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Review on Materials Used In Additive Manufacturing Technologies

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Abstract:
Background*: Additive Manufacturing is emerging as an enabling technology for a good range of new applications. From fundamentals point of view, the available materials of Additive Manufacturing printing processes must be considered for every specific application. Additive manufacturing is a technology where 3D structures are designed and printed which is currently doing good for the manufacturing sector of many industries such as automotive, aerospace, medical, jewellery, constructions etc. Additive Manufacturing is a fast-emerging technology which has been exceedingly used for mass customization and fabrication of free design sourced products. Additive manufacturing is a method where the materials are put together in a desired shape via a certain process with the appropriate material type. The property of the materials used for 3D printing is very dependent on the type and composition of the material.*
Conclusion: *The varied types and compositions of materials hugely impacts their implementation in potential applications which is discussed in this paper.*
Key Word*: Additive Manufacturing, 3D Printing, printing material.*

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I. Introduction

Additive manufacturing is basically the construction of a three-dimensional object from a CAD model or a digital 3D model. It can be done in a variety of processes in which material is deposited, joined or solidified under computer control, with material being added together (such as plastics, liquids or powder grains being fused), typically layer by layer. Since the inception of additive manufacturing, it has seen rapid growth due to the massive demand in the small, medium, and large businesses. As the demand increases, newer types of 3D printing devices are developed to utilize different materials such as plastic, ceramic, metals, and composites to form 3D printing parts. In industrial additive manufacturing, the materials are carefully selected for each and every type of manufacturing process. These materials have their own set of benefits and drawbacks. Each manufacturing process transforms the material through a different process. Choosing the right material for the right process comes down to several factors, such as material type, texture, cost, printing technology.

In additive manufacturing, however, the material properties are being established alongside the geometry of the part. The staple or raw material used has an impact (i.e., the chemical makeup of the polymer, the dimensions and distribution of metal powder particles) but process parameters also play a role in factors such as strength, ductility, porosity and surface finish of the final part. This brings new challenges unique to additive, but also opportunities. When the material properties are determined alongside the geometry, it becomes possible to intentionally and precisely control those properties in specific regions of the part — to introduce properties such as porosity, stiffness, or flexibility.[1], [2]

II. Literature Review

M. Shailaja et. al worked on A review on printing materials of Additive Manufacturing studied that the types of materials available and which is used for different AM technologies. 3D printing is versatile in terms of materials and the versatility of 3D printing material comes from system variety but for each specific applications such as bio-printing, the biocompatible materials are still limited and further development of materials are still required. All the new printers or processes for materials have not gone beyond the seven categories and most still work with a single material with limited industrial applicability. The development of smart materials should be in parallel with advances in 3D printing techniques.

Sangeetha et. al worked on Review on various materials used in Additive Manufacturing studied that the major material categories mentioned are metals, ceramics, polymers, biomaterials and smart-materials. Every particular material has its own type of feedstock for efficient printing. The commonly used types are filament, liquid based, powder based or in pellet form. The field of applications each material used are influenced by their properties. Metal 3D printing is on high demand in auto and aero industries, ceramics, biomaterials and smart materials have high potential applications in the biomedical industries and the polymers, which is very widely used in many sectors including auto, aero, art, medical etc. The 3D printing technology is pushing its limits with technology like 3D printing with lunar substances for the applicability for lunar colonization.

Anketa Jandyal et. al worked on 3D printing A review of processes, materials and applications in industry studied that 3D printing being a sustainable technology has a potential to replace conventional technologies. 3D Printing apart from being cost effective is also environment friendly, hence can help to mitigate the adverse effects of industrialization on the environment. Based on the literature studied it can be concluded that a number of 3D printing technologies have evolved having different materials compatible with them. Each 3D printing technology is associated with different advantages and disadvantages. Apart from the capability to handle complex and intricate shapes, 3D printed parts require very less post processing. Amongst the 3D Printing technologies, FDM is the most common technology but is more suited for polymeric materials. The powder based technologies such as SLS face various issues such as difficulty in transportation and storage of powders.[3]–[5]

Esmeralda Uribe-Lam et. al Use of additive manufacturing for the fabrication of cellular and lattice materials studied that a controlled distribution of material within a part often pushes the manufacturing processes to the limit. Cellular and lattice materials demand high levels of accuracy in the fabrication of their composing elements (frequently beams and rods). This exposes the need of a versatile manufacturing alternative. From the geometrical capabilities to the range of material options, additive manufacturing has gained more interest and attention from the related communities. As a result, a thorough review of the literature revealed numerous works where additive manufacturing was employed in the fabrication of cellular and lattice materials. A categorized review of the fabrication of porous materials via additive manufacturing was reported. Remarks are given, according to different aspects intrinsic to both the manufacturing (materials and post-processing) and the nature of the design (topology) of architected materials. Vat photo polymerization is an ideal option for 3D lattice structures with very complex geometries that cannot be achieved with other additive-manufacturing processes. The printed parts produced by these techniques will be thermoset and rigid with a lower cost than traditional fabrication such as injection moulding. Sintering or heat treatment is required to achieve optimal mechanical properties. Metals and ceramics are the main materials used in powder bed fusion processes to fabricate cellular materials. High-temperature cellular materials can be printed by electron-beam melting, selective laser sintering, selective laser melting, and binder jetting. Small particle distribution in powders produce finer structures with powder bed fusion processes.

