhanced mechanical properties are crucial. By understanding the adhesion behavior of PDA coatings on PLA pellets, this research opens up new possibilities for improving the performance of 3D printed objects and expanding the applications of PLA in various industries.
Anant Prakash Agrawal Prabhu Paramasivam et.al., [31] This study investigates the effects of infill patterns, infill densities, and layer thicknesses on the mechanical properties of 3D printed ABS materials using Fused Filament Fabrication (FFF) technology. The results show that the concentric infill pattern with 80% infill density and 100 µm layer thickness yields the best mechanical properties, with 123% and 115% higher tensile strength and 168% and 80% higher impact strength compared to line and triangle patterns, respectively. The findings suggest that the concentric pattern with higher elongation at break percentage exhibits higher ductility and is more likely to deform before fracturing under tensile load. The study concludes that the loading capacity and mechanical strength of 3D printed samples are influenced by the number of layers deposited, and an increase in layers leads to a corresponding rise in overall strength. The research contributes to the understanding of the relationships between process parameters and mechanical properties in 3D printing, enabling the optimization of additive manufacturing techniques for various industrial applications.

Bankole I. Oladapo et.al., [32] This study investigates the development of 3D printed scaffolds using poly(lactic acid) (PLA) filaments with 5% and 20% carbon apatite (cHA) for bone regeneration. The scaffolds were characterized using Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray (EDX) techniques, showing good load dispersion. The results demonstrate that the incorporation of cHA improves the mechanical properties of the scaffolds. The study highlights the potential of PLA/cHA composites for bone tissue engineering applications. The scaffolds exhibited a porosity percentage of approximately 62% and 41% for 5% and 20% cHA, respectively, making them suitable for cell growth and tissue regeneration. The research contributes to the development of biomaterials engineered with biological systems for medical purposes, particularly in the field of bone regeneration. The findings have implications for biomaterial industries, enabling the creation of innovative materials for tissue engineering applications. The study demonstrates the potential of 3D printing technology in producing customized scaffolds with tailored properties for specific medical applications.
Bankole I. Oladapo et.al., [33] This study aimed to manufacture and characterize 3D-printed poly(lactic acid)/carbonated hydroxyapatite (PLA/cHA) scaffolds for bone tissue regeneration. The degradation tests confirmed the release of calcium and phosphorus from the composites, indicating their potential for bone regeneration. The study demonstrated the viability of producing PLA/cHA composite scaffolds, particularly with a 10% cHA proportion, which showed promising results for bone regeneration applications. The research highlights the potential of 3D printing technology in

producing customized scaffolds with tailored properties for specific medical applications. The study contributes to the advancement of biomaterials research, providing new insights into the design and production of hybrid nanocomposites for medical applications.
Narinder Singh et.al., [34] This research focuses on developing an in-house feedstock filament wire made from recycled polymer waste, specifically high-density polyethylene (HDPE), reinforced with SiC/Al2O3 ceramic particles. The goal is to create a sustainable and low-cost material for additive manufacturing (FDM/3D printing) and rapid tooling applications. The process involves collecting waste HDPE, manual segregation of contaminants, and blending with ceramic particles in various proportions. Rheological and thermal properties, such as melt flow index (MFI), melting temperature, decomposition, and enthalpy, were evaluated. The results show insignificant effects on thermal and rheological properties after reinforcement, making the composite material suitable for FDM/3D printing. Mechanical properties of the composite wires were also studied, yielding good results. This research demonstrates a viable method for recycling waste polymer, reducing waste, and increasing the material's life cycle. The technique has potential applications in additive manufacturing and rapid tooling, encouraging further research in using recycled waste polymers. By developing an in-house feedstock filament wire from recycled materials, this research contributes to sustainable development and the reduction of plastic solid waste.

Kim Ragaerta et.al., [35] This review provides a comprehensive overview of current pathways for recycling polymers, including both mechanical and chemical recycling. Mechanical recycling, the most widely used industrial technique, involves sorting and reprocessing waste polymers. However, challenges such as contamination and mixing of different plastics types in waste can affect efficiency. Chemical recycling, on the other hand, involves techniques like chemolysis, pyrolysis, and gasification to break down polymers into raw materials. The review discusses the principles of these recycling pathways, predominant industrial technologies, design strategies, and recycling examples of specific waste streams. It also highlights the main challenges and potential remedies to these recycling strategies, grounding them in relevant polymer science. The review concludes that both mechanical and chemical recycling have high industrial potential and can be complementary pathways for closing the loop on polymers, preferring them over energy recovery and land filling. By discussing the current state-of-the-art in polymer recycling, this review provides an academic and applied perspective on the topic, emphasizing the need for efficient recycling strategies to manage solid plastic waste.
Fabio A. Cruz Sanchez et.al., [36] This study addresses the challenge of low polymer recycling rates and the increasing demand for thermoplastic materials in additive manufacturing. The research focuses on recycling Polylactic Acid (PLA) used in Fused Filament Fabrication (FFF) 3D printing. A generic methodology is proposed to evaluate the recycling feasibility of thermoplastic polymers for open-source additive manufacturing. The methodology consists of five steps: material selection, characterization, recycling process, mechanical property evaluation, and recyclability assessment. The results show a reduction in mechanical properties with each recycling cycle, but the material remains suitable for 3D printing applications. The research contributes to understanding the potential for distributed recyclability of PLA and other polymers in additive manufacturing, promoting a more circular economy. The proposed methodology can be applied to other materials and recycling processes, making it a valuable tool for advancing polymer recycling and sustainable additive manufacturing practices.
Zixiang Weng et.al., [37] This study developed acrylonitrile butadiene styrene (ABS) nanocomposites with organic modified montmorillonite (OMMT) for fused deposition modeling (FDM) 3D printing. The 3D-printed samples showed improved mechanical and thermal properties compared to injection-molded samples. The flexural strength and modulus increased with OMMT content, reaching a maximum at 5 wt% loading. The linear shrinkage ratio and thermal stability also improved with OMMT addition. The results suggest that ABS/OMMT nanocomposites are promising materials for FDM 3D printing, offering enhanced mechanical and thermal properties. The study demonstrates the

