

# Advancements in 3D Printing Materials for Diverse Industries: A Review and Future Prospects

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**Abstract.** 3D printing has brought significant changes in many industries. It helps to create products with impressive strength and versatility. This paper aims to investigate and evaluate the different types of materials used in 3D printing, evaluating the advantages, disadvantages, and applications of different materials. It majorly focuses on thermoplastic, metal-based materials, and hybrid and composite materials. This paper also provides the current and future scenarios of 3D printing. This review covers all valuable insights into a large spectrum of different types of materials used in 3D printing and provides a small glance at these transforming industries. As the study expands the development of innovative materials and printing techniques will surely come to the surface and will expand the possibilities of 3D printing applications in the future.

**Keywords:** 3D Printing, Metal-based materials, Hybrid materials, Composite Materials, Additive Manufacturing

## 1 Introduction

Additive manufacturing (AM), also known as three-dimensional (3D) printing, encompasses a set of techniques used to construct objects from 3D model data, typically through a layer-by-layer process, in contrast to subtractive manufacturing methods like machining. Technological progress has led to a growing utilization of 3D printing for producing final parts (Goh et al., 2017; Yap and Yeong, 2014; Carbon, 2017) [1]. 3D printing is a rapidly growing industry with new enhancements coming every next day it has the potential to completely change the way of manufacturing process. The rise of 3D printing resulted in a shift in manufacturing industries as 3D printers help to materialize the concepts via design into reality by layer-by-layer fabrication technology [2]. The ability of 3D printers to use various materials in printing has been the sole reason for their success. This has opened up many possibilities in upcoming industries as it provides them the opportunity to improve their manufacturing efficiency. In this paper, we will examine the material used in 3D printing

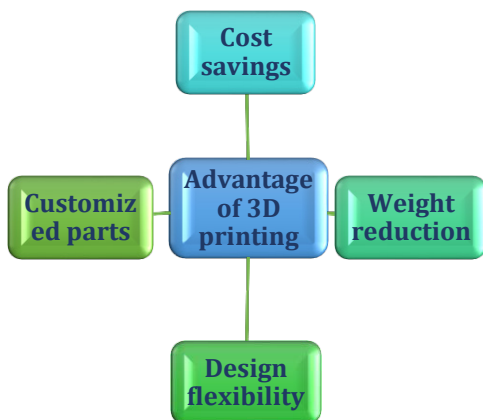
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with a particular emphasis on thermoplastic, metal-based materials, and hybrid and composite materials.

One important step is the material choice as it plays a crucial role in determining the effectiveness of 3D printed products. Currently, there are many materials with different properties used in 3D printing commonly used materials are plastics, metals, ceramics, composites, and polymers. Plastics are used due to their cost-effectiveness and versatility.

Their uniqueness of easily getting molded into a variety of shapes and availability of it in various



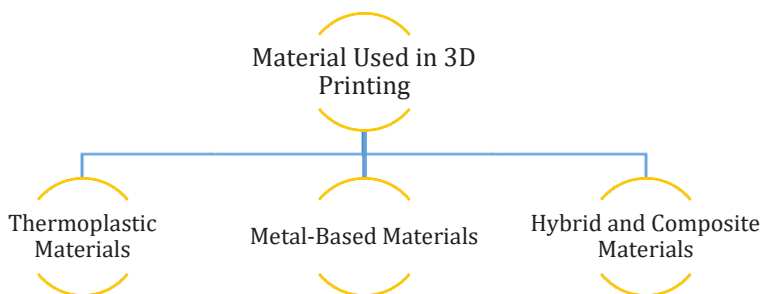
**Fig. 1.** Advantage of 3D printing

colors are striving factors to choosing it. Metals in contrast are renowned for their strength and durability due to which they are commonly used in aerospace, automotive, and tooling applications. 3D metal printing has changed the traditional approach to the manufacturing process. The adaptability and capability of metal printing help in producing complex geometries and intricate designs which improves the overall functionality of the product.

Ceramics are also one of the popular materials utilized in 3D printing[3]. It shows excellent strength and heat and chemical resistance making them the perfect match for machinery, electronics, and biomedical engineering. Composites which are made up of multiple materials exhibit phenomenal distinctive properties that no single material can have alone. They are used in small and medium-sized mechanical components. Polymers are also used in 3D printing and are commonly seen in various fields such as footwear, dental devices, tooling, and wearable technology.