Akash Bhatia et. al Additive manufacturing materials, methods and applications studied in detail about wide range of materials and methods used in additive manufacturing. Materials which are most commonly used such as polymers, metals and alloys, composites, concrete, ceramics to the materials which are under development stages such as biomaterials, food printing materials, smart materials, glass, resin and wood are discussed in detail with their respective 3D printing methods Every material has different mechanical and chemical properties due to this every material have different applications in industrial sectors. Additive manufacturing has capability to revolutionize industrial sectors by using its ability to print all these discussed materials at affordable cost. Recent studies shows that the cost of 3D printers reduced and its accuracy and precision is improved. Advancements in additive manufacturing provide lots of benefits such as reduced man power, reduced time wastage, reduced wastage of materials and improved product quality. These advancements and optimization help to achieve a shift in the industries from 'rapid prototyping' to 'rapid manufacturing'. Additive manufacturing is not only limited to prototyping but also used as a small-scale manufacturing of desired and customized products. Additive manufacturing materials and methods is the future of manufacturing industries, health care sectors, food sectors and construction industries etc.

M Bhuvanesh Kumar et. al Methods and materials for additive manufacturing: A critical review on advancements and challenges studied that efforts are being taken around the world to introduce quality products with better physical and functional performance. Developing better materials and metallurgical knowledge is the base for quality products and their sustainability in research. This paper covered the insights of mechanical and microstructural characteristics of 3D printed metallic materials and composites such as steels, Al and Mg alloys, Ti and its alloys, Ni/Co-based alloys, high-entropy alloys, magnetic alloys, BMGs, and metal matrix composites. The main challenges observed from the literature concerning metallic materials are difficulty in bringing required microstructural characteristics that directly influence the mechanical and other properties. Metal matrix composites are the best alternatives for conventional materials to improve strength related aspects of 3D printed parts. The other segment in AM is polymers and polymer composites. Resins and powders are commonly used in polymer-based AM processes such as FDM, SLA, SLS, FDM, and poly jet printing. Frequently used polymers in AM are ABS, PLA, and polyamides and thermosetting polymers.

Ela Sachyani Keneth et. al 3D Printing Materials for Soft Robotics studied that there are still challenges involving the development of materials that are tailored for the various printing technologies, and that are capable of enabling printing of fully functional soft robotics devices, without post-printing assembly. We expect that further research that is focused on flexible and stretchable materials, reversible SMPs, and SH properties will lead to significant progress in soft robotics. In addition, further development of printing technologies is required, mainly for multi-material printing, and printing embedded electronics. The future goal in this field is the successive fabrication of all-printed robots that can be activated immediately, without the need to attach wiring, or to assemble parts. This will include printing of the power sources, such as batteries, pumps, or fuel cells, and any other needed components as well as the ability to print all the different parts of the robot, that is, actuator, sensor, and control system at once, using one printer.

Amit M. E. Arefin et. al Polymer 3D Printing Review: Materials, Process, and Design Strategies for Medical Applications studied that polymer 3D printing for medical applications was conducted, and highlighted how material, process, and design decisions influence application performance, therefore necessitating designers to carefully consider all factors when configuring parts. Recent research has demonstrated a diversity of polymer materials with varied properties according to 3D printing processing parameters. Design strategies enable the directed placement of materials to achieve improved performance with configurations such as architected or multi-material structures. Because of the complexities involved in considering all factors that influence application performance, it is recommended that researchers conduct further experiments considering the interactions of materials, processes, and design strategies, while developing new methodologies to handle decision making and configuration for applications. Overall, advances in 3D polymer printing have demonstrated many successes for implemented designs, with a need for continued research to fully leverage the technology for wide-ranging applications in engineering and medicine.

III. Materials

There are many materials that can be used in Additive Manufacturing technologies such as polymers, ceramics, metals, nylon, ABS, photopolymer resin etc. Below are mentioned a few of the most commonly used materials in Additive Manufacturing, its advantages and disadvantages

1. Nylon

Nylon or Polyamide is a synthetic thermoplastic material, commonly known as plastic. It was initially created as a replacement material for silk. Nylon is inexpensive and considered as one of the strongest thermoplastic materials in the world. It is used to create very complex geometrical structures. Due to the high flexibility, durability, low-friction, and corrosion-resistance features, Nylon is widely used in different additives manufacturing projects such as prototyping, modeling, and even footwear and accessories.

