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Creating a robust composite material from waste plastic and steel for application in 3D printing

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Abstract
This project investigates the future possibilities of additive manufacturing by creating a strong composite material from waste plastic and steel for 3D printing. The research uses polyethylene terephthalate (PET) and steel particles generated from industrial waste to optimize material characteristics for improved printability and structural integrity. Key objectives include determining feasibility, optimizing formulas, and assessing environmental sustainability. The findings promise to transform additive manufacturing by providing sustainable solutions while tackling global concerns such as plastic waste and material demand in a variety of sectors.
Fused Deposition Modeling (FDM) is a popular additive manufacturing process for 3D printing. It works by layering thermoplastic filaments through a heated nozzle onto a build platform. The material is placed in a regulated manner and solidifies upon contact with the build surface or previously deposited layers. FDM printers use computer-aided design (CAD) files to precisely create three-dimensional objects with defined dimensions and geometries. FDM technique is regarded as versatile, cost-effective, and suitable for prototyping, producing functioning parts, and constructing complicated geometries. Rapid prototyping is one 3D printing application that uses Fused Deposition Modeling (FDM). FDM enables the rapid and cost-effective creation of prototypes directly from CAD models, facilitating iterative design processes and shortening product development cycles in a variety of sectors.

Keywords: Additive manufacturing, composite material, waste plastic

Introduction
Additive manufacturing, often known as 3D printing, has transformed the way we create, design, and manufacture products in a variety of sectors. Unlike traditional subtractive manufacturing processes, which entail removing material from a solid block, additive manufacturing creates items layer by layer using digital models. This layer-by-layer method provides remarkable versatility, allowing for the construction of complicated geometries and detailed patterns with unprecedented precision. In recent years, additive manufacturing has received substantial attention for its potential to address sustainability issues and usher in a new age of environmentally friendly production. One area of special interest is the creation of composite materials made from recycled or waste resources, such as plastic and steel. By utilizing the adaptability of additive manufacturing technologies, these composite materials may be designed to fulfill specific performance needs while also decreasing environmental impact. The notion of generating a strong composite material from waste plastic and steel for additive manufacturing applications is extremely promising. Waste plastic, which has a large environmental impact, may be recycled as a matrix material, with steel particles acting as reinforcement to improve mechanical attributes like as strength and durability.

Types of Additive Manufacturing
Additive manufacturing involves a multitude of processes, each with its own distinct approach to producing products layer by layer. Some of the most popular kinds of additive manufacturing are.

1. Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) is one of the most popular 3D printing processes. Extruding thermoplastic filaments via a heated nozzle deposits material layer by layer to create the item.
2. Stereo lithography (SLA) employs a photo polymerization technique to cure liquid resin layer by layer with a UV laser. This process results in highly detailed and precise pieces with smooth surface finishes.

3. Selective Laser Sintering (SLS): A high-powered laser is used to selectively fuse powdered materials, such as plastics, metals, or ceramics, into solid objects layer by layer. It is known for its ability to produce complex geometries and functional prototypes.
4. Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS) are metal powder-specific versions of SLS. A high-powered laser selectively melts and fuses metal powder particles together, resulting in completely dense metal components.
5. Electron Beam Melting (EBM) is another metal additive manufacturing technology in which metal particles are melted and fused using an electron beam rather than a laser. It is ideal for manufacturing huge, complicated metal parts for aerospace and medical applications.
6. Binder Jetting is the process of depositing a liquid binding agent layer by layer over a powdered substance in order to bind the particles together and create the product. It is widely used to create sand molds, metal components, and ceramic sculptures.
7. Material Jetting: Material jetting operates similarly to inkjet printing, where droplets of liquid photopolymer are selectively deposited and cured layer by layer using UV light. This technique can produce high-resolution, multi-material parts with smooth surface finishes.

Composite materials

In 3D printing are materials created by mixing two or more unique materials with various qualities to obtain certain performance characteristics. The use of composites in 3D printing broadens the potential of additive manufacturing by allowing for the fabrication of products with increased strength, stiffness, durability, and other desirable properties.
There are numerous ways to create composite materials for 3D printing.

1. **Reinforced filaments:** In this method, typical filament materials like thermoplastics are blended or coated with reinforcing elements like fibers (e.g., carbon fiber, fiberglass) or particles (e.g., metal powders, ceramics). These reinforced filaments can then be utilized in Fused Deposition Modeling (FDM) printers to create items with higher mechanical characteristics.
2. **Multi-Material Printing:** Some 3D printers can print various materials concurrently or consecutively. This enables the construction of composite structures including different materials in certain parts of the component. For example, a 3D printer may deposit a support material that may be dissolved later, leaving behind a composite item.
3. **Powder Bed Fusion:** Metal matrix composites (MMCs) can be produced using powder bed fusion techniques such as selective laser sintering (SLS) and selective laser melting. These procedures employ a laser to selectively fuse metal powders, with reinforcing elements such as ceramic or metallic particles added into the powder bed. This results in pieces with better mechanical characteristics than pure metals.
4. **Composite Laminates:** Laminated composite structures can also be created utilizing 3D printing methods. This entails printing separate layers of various materials and then gluing them together to create a composite structure. Multi-material inkjet 3D printers, for example, may deposit several materials layer by layer to form laminated composite component. In the present work, two composite materials—HDPE and steel - are being examined. The mediumCompound, HDPE, is the furthermost widely used pliablearound the globe, accounting for more than 35% of the worldwide pliablesouk, however it is hardly employed in AM due to many complications.

