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Research facility Training and Workshop on Metal 3D printing with Smart Materials

Velmurugan C[1]*, Vijaya Kumar P[2]

[1,2] Department of Mechanical Engineering, Indian Institute of Information Technology Tiruchirappalli, Sethurapatti, Tiruchirappalli, Tamil Nadu, India, *velmuruganc@iiitt.ac.in.

Abstract: This article deliberates the emerging trends on metal 3D printing and smart materials discussed in a technical program designed for the researchers. This initiative is sponsored by the Science and Engineering Research Board under the Department of Science and Technology of the Government of India, as part of project's Scientific Social Responsibility. The metal 3D printing is an advanced technology allowing precise and efficient fabrication of intricate metal components. However, the adoption of this technology among new researchers has been hindered by limited awareness and high cost of the equipment compared to traditional manufacturing techniques. To address these challenges, the experiments were conducted using a customized metal 3D printer to enable the fabrication of metallic parts. The practice focused on Fused Deposition Modeling, a technique falling under the Material Extrusion category in Additive Manufacturing. The results of the practice successfully achieved its primary goal as the simple and intricate metallic parts can be fabricated using fused deposition process with accurate dimensions and meets other specified parameters.

Keywords: fused filament; 3d printing; smart materials; post-process; training

1. Introduction

The department of science and technology (DST) - science and engineering research board (SERB) sponsored a one-day research facility training on 'Metal 3D Printer' and a one-day workshop on '3D Printing of Smart Materials' conducted on March 23rd and 24th, 2023 under the project scheme of Scientific Social Responsibility (SSR) activity. The events conducted with the active participation of researchers from different academic institutions. Dr. Velmurugan C, Assistant Professor, Indian Institute of Information Technology Tiruchirappalli, spearheaded both programs. During the sessions, participants gained insights into polymer and metal material fabrication, including post-processes, utilizing the fused filament fabrication (FFF) method and high-temperature muffle furnace (MF).

Material extrusion stands out as one of the most cost-effective approaches to produce polymer and metal-based parts, encompassing seven generally applicable techniques for crafting polymer, metal, and ceramic components [1]. Specifically for our project, we acquired an FFF setup and MF, instrumental in facilitating the mentioned programs and enhancing the practical knowledge of participants. In the fabrication of polymer-based components, filament forms of polylactic acid (PLA), polyethylene terephthalate glycol (PETG), and acrylonitrile butadiene styrene (ABS) were employed. Simultaneously, stainless steel (SS) served as the metal material for crafting metallic components [2, 3]. The additive manufacturing (AM) process was delineated into pre-process, process, and post-process stages for the development of any 3D (three dimensional) component.

To begin, the pre-process entails the creation of a computer-aided design (CAD) file and the transformation of this file into a stereolithography (STL) file. Initially, a CAD file is generated to represent the design of the component intended for printing using the FFF setup. Subsequently, the CAD file undergoes conversion into STL format. Following this, the STL file is imported into slicing software, allowing for the selection of input settings to meet specific requirements. Additionally, the sliced file is saved as a G-code file. Moving on to the processing stage, it involves the physical realization of a 3D object, building upon the groundwork laid in the previous stage. The object takes shape as filament (either polymer or metal) is extruded through a heated nozzle and deposited layer by layer onto the build platform. Finally, the post-processing phase commences after the as-printed part is removed. During this stage, only the support material is removed for polymer-based components. In contrast, metal-based components undergo debinding and sintering processes [4, 5].

Professionals shared their research expertise on diverse topics such as 3D printing of smart materials, advancements in additive manufacturing, and 3D printing with design for additive manufacturing. These themes were particularly relevant and well-suited for the workshop, and the faculty members actively engaged in each session, effectively interacting with the experts to address any queries. The key subjects covered during the workshop included the evolution of smart materials, design considerations for additive manufacturing, polymer 3D printing, multi-polymer printing, and metal printing.

The initiative of the Indian government through the DST-SERB scientific social responsibility (SSR), the workshop aimed to foster awareness among young researchers and faculty members regarding upcoming technologies. During the workshop, experts facilitated brainstorming sessions covering various topics related to 3D printing. Research students were provided hands-on experience in independently designing and printing components, enabling them to effectively implement their ideas using our research facilities. As a result of the workshop, all participating research scholars and faculty members felt more self-assured in their ability to work with 3D printing at any given time.

Research scholars who acquire a solid foundation for building a successful career in Industry 4.0 are likely to find inspiration in such endeavors. The inclusion of innovative ideas and projects in 3D printing has enabled faculty members to enhance their comprehension of this transformative manufacturing process, facilitating more effective teaching for their students. Consequently, the regular implementation of research facility training/workshop programs in 3D printing, similar to the one discussed here, would be highly beneficial. This approach could expedite the development of a skilled workforce for the nation.

The mechanical engineering department takes pride in orchestrating these initiatives dedicated to researching smart materials in additive manufacturing. The research facility training sessions and workshops are endorsed by DST-SERB, emphasizing the importance of training, especially in the production of intricate, tailored components. It is now imperative for the researchers across all disciplines to assume the responsibility of overseeing tasks related to 3D printing. Recognizing the significant growth in 3D printing research in recent years, it's crucial for researchers to gain exposure to keep pace with the demands of mass-producing components.

