Types of Polymers Using in 3D Printing and Their Applications: A Brief Review

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Abstract:

The technology based on using 3D printing machines (3DPs) can be considered a promising approach in industry. A 3D printer might be define as machines which manufacture 3D products or models that already designed by computer aided design (CAD) software programs. These machines can create geometries that are very complicated and so difficult to fabricate by traditional manufacturing approaches. Additionally, it has capability to create items that is so complex internal design products with lower time and cost. Several kinds of materials have been applied in this technology. The polymers is one the most common materials that are using in 3D printing. This review seeks to clarify the features and benefits of different types of polymers including Acrylonitrile Butadiene Styrene (ABS), Polylactic acid (PLA), Acrylonitrile styrene acrylate (ASA), Polyethylene terephthalate (PET), Glycolized polyester(PETG), Polycarbonate (PC), Polypropylene (PP), Nylon, and Hybrid and composite materials.

Introduction

A new revolution in industry world has been appeared in the last three decades called 3D printing. The 3D printer can be defined as kind of machines has specific-purpose which fabricate3D geometry parts or models of devices and components using an additive manufacturing (AM) process. This geometry was already designed by using software program called computer aided design (CAD) (Al-Gawhari &Mohammed Ali, 2022). Several types of materials were applied in this technology. Fused deposition modeling (FDM) technique is the most widespread way for polymer-based 3D printing (Fafenrot et al., 2017). Moreover, many other additive manufacturing methods are offered, for example, DMD (direct metal deposition), 3D printing, IJM (inkjet Modelling), SLS (selective laser sintering), and SLA (stereo-lithography). Each One of these technologies is different in terms of the technique and resources that are used for production. There are several advantages that can be obtained by this technology including flexibility in fabrication 3D complex design geometry, quick prototyping solutions, lightweight product with minimal waste materials and this technology. However, there are some limitations such as high cost of production, only limited metals and polymers can be used, size limitations, and this technology can cause reduce of manufacture jobs opportunities in addition to the risk of using they prohibited Components and Pirated Products.

The polymers are one of the most materials common in this method of manufacture. Polymers are the materials that are often utilized in 3D printing because their features of affordability, versatility, and simplicity of use. They are set of materials that can be melted and extruded into several shapes, like plastics, rubber-like substances and resins (Zhou et al., 2020). There are a number kinds of polymers used in 3D printing, each type has own exclusive applications and characteristics. This work seeks to explore and clarify the most common polymers that are using in 3D printing.

Acrylonitrile Butadiene Styrene

ABS (Acrylonitrile Butadiene Styrene) is a kind of thermoplastic polymer very often applied in 3D printing manufacturing as filament. It is applied in the body of automotive, instruments and cases of mobile phones. It is a thermoplastic that has a number of elastomers related to polybutadiene, letting it resistant to shocks and more flexible (Borate, 2018). ABS has been used in the powder bed methods like SLS as a powder form, and as a liquid state for SLA and PolyJet techniques. The Poly Jet is great three dimensions printing machinery that produces accurate parts, smooth, prototypes and tooling with tiny layer resolution and accuracy reach to less than 0.014 mm. It can create very thin walls in so complex designs.

ABS is heated between 230ºC and 260ºC during operation in 3D printing. The toughness of this material makes it able to withstand wide range of temperatures (minuses twenty °C to eighty °C). Additionally, it has high strength property, moreover it has recyclable characteristic and able to join with chemical methods. But ABS can't shrink and biodegradable when interaction with air, therefore, at the stage of printing machine need essentially be heated to avoid warping. Additionally, it is suggested to use a secure chamber 3D printer to decrease emissions of harmful particles (Agashe, 2020).

In order to obtain lightweight products with good resistance at low temperatures, ABS is considered the mostly known polymer for this request. Generally, it is useful in the domestic application. Also, it is applying in boat hulls, toys, pieces and decoration (Shinde et al., 2020)

ABS polymer is very commonly applied material in the FDM sector with PLA.