Literature survey

Edgar Adrian Franco Urquiza (2024) [16] the innovation of four-dimensional (4D) printing is made possible by technological advancements and the creation of new and improved materials. Three-dimensional (3D) printing is no longer feasible. The process of precisely constructing objects with complicated shapes through the deposit of material in layers is known as 3D printing. With the advent of intelligent materials that can change shape over time or in response to external stimuli, coupled with the ability to place two or more filaments of different polymeric materials, current 3D printing technology opens up new avenues for innovation and progress toward innovative 4D printing technology.

Christopher Prasanna (2023) [17] by developing predictive DNN models, this work aims to advance model-based control techniques for PAFPs. The ambulation data of one patient was used to train three DNN architectures and the analytical regression model. The trained DNNs demonstrate the ability of sophisticated, high-fidelity models to accurately forecast complete ankle torque values, which are frequently only available through the completion of offline full-body inverse dynamics. Forecasts conducted at one and twenty samples ahead of time, or half a gait cycle, were both within five percent of the total range of PAFP torque values. The outcomes demonstrate these models' real-time ability to estimate unobservable processes. These human-robot predictive models enable model-based control strategies, which may enhance the performance of powered prosthetic devices.

Anketa Jandyal *et al*. (2022) [18] being an additive process, 3D printing has become a viable technique for the production of technical components, in contrast to traditional manufacturing processes. 3D printing is a sustainable technology for industrial application because of its energy efficiency, low post-processing waste, ease of manufacture, low human participation, and minimal material waste. The merits and downsides of various 3D printing technologies are covered in this study. A thorough explanation of the various materials suitable for every kind of 3D printing method is provided. Each process type's numerous application areas are also presented in the study. There is also a special section on industry 4.0. The review of the literature showed that while 3D printing has advanced significantly, there are still problems that issues that must be resolved, like material incompatibility and material expense. Subsequent investigations may be conducted to enhance and adapt the procedures to accommodate an extensive variety of substances. More attention needs to be paid to creating affordable printer technologies and materials that work with these printers in order to increase the number of applications for 3D printed items.

Xiaoyong Tian *et al*. (2022) [19] the application of continuous fiber reinforced polymer composites (CFRPC) in the automotive, aerospace, and space industries has been extensive because of its low weight, high specific strength, and modulus when compared to metal and alloys. A new chapter in the design and construction of complex composite structures with excellent performance and low cost was brought about by advances in CFRPC 3D printing. A technological enabler to close the gaps between cutting-edge materials and creative structures was CFRPC 3D printing. The state-of-the-art in CFRPC 3D printing has been evaluated based on correlations between materials, structure, method, performance, and functionalities. Typical uses and a prospective view for 3D printing CFRPCs were presented in order to seize the chances and confront the difficulties, which require a great deal of multidisciplinary study including structural design, innovative materials, equipment and process, and smart performance in the end.

Amit M. E. Arefin *et al*. (2021) [20] recent research indicates that the usage of polymer 3D printing, an emerging technology, will grow in the industrial sector, especially in the medical domain. The benefit of polymer printing is that it makes it possible to print inexpensive functioning parts with a variety of characteristics. Here, we examine the latest developments in polymer 3D printing research by examining studies on materials, methods, and design approaches for use in medical fields. Polymers with favourable mechanical and biocompatibility qualities have been developed as a result of material science research; the mechanical properties can be tuned by adjusting the parameters of the printing process. Extrusion, resin, and powder 3D printing are appropriate polymer printing techniques that allow for targeted material deposition in the creation of useful and personalized architectures. Design techniques that allow for the balancing of materials, like the hierarchical arrangement ofopposing requirements for tissue scaffolds, such as biological and mechanical ones.

Henri Vahabi *et al*. (2021) [21] one significant issue with polymers is their flammability. FRs are essential to our lives' safety. Because of fire and environmental restrictions, as well as the widespread usage of polymers in practically every aspect of our lives, the science of flame retardancy and the creation of flame-retardant polymer materials are therefore always evolving and will continue to encounter obstacles. New fire codes are presently being developed for a few industries, including buildings and cars. Meanwhile, as new manufacturing technologies develop on a regular basis, flame-retardant solutions must also be flexible enough to accommodate them. This paper highlights current developments in polymer flame retardancy and aims to illustrate the value of utilizing 3D printing technology to create the next generation ofchemicals that resist flames.