## 2 Materials used in 3D printing:

Materials used in 3D printing can be categorized based on their composition and properties. 3D printing, also known as additive manufacturing, is a process of creating three-dimensional objects by adding material layer by layer[4]. The choice of materials for 3D printing is crucial as it directly affects the final properties of the printed object.



**Fig. 2.** Different types of Material used in 3D printing

### 2.1 Thermoplastic Materials in 3D Printing:

Thermoplastic materials have a significant role in 3D printing which is suitable for various applications and industries. One renowned advantage of using thermoplastic materials is availability and affordability. It is easily accessible in different forms such as filament, pellets, etc. which makes it user-friendly with different 3D printers. It is a perfect choice for hobbyists, education settings, and small scale due to its accessibility. It is widely used for its excellent printability and user-friendliness. [5] They possess relatively low melting points benefiting them to retain their mechanical properties despite numerous cycles of melting, extruding, and solidification. This increases the overall efficiency and facilitates a smoother and faster printing process due to these characteristics and hence reduces time. [6] Thermoplastic material’s mechanical properties can be directed in specific applications that offer a wide array of characteristics, including flexibility, strength, impact resistance, and temperature resistance. As a result, 3D-printed parts can be customized to meet the mechanical requirements of diverse industries, ranging from aerospace and automotive to medical and consumer goods

These materials also possess diverse aesthetic options as these are available in different colours and even translucent which makes the product more appealing and finalized.

As every good thing has certain limitations thermoplastic materials in 3D printing have their limitations too [7]. Despite satisfactory mechanical properties they fail to imitate the strength and performance of more specialized materials like metals or composites. Due to this certain application is bound to use alternate options for better yield.

Thermoplastics are sensitive to environmental conditions, such as temperature and humidity which can impact the final product if not taken care of. So, it is advised that controlled printing environments are necessary to achieve precise results.

**Table 1:** Thermoplastic 3D Printing Materials: Advantages and Disadvantages

Thermoplastic Materials	Description	Advantages	Disadvantages
<b>Polylactic Acid (PLA)</b>	Polylactic Acid (PLA) is an exceptional material for 3D printing, especially suitable for hobbyists, educational applications, and rapid prototyping. PLA's adaptability and ability to biodegrade outweigh any limitations[8]. PLA serves as an excellent starting point for individuals	Its user-friendly nature, eco-friendliness, and visually appealing characteristics position it as a preferred choice	It may not possess the mechanical properties found in certain industrial-grade materials

	venturing into the realm of 3D printing and remains a favoured material within the additive manufacturing community.	for creators aiming to materialize their ideas PLA has adaptability and the ability to biodegrade	
<b>Acrylonitrile Butadiene Styrene (ABS)</b>	Acrylonitrile Butadiene Styrene (ABS) is a durable and adaptable thermoplastic material that has become popular in the field of 3D printing. In general, ABS remains a favoured material among 3D printing enthusiasts due to its combination of strength, flexibility, and ease of use for various applications	Impressive mechanical strength, ability to withstand impacts, and ease of manipulation make it a great option for creating functional prototypes and final products	It is important for users to be aware of the fumes produced during the printing process and take appropriate measures to ensure proper ventilation
<b>Polyethylene Terephthalate Glycol (PETG)</b>	Polyethylene Terephthalate Glycol (PETG) has a unique combination of strength, flexibility, ease of use, and chemical resistance. PETG's versatility and reliability have been consistently demonstrated across a wide range of industries, from functional prototypes to end-use products. PETG is expected to maintain its status as a fundamental material for 3D printing enthusiasts and professionals who value dependable and high-performance thermoplastic.	Its minimal warping and impressive printability make it the preferred choice for manufacturing both large and intricate parts	PETG possesses problems in storage due to its high hygroscopicity
<b>Polyethylene (PE)</b>	Polyethylene (PE) is a multifaceted and utilitarian thermoplastic material that presents distinct benefits for specific 3D printing applications. With ongoing technological advancements, the utilization of PE in additive manufacturing is projected to expand, providing users in diverse industries with novel opportunities and applications.	Its ability to be printed, along with its resistance to impact and flexibility, make it appropriate for functional parts and prototypes that necessitate mechanical durability Despite this, PE remains a valuable material choice for cost-efficient and functional 3D printing endeavours	Potential difficulties with dimensional precision and availability.
<b>Polypropylene (PP)</b>	Polypropylene (PP) has exceptional printability, durability, and resistance to chemicals. These unique properties make it particularly suitable for various	It is perfect for individuals who aim to create parts that are	Potential challenges related to print