ABS is one of the oldest polymers to be used with 3D printers industrial, it was developing about 1990. This type of polymer is known a 'terpolymer' and gotten greatest frequently by polymerization of 55% styrene, 20% acrylonitrile, and 25% butadiene. Controlling these specific quantities can modify the ABS properties; styrene, for instance, is resin that gives ABS its rigidity and brilliance, whereas butadiene offers it its low temperature properties and impact resistance. Moreover, it is very affordable in terms of cost (Shivkumar ,2017).

The ABS filaments characteristics in 3D technology are offered in the filaments form 1.75 mm diameter and in a number of colors, ABS has favorite properties for several manufacturing that would like to 3D print purposeful items or prototypes. While it is so hard to fabricate with 3D printer than PLA, ABS stay a very desirable polymer for 3D technique engineers because it is with stand to impact and wide range of temperature (between minuses twenty °C and eighty °C). It is providing smooth, opaque, and sparkly surfaces. It has ability to weld using chemical processes such as acetone (Halim et al., 2021).

The ABS melting temperature point is about 200°C, so it is suggested that the extrusion heat have to be between 230 and 260°C and the heating plate must be (between 80 and 130°C).

This plastic shrink when contact directly with air, producing the part to shrink (or warp) and thus coming off this one from the platform. For big parts, it is better to use an adhesive lacquer or a special adhesive like Kapton. Finally, a 3D printer with a closed field is better because ABS plastic releases particles that can be risky for the worker.

PLA

PLA identified as polylactic acid prepared from renewable materials like, tapioca roots, sugar cane, or corn starch, different from other polymers made mostly from oil. As it is ecological origins this polymer has been common within the 3D technology sector. The scientist t called Wallace Carothers was created the PLA in the 1930s, most recognized for the improvement of neoprene and nylon in the DuPont Company in the USA. This material was produced finally for use in 1980s by the Cargill Company in the USA.

This material unlike ABS is biodegradable polymer so it is considering a sustainable polymer. PLA fabricated by renewable materials like corn starch. PLA can be considering the easiest polymers to print, because it has ability to shrink slightly after finishing the process of 3D printing. There is no required to heat the platform before printing in PLA, dissimilar with ABS polymer. PLA prints between 190ºC to 230ºC that is at a lower temperature compare with ABS (Ligon et al., 2017).

This polymer is simple to work, consistent, and in many colors, therefore it has been appropriate for FDM 3D printing.

This polymer is made by fermenting a carbohydrate compound like corn powder. In this process, the raw material is minced to dismiss the starch from the corn, mix it with lactic monomers or acid. By this admixture the starch is converted into corn sugar or dextrose (D-glucose), to end, glucose fermentation yields L-lactic acid, the elementary component of PLA. This is considering as a type of a non-Newtonian pseudo-plastic liquid. The viscosity (flow resistance) can be change regarding to the subjected stress. PLA is a good cut material, on other word, the viscosity reduces when stress is applied (Sandanamsamy, 2021). Because PLA is made from renewable materials and also it has a good mechanical property it has been wide acceptance within 3D printing especially for beginners due to it is a so easy to deal with. The melting point of 180ºC, which is lower than ABS filament melting rang (200-260^{0}C). Therefore, what time printing with PLA, the use of a pre

heated platform and the secure environment chamber are not essential. PLA is describing a semi-crystalline polymer (Amit,2021).

PLA has better resistance to heat compared with ABS; therefore it is a wide used in the food production. There is no request to difficult post-processing. It can be treated or sanded with acetone fluid if required and the supports materials are commonly simple to take away. Here may be some issues with the first layer of this polymer, therefore, to facilitate its detachment when the part is finished; it is suggested to add adhesive tape onto the tray.