Material Production Method: Models were produced in open AL mould soaking free space oven held at 225 °C and a Pr of 24-26 psi vacuum. Moulds were sized rendering to the examining requirements that control the kinds of trials to be steered. Plastic pallets and steel jots were blended as they were positioned into the moulds. As the pellets liquefied into the moluds and took up a reduced amount of space in the mold, extra plastic, and steel (Blended at appropriate percentages) were added to the moulds. This procedure sustained up till the mould was fully occupied and the pliable was completely liquefied. As the pellets melted uniformly, vacuum pressure was applied in the oven to remove air bubbles from the polymer 10%, 20%, 40%, and 60% steel to HDPE ratios were used to fill the moulds in order to test the steel reinforcements' efficacy. For each proportion and testing model type (tensile, compression, and flexural), six trials were set up. Each type of model required a different amount of time to heat up or melt; the smaller compression models required 1.15 hours, while the larger flexural and tensile models required 2.5 hours.

Mechanical Testing Procedures

Every model, suitable sizes of the trial segment were made using a digital caliper at numerous places during the trial segment. Rendering to the examination Material Test System benchmark for flexural testing [Criado-Gonzalez], the smallest amount cross-sectional area at the middle of the beam for flexural testing was used to determine appropriate stress values.

Tensile, flex, and compression testing were conducted using the Material Test System universal examination apparatus [Kukkonen]. The models were evaluated using a Material Testing System extensometer and an MTSL and mark load frame with a 90 kN load cell strain for the tensile examination of the model was measured using a measure

Results

There were 26 tensile specimens examined with five different steel and plastic ratios. Table 1 summarizes the complete findings of the tensile test. Variations in the ratio revealed distinct outcomes for various failure mechanisms. The greatest elongation point was 1.5%, the highest modulus of elasticity was 3.54, and the highest tensile strength was 25.91 MPa in samples with an average ratio of 75%.

Table 1: Average Values of all the proportions

Model title	UFS (MPa)	MOE (GPa)	Y.S. (MPa)	M.E. (%)
100% HDPE	22.29±6.60	0.10±0.02	13.7±2.76	29.11±14.26
10% STEEL	39.8±3.2	0.92±0.03	20.96±3.26	6.67±0.94
20% STEEL	37.85±2.76	0.68±0.21	24.23±8.96	9.45±5.76
40% STEEL	18.76±3.73	0.09±0.02	9.97±8.46	22.42±4.78
60% STEEL	28.27±5.51	0.21±0.10	18.87±8.40	15.40±8.43

Table 2: Steel and concrete's mechanical characteristics

Model tittle	Ultimate Flex Strength (MPa)	Modulus of Elasticity (GPa)	Y.S. (MPa)	Max. Strain
100%HDPE	28.84±2.65	0.51±0.01	19.94±0.91	0.21±0.01
10%STEEL	30.24±0.37	0.53±0.06	14.62±2.24	0.21±0.01
20%STEEL	22.97±1.64	0.49±0.03	11.21±2.72	0.16±0.03
40%STEEL	27.61±4.43	0.39±0.04	14.24±1.84	0.16±0.03
60%STEEL	37.99±3.18	0.39±0.10	18.37±3.38	0.22±0.02

Properties	Concrete	Steel
Strength in tension	weak	Virtuous
Strength in compression	Safe	safe, but slender bars will buckle
Strength in shear	Fair	Virtuous
Durability	Safe	Rusts if unguarded
Fire resistance	Safe	Weakened-loses strength quickly in hot weather

When comparing the mechanical properties of steel and concrete, as shown in Table [20], we find that they are somewhat similar. In certain regions, steel's mechanical properties are more robust than those of concrete. Steel has good strength in shear, compression, and tension as a result. Concrete is commonly employed in large-scale 3D printing projects and primary structural projects. It has been used in many conventional methods for decades. Thus, one of the primary reasons for researching and developing a strategy to use steel fibers in 3D printers is that they have similar qualities. This dissertation also demonstrates that steel is a suitable material for large-scale.

Flexural Testing

Three-point bending Tests were conducted to determine the bending characteristics of samples at various steel and plastic ratios. Every ratio was evaluated with six samples. The failure in this test is taken into consideration if the sample has a minor fracture, which lessens the load the sample will experience. Some samples, meanwhile, did not entirely decompose. Some samples were so flexible that they continued to bend until they came into contact with the consistency of bending. The point of contact was used to measure the test. The table below provides an overview of the findings.

Conclusion

- The objective of this research was to find out if it is conceivable to create a composite substance for large scale 3d printing which will be used by the supporting frame work at construction site that uses usual ecological resources.
- In this research, Research has demonstrated that steel and HDPE polymer can be combined to create a material that is comparable to those now employed in large-scale digital production.
- To quickly find out if this composite material functions properly, material testing samples were manufactured utilizing a fairly basic oven moulding technique.
- To resolve baseline material attributes for HDPE/steel composite materials with different steel to polymer ratios, tensile, flexural, and compression samples were created.
- Tensile, flexural and compression tests were complete using five different proportions (10%, 20%, 40% and 60%). The 60% steel tensile sample shows the maximum ultimate tensile strength 21.26MPa and maximum modulus of elasticity 2.97 GPA.

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