	functional applications in industries such as automotive, aerospace, and consumer goods. As the technology progresses and new formulations are introduced, the adoption of PP in additive manufacturing is expected to increase, presenting users in diverse industries with new opportunities.	durable and possess exceptional printability	time and bed adhesion
<b>Nylon (PA)</b>	Nylon (PA) has outstanding mechanical attributes, such as strength, flexibility, and self-lubrication, render it. With the continuous advancement of 3D printing technology, the versatility and durability of Nylon are expected to fuel its growing adoption in additive manufacturing, thus presenting users in various sectors with new possibilities.	Highly suitable for the production of functional prototypes and final parts in a wide range of industries	Nylon's tendency to absorb moisture necessitates careful handling and storage
<b>Polycarbonate (PC)</b>	Polycarbonate (PC) has exceptional mechanical properties and resistance to high temperatures. Its remarkable strength, impact resistance, and chemical stability make. Polycarbonate is anticipated to continue making significant contributions to various industries, thereby providing users with new possibilities for the creation of robust and dependable 3D-printed components.	It an ideal choice for the production of high-performance parts in demanding applications	Polycarbonate may pose certain challenges related to printing temperature and warping
<b>Thermoplastic Polyurethane (TPU)</b>	Thermoplastic Polyurethane (TPU) has impressive flexibility, resistance to abrasion, and tear strength. It is an excellent choice for manufacturing functional and long-lasting parts across a wide range of industries and is expected to gain even more popularity, providing users in various applications and industries with an expanded array of possibilities.	It is a valuable material option for users aiming to produce high-performance 3D printed components with a rubber-like quality	While TPU may require some adjustments in print settings and post-processing

## 2.2 Metal-Based Materials in 3D Printing:

Metal-based materials also play an important role in revolutionizing the field of 3D printing [9]. The ability of metal-based materials to create intricate complex metal parts with extraordinary precision and details stands as a distinguishing feature. This feature opens up a wide range of applications including medical, automobile, and aerospace industries. It is used to create lightweight components for aircraft to customize medical implants which are revolutionizing the current industries.

The shape memory capability of commercial resins from Stratasy's has been previously verified in studies (Qi et al., 2014; Yu et al., 2015; Joanne Ee Mei et al., 2017). Zhang et al. (2019)[10] employed a combination of hybrid multi-material 3D printing techniques, involving material jetting and DIW, to create a fast-response, stiffness-tunable soft SMP actuator. This actuator exhibited a notable load capacity and effective shape adaptability, as

demonstrated by a robotic gripper capable of holding and lifting various weights and shapes. The soft actuator consisted of a multi-material actuator body along with a DIW-printed conductive circuit on top of the SMP slices. The Agilus30 and Vero Clear materials were used with PolyJet for printing. To expedite the softening-stiffening process of the SMP, a deformable conductive circuit was printed using silver nanoparticles, enhancing the heating and cooling rates. This research highlights the potential of integrating different AM techniques to directly manufacture SMP actuators with printed conductive circuits.

Rossiter et al. [11] introduced a two-membrane antagonistic actuator produced with the Stratasys PolyJet printer. In this study, nearly all-dielectric actuator membranes and supplementary components were fabricated through 3D printing, utilizing Tango and Vero materials. Despite the high-resolution structures achieved, the printed elastomer did not match the mechanical and electrical integrity of commercial dielectric materials.

The mechanical properties of metal-based, materials are hard to compete with as it shows superior strength, toughness, and thermal conductivity compared to other 3D printing materials. Metals like titanium, aluminum, stainless steel, and nickel-based alloys produce end-use parts with high reliability and structural integrity due to their excellent mechanical performance.