2. Contextual Information

Fused Filament Fabrication (FFF), also known as Fused Deposition Modeling (FDM), is a popular 3D printing technology. Fig.1 shows a customized FFF setup which is used for printing both polymer and metal parts. FFF is an additive manufacturing process where a three-dimensional object is created layer by layer by depositing and fusing material in a controlled manner.

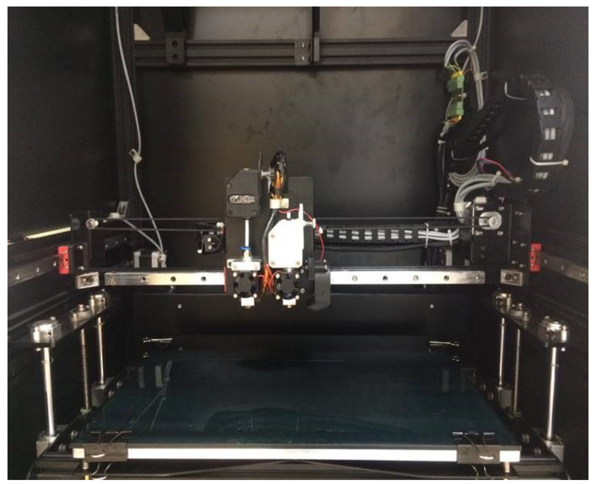

Fig.1 Fused Filament Fabrication setup

First, a 3D model of the object is created using computer-aided design (CAD) software. Then the 3D model is sliced into thin horizontal layers using slicing software. Each layer represents a cross-section of the final object. The filaments (polymer or metal) are used as the printing material. It is loaded into the 3D printer. Then the 3D printer's nozzle heats the filament to its melting point. The melted filament is extruded onto the build platform or previous layers in a specific pattern, following the sliced design. Table 1 represents the main features of 3D printer setup.

Table.1 Main features of 3D printer setup

Specifications	Range
Mechanism	Linear Rail
Max. Build Size (mm^3)	300×300×400
Layer Resolution (mm)	0.1 – 0.4
Extruder type	Dual
Print Speed (mm/s)	60

Nozzle Size (mm)	0.6
Max. Extruder Temperature (ºC)	300
Slicer Software	Simplify3d

Further, the printer continues to add layers one at a time, with each layer bonding to the previous one as it cools and solidifies. For complex or overhanging geometries, temporary support structures may be added during the printing process. These supports can be removed once the print is completed. Then the printed object is allowed to cool and solidify completely. Post-processing steps, such as removing supports, sanding, or painting, may be performed to improve the final arrival of the printed object.

Fig.2 Debinding and sintering muffle furnace setup

Fig.2 represents the debinding and sintering muffle furnace setup. The use of this muffle furnace is common in both debinding and sintering processes. It is an electrically heated furnace with a separate chamber (muffle) to isolate the part from direct contact with the heating elements. This helps to create a more controlled and uniform temperature environment for the debinding and sintering (D&S) processes. Both D&S are critical steps in the process of producing metal or ceramic parts using AM techniques, particularly in the context of technology like metal fused filament fabrication (MFFF). In debinding, it is necessary to remove the binders that are mixed with the metal powders while making the filament. The part is heated in a controlled environment to a temperature where the binders begin to break down and volatilize. This temperature is below the melting point of the metal. The binders are removed as gases, leaving behind a porous structure called a brown part. In sintering, the process of heating the debound part to a higher temperature, typically close to the melting point of its temperature. This process helps the metal particles fuse together, eliminating the porosity and creating a dense, solid object. At the sintering temperature, the metal particles diffuse and bond together. After sintering, the furnace is gradually cooled to prevent thermal shock and maintain the integrity of the final part. Overall, debinding and sintering are essential steps in achieving the desired mechanical properties and final density of the metal parts.

3. Proposed Topics

Three subject experts gave lectures on the following topics as part of this training program.

3.1. Role of 3D printing in Development of Smart Materials

3D printing, also known as additive manufacturing, has played a substantial part in the development of smart materials. These materials have the ability to respond to external stimuli, such as changes in temperature, pressure, or electrical fields, in a controlled and predictable manner. These materials have a wide range of potential applications in different industries, including aerospace, automotive, healthcare, and electronics. 3D printing has contributed to the advancement of smart materials in several ways: 3D printing permits the precise and customizable fabrication of smart materials. This means that designers and engineers can create complex, tailor-made structures that respond to specific stimuli. 3D printing is an ideal tool for rapid prototyping and iterative design. This capability is essential for the development of smart materials, as it allows researchers to quickly test and refine their designs. It reduces the time and cost of developing new smart materials. 3D printing permits the fabrication of complex, intricate geometries that would be challenging or impossible to achieve using traditional manufacturing methods. Smart materials often require precise and intricate structures to achieve their desired functions, and 3D printing makes it possible to create those structures. 3D printing enables the exploration of new material compositions and combinations. Researchers can experiment with different materials, composites, and additives to create smart materials with enhanced properties. 3D printing is deposited layer by layer, reducing material waste compared to subtractive manufacturing methods. This is environmentally friendly and cost-effective, especially for expensive or specialized smart materials. Overall, 3D printing has significantly contributed to the development of smart materials by enabling customization, integration of components, graded structures, and accessibility. It has opened up new possibilities for materials design and innovation, making it a valuable tool in the field of smart materials research and development.