potential of polymer nanocomposites for additive manufacturing, enabling the creation of high-performance 3D-printed materials. The findings have implications for various industries, including aerospace, automotive, and healthcare, where high-performance materials are critical. The research contributes to the development of sustainable and innovative materials for 3D printing applications.
Alex K. Cress et.al., [38] This study investigates the recycling of acrylonitrile butadiene styrene (ABS) thermoplastic polymers using fused deposition modeling (FDM) 3D printing. The research aims to understand the effects of recycling on the mechanical properties of FDMed ABS and identify optimal processing parameters to minimize porosity and improve performance. The study reveals that recycling increases elemental iron content and affects the mechanical properties of ABS. Tensile tests and characterization techniques, such as DSC, TGA, FTIR, XRF, and GPC, were used to analyze the effects of recycling. The results show that optimizing FDM processing parameters, such as airgap, extrusion ratio, and nozzle temperature, can improve the mechanical performance of recycled ABS. Additionally, vibration-assisted FDM can further reduce porosity. The study contributes to the development of sustainable and circular manufacturing practices by demonstrating the potential of recycling ABS for high-quality 3D printing applications. The findings have implications for industries adopting additive manufacturing and seeking to reduce waste and environmental impact. By optimizing FDM processing parameters, manufacturers can create high-performance products from recycled materials, promoting a more circular economy.

Emily J. Hunt et.al., [39] This study explores the potential of distributed manufacturing and recycling of polymers using 3D printing technology. With the advent of affordable self-replicating rapid prototypers (RepRaps) and recyclebots, the economic benefits of custom distributed manufacturing have increased significantly. The research proposes a recycling code model based on China's resin identification codes, which can be expanded to accommodate new 3D printing materials. The model categorizes plastics into five types: non-recoverable, recoverable, recycled, reworked, and repeatable use. Open SCAD scripts were developed to print recycling symbols into products, enabling prosumers to participate in distributed recycling. The study demonstrates the feasibility of this system and outlines the necessary software and policy tools for widespread adoption. The results suggest that a larger resin code identification system can be adopted in the US to expand distributed recycling and manufacturing of plastic-based 3D printed products. This research contributes to the development of sustainable and circular manufacturing practices, enabling the recycling of polymers and reducing waste. By leveraging 3D printing technology and distributed manufacturing, this system has the potential to significantly impact the environment and the economy.
F. Ronkay et.al., [40] This study investigates the recyclability of marine plastic waste, specifically PET bottles and HDPE caps, after exposure to artificial accelerated weathering simulating marine conditions. The research aims to address the challenges of collecting and recycling marine plastic waste, which poses significant environmental and economic concerns. The results show that weathered PET samples can be successfully recycled mechanically and used to manufacture plastic products, despite some changes in properties such as intrinsic viscosity and surface morphology. The study demonstrates that marine plastic debris can be a valuable source of recyclable material, reducing the need for virgin plastics and mitigating the environmental impacts of plastic waste. However, the recyclability of weathered plastics may be affected by changes in properties such as rigidity and strain at break. The research highlights the potential for closed-loop recycling of marine plastic waste and contributes to the development of sustainable solutions for managing plastic pollution in the marine environment. By exploring the recyclability of weathered plastics, this study supports the transition towards a circular economy and helps address the global challenge of marine plastic waste.

I. Conclusion

In conclusion, 3D printing with recycled materials is a revolutionary technology that combines innovation with environmental responsibility, offering a sustainable solution for various industries. By utilizing waste plastics, we can reduce pollution, conserve resources, and create valuable products, promoting a circular economy. This study successfully demonstrated the transformation of plastic waste into 3D printing feedstock, producing recycled PET and composite filaments, and highlighting the importance of material compatibility and process optimization. The research optimized filament production and 3D printing parameters using waste polypropylene and carbon fibers, achieving improved mechanical properties and print quality. While mechanical recycling has limitations, various recycling technologies for post-consumer plastic waste have significantly enhanced eco-friendliness, promoting recycling, treatment, and recovery. As we continue to advance additive manufacturing, we can create a more sustainable future, one layer at a time, and mitigate the environmental impacts of plastic waste. This technology has far-reaching implications, empowering individuals and industries to contribute to a more environmentally conscious world.

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