The advancing technology has expanded the ability to utilize various metal alloys in 3D printing which helped in expanding the range of materials with specific properties for example, titanium alloys are highly biocompatible, making them ideal for medical and dental applications, while aluminum alloys excel in lightweight automotive parts[12]. This diversity allows for the customization of material selection to meet the requirements of each specific application.

Selective laser melting (SLM) and electron beam melting (EBM) are metal-based 3D printing techniques that offer super precise control over the microstructure of printed parts. This level of control enhances the performance and functionality of the final project as it enables the creation of graded materials, lattice structures, and optimized geometries.

Though Metal-based materials have major advantages but possess some serious challenges. The demand for high professionalism to handle specialized equipment used in printing and the major high cost of metal powder act as a barrier for smaller businesses and hobbyists. On top of this, the high-energy requirements of metal 3D printing can limit its environmental sustainability.

Apart from this, there are many challenges in the post-processing of Metal-Based Materials as the printed parts may require additional attention in terms of additional machining, heat treatment, or surface finishing to achieve the desired part with desired surface quality.

**Table 2:** Metal-Based 3D Printing Materials: Advantages and Disadvantages

<b>Metal Based Materials</b>	<b>Description</b>	<b>Advantages</b>	<b>Disadvantages</b>
<b>Stainless steel</b>	Stainless steel has remarkable strength, resistance to corrosion, and the ability to be shaped into various designs making it the preferred choice for manufacturing functional and long-lasting parts. As technology continues to advance, stainless steel is projected to remain an essential material in additive manufacturing	It is a valuable material for those seeking to produce high-performance and corrosion-resistant 3D-printed components.	There may be certain difficulties in the printing and post-processing phases of parts printed with stainless steel

<b>Titanium</b>	Titanium offers exceptional strength, biocompatibility, and resistance to corrosion. Its lightweight properties and ability to interact well with living organisms have opened up numerous opportunities in industries such as aerospace and medicine. With ongoing technological advancements and emerging developments in Titanium 3D printing, this material is expected to continue playing a crucial role in additive manufacturing, fostering innovation and progress across various applications.	It is helpful to persons who aim to produce high-performance and biocompatible 3D-printed components.	The high cost and specialized equipment required for 3D printing with Titanium are some of the disadvantages
<b>Aluminium</b>	Aluminum has lightweight properties, impressive strength, efficient thermal conductivity, and resistance to corrosion have established it as a preferred choice in industries spanning from aerospace to electronics. As technology progresses and the cost of aluminum powder decreases, it is anticipated that aluminum will continue to hold a prominent position in additive manufacturing, thereby opening up new possibilities for innovation and development across various applications.	It is an appealing option for producing 3D-printed components that are both high-performing and lightweight	Despite the challenges posed by its high melting point and thermal considerations
<b>Cobalt Chromium (Co-Cr)</b>	Cobalt Chromium (Co-Cr) has significant progress in the medical and aerospace fields through additive manufacturing. Its ability to be compatible with the human body, strong mechanical properties, and resistance to corrosion make it a preferred choice for manufacturing personalized medical implants and high-performance aerospace parts. As technology continues to advance and new applications arise, Cobalt Chromium is expected to maintain its prominent position in additive manufacturing, driving progress and innovation across various industries.	It is an invaluable material option for individuals who wish to create customized, biocompatible, and long-lasting 3D-printed components	While the use of specialized equipment and considerations for post-processing can present challenges
<b>Nickel-based alloys</b>	Nickel-based alloys offer unparalleled strength, resistance to corrosion, and capability to withstand high temperatures. These exceptional properties make them an optimal choice for the production of crucial and high-performance components in various industries such as aerospace and automotive. As technology continues to advance and the cost of nickel-based alloy powder decreases, these alloys are anticipated to maintain their leading position in additive manufacturing.	It is a valuable material option for users who aim to create long-lasting, heat-resistant, and corrosion-resistant 3D-printed components.	While the use of specialized equipment and careful considerations may present certain challenges

	This will foster innovation and drive growth across diverse applications.		
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### 2.3 Hybrid and Composite Materials:

Hybrid and composite materials depict a distinctive mixture of properties and functionalities that are hard to achieve from traditional materials alone. The main reason to include hybrid and composite materials in 3D printing is their capability to mix some of the finest attributes of different materials and possess that all-in-one material. Due to this specific feature, it shows diverse properties like augmented strength, stiffness, and other customized properties. This helps to create a finalized product with specific properties exactly required by the industries. It is suitable for a broad spectrum of applications across various industries.