Nylon requires a high temperature to print, and it is harder to get Nylon to stick to the print bed compared to other materials. Nylon is primarily used in Selective Laser Sintering (SLS) or Fused Deposition Modelling (FDM) and Fused Filament Fabrication (FFF) printers.

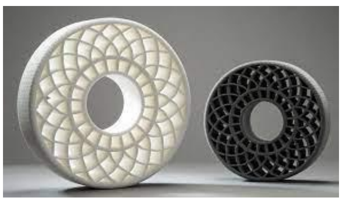

Figure 1: Nylon

Advantages:

- Nylon is highly durable and flexible.
- Good replacement for injection molding applications
- Nylon has great mechanical properties and can be used for a range of applications.
- Nylon can be easily colored, dyed, tumbled and smoothed.

Disadvantages:

- Due to the temperature difference, there can be some shrinkage in the material.

- Post-processing can be challenging for SLS parts if you're not familiar with the correct steps
- Long cool down cycles limit the productivity
- FDM & FFF nylon filament requires proper drying to achieve the best results.

2. ABS

ABS filament is one of the most common filaments used in 3D printers. It contains elastomers, which makes the material more flexible and shock-resistant. ABS is most used in car bodyworks, home appliances, and mobile phone cases. ABS is a durable material and can withstand the temperature between -4°F to 176°F. Along with the high strength, it is a recyclable material and can be used in chemical processes. However, ABS is not a biodegradable material and can shrink in contact with moist air. It cannot be used in open platform 3D printers; the Printing platform must be closed and heated to prevent warping and shrinkage.[6]

Advantages:

- Most readily available and low-cost material
- ABS has a longer lifecycle compared to Nylon
- ABS comes in different colours.
- ABS is highly efficient in creating prototypes and models.

Disadvantages:

- Need a closed platform to prevent warping.
- ABS is non-biodegradable. So, it is challenging to get rid of.
- ABS releases toxic fumes and smell at high temperature.

3. Photopolymer Resin

Resin is one of the most popular 3D printing material out there. Resins are UV light-sensitive, and they work by using a light source or laser to solidify the resins. Photopolymer resins are used in technologies like SLA, DLP, MultiJet, and CLIP technologies. Resins are used in creating intricate details with smoother surfaces. The difference between FDM filament and resins is that you cannot mix different resins to get different results. There are different types of resins for different needs. More durable resins are used in engineering applications, flexible resins are used in footwear, etc.

Figure 2: Photopolymer resin

Advantages:

- Resin can be used in a multitude of applications
- It doesn't shrink like other polymer materials
- Resins have high chemical resistances
- Resin can be used to produce intricate designs and a smoother surface finish.

Disadvantages:

- Resins can be expensive
- Resins are photo-reactive. So, you have to be careful when storing resins
- High heat can cause premature polymerization.

4. Polylactic Acid (PLA)

PLA, also known as polylactic acid, is a biodegradable material. It is created using organic raw material like corn starch. PLA is one of the easiest 3D printing material as it doesn't need any heated platform to print, and PLA also prints at a lower temperature than ABS.

With a high cooling and solidification speed, it's difficult to manipulate with the design. Also, the PLA models can deteriorate if it comes in contact with water. The simplicity, the variation of colors, and the properties of PLA make it the best material to use in FLA 3D printing.

Advantages:

- PLA is easier to print
- PLA is available in a wide range of colors
- PLA can be used to print sharp aged designs.

Disadvantages:
- PLA is vulnerable in high heat. It deforms when exposed to high temperature
- The materials created with PLA are not sturdy.

5. PET/PETG

Polyethylene terephthalate or PET is commonly seen in disposable plastic bottles. Due to higher chemical resistance and rigid compositions, PET is used in manufacturing plastic containers used in packaging food. PET is a translucent filament with different variations such as PETG, PETT, and PETE. The general temperature of the printing PET is 167°-194°F. PETG or glycolysis polyester is a variation of PET and the most commonly used PET in the additive manufacturing market. It is an amorphous and recyclable plastic with the characteristics combined of PLA and ABS.

Advantages:
- PET is a strong, durable and recyclable material
- It can be sterilized to use in the food packaging industry
- Its temperature resistance and easy to print.

Disadvantages:
- The material reacts to UV light and may weaken the material
- PET is prone to scratching.