3.2. 3D printing of Metallic materials

3D printing of metallic materials, also known as metal 3D printing which is a rapidly growing technology which consents the development of complex and precise metal parts and components. Here's an overview of the key aspects of 3D printing with metallic materials: Several 3D printing processes are employed for printing the metallic materials. Some of the most common methods include: Powder Bed Fusion (PBF) - This includes techniques like Selective Laser Melting (SLM) and Electron Beam Melting (EBM), where a high-energy laser or electron beam selectively fuses layers of metal powder to create the desired object. Directed Energy Deposition (DED) - In this process, a focused energy source (e.g., laser, electron beam, or plasma arc) is used to melt and fuse metal wire or powder as it is deposited layer by layer. Binder Jetting (MJ) - Metal powder is selectively bound together using a liquid binder and then sintered to create the final component.

A wide range of metallic elements can be used in 3D printing, including stainless steel, titanium, aluminum, Inconel, cobalt-chrome, and even precious metals like gold and silver. The choice of material depends on the specific requirements of the application, such as strength, corrosion resistance, or thermal properties. The main advantages such as complex geometries, reduced waste, customization, rapid prototyping, lightweight structures, etc., also the challenges are cost, post-processing, and size limitations. Metal 3D printing continues to advance, with ongoing research and development efforts aimed at expanding the range of printable materials, increasing production speeds, and enhancing the technology's affordability. This technology has the potential to revolutionize manufacturing across multiple industries by offering unprecedented design freedom and efficiency.

3.3. 3D Printing and Design for Additive Manufacturing

Design for Additive Manufacturing (DfAM) is a critical aspect of utilizing 3D printing effectively. It involves designing parts and components with the unique capabilities and constraints of AM processes in mind. Here are some key principles and considerations when it comes to DfAM: It often starts with topology optimization. This is a design method that practices computer algorithms to optimize the material distribution within a given design space.

The result is a structure that is lightweight and efficient, minimizing the use of material while maintaining necessary strength and performance. It can lead to organic, complex shapes that are well-suited for 3D printing. One of the most significant advantages of 3D printing is the ability to create highly complex and intricate geometries that are challenging or impossible to achieve with traditional manufacturing methods. DfAM encourages designers to take full advantage of this capability. Designers can incorporate lattices, honeycomb structures, and internal channels to reduce weight and material usage while maintaining structural integrity. 3D printing often requires support structures to stabilize overhanging or complex features during the printing process. DfAM should take into account the need for these structures, as they can impact the part's surface finish and may require post-processing to remove.

Moreover, the choice of material is crucial in DfAM. Different 3D printing technologies support various materials, each with its own mechanical properties and characteristics. Designers should consider the material's strength, durability, thermal properties, and compatibility with the intended application. The orientation of a part during printing and the layer thickness can influence the mechanical properties of the final product. DfAM involves optimizing the orientation and layer thickness to ensure the desired performance while minimizing printing time and material usage. Also, designers should be mindful of overhangs and bridging when designing parts for 3D printing. Some printers can handle overhangs to a certain extent, but steep angles may require support structures. Understanding these limitations and designing accordingly is essential. Obviously, proper tolerances and clearances should be considered in DfAM to ensure that assembled parts fit correctly. The printing process may introduce slight deviations, so these factors should be taken into account during design.

DfAM can often to reduce the number of parts required for an assembly. At that time, designers can create assemblies that consolidate multiple components into a single printed piece, reducing complexity and potential points of failure. Different 3D printing processes have unique constraints, such as minimum feature sizes and wall thicknesses. The designers should be aware of these constraints and design within them. Specialized software tools, often generatively designed, can aid in DfAM. These tools can help designers optimize parts for 3D printing by automatically generating designs based on specific parameters and constraints.

DfAM is an iterative process that combines engineering expertise with an understanding of the capabilities and limitations of 3D printing technology. It can lead to more efficient and innovative designs, reducing material waste and manufacturing costs while improving performance and functionality. As 3D printing technology continues to advance, DfAM will play an increasingly important role in various industries, from aerospace and automotive to healthcare and consumer products.

4. Summary

The participants gained a comprehensive understanding of seven distinct techniques employed in additive manufacturing. They also acquired insights into a variety of polymer and metal materials. Through hands-on training sessions, they actively engaged in fabricating polymer and metal-based components, utilizing both software and hardware resources available in our laboratory. This valuable opportunity significantly contributed to enhancing their theoretical and practical knowledge of the 3D printing process and materials. This newfound knowledge equips them with the skills needed to develop complex-shaped components for a wide range of applications.

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