The disadvantages of the PLA polymer, it has a higher viscosity that may be cause a clogging in the head of print. Also, it is usually doesn't recommended to use it if the geometry have big mechanical complexities. PLA is a harder polymer to operate because it's high-speed cooling and solidification parameter. Moreover, this product can worsen when it been in contact with water.

ASA

ASA is a polymer which has approximately the same features to ABS; however it shown a better resistance to Ultraviolet radiation. Like ABS, it is recommended to print this material by way of a pre- heated platform in order to avoid the problem of warping. The printing by ASA, like print ABS and the same sets are used; however, more attention is required to print with a safe chamber to prevent the risk of styrene fluid releases (Kumar et al., 2021).

Polyethylene Terephthalate

PET (Polyethylene terephthalate) is usually used in disposable bottles. PET is the ideal material for any parts projected for food keeping. Additionally, this polymer has perfect chemical resistance and is to some extend rigid. The best temperature of printing with 75 – 90ºC. Commonly PET is available in markets as a filament, with different form like PETE, PETT, and PETG. Pros of PET include that the polymer is fully recyclable and doesn't release

any odors during printing (Chakraborty et al.,2022).

PETG

Glycolized polyester (PETG), is a thermoplastic commonly used in the3D printing sector, combining both the strength of ABS and the simplicity of PLA 3D printing. As the PETG is an amorphous plastic therefore it is fully recycled materials. It has similar chemical structure as polyethylene terephthalate, l well-known via its abbreviation PET. In order to reduce its brittleness Glycol can be added making it more fragility. It is one of the most commonly used polymers on the industry, representing for 18% of global plastic production over the world. As the PET has some problems with overheating during fabricating process that make PETG is recommended as an alternative (Alarifi, 2023). PETG is a copolymer, having the properties of both glycol and PET. It has a brittle appearance, ductility, impact and chemical resistance, hardness, and transparency. Also, it has good thermal stability and easily extruded material with perfect food compatibility. On the downside, it has low-rate warping, therefore, is better to use a Build -Tak sheet to make sure the material grips to avoid this problem. It is also more susceptible to scratches compared PLA. Finally, it can speedily receipt moisture and will keep better in a dry and cool environment (Loskot et al., 2023).

Regarding printing parameters. The extrusion temperature of PETG between 220° and 260°C and it is recommended to heat the tray lower than 80°C. The printing speed is 40-60mm/s. It is unsuitable to add supports due to its sticky appearance and it will be hard to remove.

Polycarbonate (PC)

Polycarbonate is a polymer well-known in the 3D printing industry for its transparency and impact resistance. It is so far strong thermoplastic with lightweight, suitable for many applications. It is difficult to print with as PLA or PETG as it requires a relatively high extrusion and build plate temperature. However, 3D printing with polycarbonate lets heat resistant and complex and parts to be made with FDM machinery (Mercado, 2020).

The built-up process of PC, it is generally gotten by polycondensation – in this case of phosgene and bisphenol A. It is mostly used in the manufacture of optical glass due to its transparency because it is lower density compared with glass. Also, it is used in the fabrication of bulletproof windows and motorcycle helmets due to its great impact resistance. In order to increase the strength of the PC it can be reinforced with fibers, such as glass fibers or carbon or, that making it lighter (Kumar et al., 2019). The polycarbonate filament can resist at heat between 140 0C -150 0C, therefore increasing the whole number of applied applications. Actually, the Polycarbonate was banned from use for baby feed bottles and other products because release dangerous particles called (bisphenol A), which are very harmful for human health. Moreover, it is a hygroscopic thermoplastic, in other i word it absorbs moisture from the air. Therefore, if it is not putted in a dry place, it will be likely to swell, producing extrusion issue. This material is so very sensitive to hydrolysis and UV; therefore it is not suitable for outdoor applications. The polycarbonate filament shows some problems due to the adhesion to the build plate: that because its manufacturing temperature is high, which make it peel off the serving dish this case known (warping). To solve this problem it is recommend using hot plate (80 - 120°C) with extrusion temperature between 260 and 310°C) in closed chamber. The polycarbonate filaments are offered are wide range forms, such as Nanovia, 3DXTech, Polymaker, Kimya (Liu et al.,2020).