6. Flexible Material (TPU)

Flexible filaments made out of TPU or thermoplastic polyurethane is also a very popular choice as a 3D printing material. TPU is characterized by high flexibility and durability, combining the properties of rubber and thermoplastics. Because of its chemical composition, TPU is a varied polymer and provides a wide range of use cases. In the manufacturing industry, TPU is generally used to create footwear soles; in the automotive industry, it is used to create tires and shock absorbers. Also, TPU is widely used in mobile phone cases and protective covers for intricate devices.

Figure 3: Flexible material (TPU)

Advantages:
- Allow manufacturers to create deformable objects
- High impact strength and shock absorbant capabilities
- Have rubber-like elasticity
- Have resistance against oil, grease, abrasion

Disadvantages:
- Some grades of TPU have a shorter shelf life
- TPU is not as cost-effective as other options

7. Stainless Steel

Stainless steel is known for its high strength and excellent corrosion resistance abilities. Stainless steel is used in various sectors, from manufacturing to assistive technologies. The 3D printing technologies used to print stainless steel are fusion and laser sintering. Similar to gold and silver, DMLS or Direct Metal Laser Sintering and SML technologies are used in printing stainless steel.[7]–[9]

Figure 4: Stainless steel

Advantages:

- Stainless steel is corrosion resistive and high in strength.
- Stainless steel has a high ductility.

Disadvantages:

- Printing with stainless steel is expensive.
- It takes too much time to 3D print using stainless steel.

8. Titanium

Titanium is a strong, lightweight, heat, and chemical resistant material mainly used for high-performance applications, such as spaceships, aircraft, and the medical field. Due to its high strength, it is incredibly challenging to the machine by tools. That makes it an excellent material for additive manufacturing.

Advantages:

- It can create sophisticated products.
- It offers an industrial-grade precision in the design.
- It’s biocompatible and corrosion-resistant

Disadvantages:

- Titanium is expensive, and the 3D printing process is costly as well

9. Alumide

Alumide is a 3D printing material made by mixing polyamide and aluminum powders using the SLS process. Alumide has a porous and metallic finish and has good mechanical strength and temperature resistance(up to 340 °F). And for these reasons, it’s used in the rapid prototyping and 3D printing industry. It’s used in creating complex modeling, designing, or production of small functional models that need high rigidity. However, Alumide has some design limits.[10]–[13]

Advantages:

- Alumide is abrasion resistant
- It’s extremely detailed and clean to print
- It features a high heat resistance and high breaking strength

Disadvantages:

- Very rough surface
- Not waterproof
- It has design limits.

10. High Impact Polystyrene

High impact polystyrene or high-density polyethylene is a lightweight and flexible material. It is widely used in making pipes and plastic bottles and packages due to its high molding ability. HIPS is used as a replacement for ABS because it has high-temperature resistance, and it is resistant to most of the chemicals except limonene. However, HIPS requires a heated printing bed to print, and it also shrinks when it cools down, leading to war page.

Figure 5: High impact polystyrene

Advantages:

- HIPS is excellent for making intricate designs
- It’s water-resistant
- It is inexpensive

Disadvantages:

- At high temperature, it produces strong fumes
- It solidifies quickly and may clog the printer nozzle if there isn’t enough heat flow.

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IV. Conclusion

In this review we have studied about the different types of materials used in Additive Manufacturing technologies. Materials which are most ordinarily used such as ABS, polymers, ceramics, high impact polystyrene, alumide etc and discussed about their various advantages and drawbacks. Every material has different mechanical and chemical properties thanks to this every material have different applications in industrial sectors. Additive manufacturing has capability to revolutionize industrial sectors by using its ability to print of these discussed materials at affordable cost. Recent studies shows that the value of 3D printers reduced and its accuracy and precision is improved. Advancements in additive manufacturing provide plenty of benefits such as reduced man power, reduced time wastage, reduced wastage of materials and improved product quality. These advancements and optimization help to realize a shift in the industries from rapid prototyping to rapid manufacturing. Metal and polymer 3D printing is growing rapidly covering large areas of application in medical, aerospace, automotive, fashion etc. The expansion of manufacturing sector after the introduction of materials used in additive manufacturing technologies are enormous.

V. Future Scope

As advancements in Additive Manufacturing technologies develops, we'll be able to use various other materials for 3D printing and high future potential applications include printed hands, commercial buildings, rocket propellant, farming tools, wastewater membranes etc. Time is extremely near were making of human organs, bones, tissues etc. employing a 3D printer will become a common sight where the patient don't need to wait for donors. Astronauts and space scientists try to make living possible in moon and other planets. Additive manufacturing is that, the solution where lunar materials can be used for construction of houses and other equipment. The researches within the area of additive manufacturing are extremely important to explore new technology advancements and discover future potential and applications. the most constraints like mass production, material limitations and standards setting should be addressed for the establishment of this trending technology. New application specific materials with good properties have to be developed for expanding its scope.

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