Blanco [13] underline the important role of 3D printing technology in both small and large-scale production and research projects. However, it is important to note the main limitation: the scarcity of 3D printing materials with limited electronic hardware. To solve this problem, scientists have investigated the integration of fibers or materials into polymer matrices, especially in composites for use in biomedical, mechanical and electronic fields. This review focuses on research on modified polymers that have the advantages of rapid modeling in composites.

**Table 3:** Composite 3D Printing Materials: Advantages and Disadvantages

Composite Materials	Description	Advantages	Disadvantages
<b>Carbon Fiber Reinforced Polymers (CFRP)</b>	Carbon Fiber Reinforced Polymers (CFRP) possess unmatched strength, lightweight characteristics, and design adaptability. The aerospace and automotive sectors have enthusiastically adopted CFRP due to its capacity to produce lightweight, high-performance components that enhance efficiency and overall functionality.	It is suitable for creation of lightweight, durable, and high-performance parts.	CFRP presents distinctive difficulties during the printing and post-processing stages
<b>Metal Matrix Composites (MMCs)</b>	Metal Matrix Composites (MMCs) possess exceptional strength, lightweight properties, and customizable mechanical characteristics. The aerospace and automotive industries have already adopted MMCs, and with continuous advancements in 3D printing technology, MMCs are expected to find applications in a broader range of industries[15]. This will further push the limits of what can be achieved in additive manufacturing.	The incorporation of a unique combination of metals and reinforcement materials in MMCs makes them a favoured option for applications that demand superior mechanical performance.	The higher cost of fabrication for high-performance MMCs.

Han et al. (2018a) [14] employed VAT photopolymerization processes to 3D print intelligent composites with responsiveness to both electric and magnetic fields. They fabricated soft actuators utilizing electroactive hydrogels (EAH), which demonstrate significant



deformability in reaction to an electric field. The DLP technique was employed to solidify the EAH precursor solution through photopolymerization. When subjected to an electric field, the EAH-printed beam immersed in a phosphate-buffered saline electrolyte undergoes bending deformation due to the distinct osmotic pressure at the interfaces on the anode side.

Majorly the aerospace and automotive sectors have implied hybrid and composite material in full terms as it best suits them. The ability to produce lightweight yet strong components makes these materials highly used to reduce the overall weight of the final product and also to enhance fuel efficiency and improve overall performance.

The remarkable electrical, thermal, and mechanical properties of these hybrid and composite materials employ these directly in the industries of electronics, robotics, and medical devices and also in more upcoming fields. This also helps the user to reduce expenses as the combination of different materials properties helps it to reduce the cost without compromising the strength and quality of the final product.

Though this exhibits such impressive features implying the hybrid and composite material in 3D printing requires careful procedure and overview. The selection of an appropriate combination of materials and the correct required parameters is a must to get the desired combination of properties and performance. Apart from this, the product may require major testing and optimization to ensure the final 3D-printed product meets the requisite specification

### 3 Conclusion:

The proceeding increase in 3D printing materials has a markable impact on many industries forcing the creation of complicated designs resulting in improved performance. Different types of 3D printing materials have different applications and properties, depending on the 3D printing process and the desired outcome.

From this, it can be inferred

- For basic entry-level 3-D printed products thermoplastic is more suitable due to its user-friendly apparatus. It is basically for small-scale industries and hobbyists. thermoplastics are suitable for FDM (fused deposition modeling) 3D printing, which is a low-cost and easy-to-use method for creating functional prototypes and end-use parts<sup>1</sup>. Thermosetting plastics are suitable for SLA (stereolithography) 3D printing, which is a high-precision and high-resolution method for creating complex geometries and smooth surfaces.
- Metals are suitable for DMLS (direct metal laser sintering) 3D printing, which is a high-performance and high-quality method for creating metal parts with intricate details and mechanical properties
- For major products with well-finished designs Metal-Based Materials and hybrid and composite materials are suggested as they provide strong and well-finished products.

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