Great Performance Polymers (PEEK, PEKK, ULTEM)

A large number of research work on printing materials aim to improve a number of high-performance filaments with excellent mechanical properties approximately similar to metals mechanical properties.

Many kinds of good -performance plastics in 3D printing in like PEKK, ULTEM or PEEK –that are known by families like or polyetherimides (PEI) or polyaryletherketones (PAEK)(Loskot et al, 2023) .

of these filaments have a great thermal and mechanical resistance and the strength property, compared with some metals, therefore, they recommended in many industrial sectors such as automotive, aerospace and medical.

About a third of these materials cannot use in all kinds of FDM machines because, the 3D printer machines essentially have a bed plate able to heat to 225°C, and an extrusion about 360°C with a closed safe chamber, but they are suitable with SLS printers when they found in powder form (Dua et al., 2021).

Polypropylene (PP)

Polypropylene is type of thermoplastic commonly applied in the cars industry, and in the work of many hundreds of daily items. PP is distinguished by its ability to take in shocks and its resistance to abrasion and, proportional flexible and rigid. However, disadvantages of this polymer such as, its weak heat temperature resistance, and sensitive to ultraviolet radations that can make it inflate, therefore, numerous researchers have advanced alternative kinds of PP, called (simili-propilenos), which are robust both mechanically and physically (Singh,2019).

Nylon

Nylon Filaments for FDM 3D printing

Nylon is so often offered with six carbon atoms, usually named PA6. It is kind a filament that several motivating features, including perfect resistance to power of impact, and abrasion. In addition, it has mechanical properties are very similar to ABS. However, nylon will need the occurrence of a pre-heated bed plate that is reached about 80°C in the 3D printer because of adhesion problems. It will also be essential to be careful in storage period due to it fast absorbs the close moisture (hygroscopic material) that

can affect the quality of printing. In extrusion process temperature, the 3D printer will growth to 250°C, or at least 225°C for definite kinds of nylon (Niknam et al., 2020).

Nylon filaments are a worthy alternative to polycarbonate because they are easy to print. It has a longer life-service, so it is perfect for printing items that required to be good resistant. So, nylon is recommended to make, tools, hinges or machine modules that must have a notable resistance such as gears.

Polyamides in powder form aren't the best common procedure for 3D printing of nylon. In (SLS) technology is Nylon, usually PA11or PA12. The PA12, is the most common in the3D industry that is available in powder form: it has so high thermal and mechanical properties resistant to stress, high rigidity, very high solid at so low temperatures and resistance to several chemicals and products (Attoye, 2018). Compared with filaments it can absorb a small amount of moisture and so easy to operate after printing (paint, colorant, etc.). Moreover, this material is a biocompatible polymer: it possible to use for making items that can contact directly with skin that allows it to be the favorite polymer for the applications of medical sector, especially for the creating of prosthetic medical devices.

PA11 is also set up on the AM sector. It is bio-sourced, derived generally from castor oil while PA12 is making from petrol; consequently PA11 is safer environmentally. It has similar the features of PA12 with some differences: PA11 has preferable thermal stability, more resistance to UV and light, and perfect features of elasticity. Geometry fabricated with this material has a longer time-consuming.

Composites

Composites are very advantageous when looking forward creating lightweight and strong parts. The parts of fibers increase the strength to a part with negligible increasing weight that is indicating to composites as better reinforced materials by fiber. There are two main kinds of reinforcement's continuous fiber or, short fiber. In the second case, cut fibers, which made up of

parts less than one millimeter in size, are mixed into 3D printing polymer to increase the stiffness and to a reduced the strength level of components. Chopped fibers usually mixed with some kinds of thermoplastics such as PLA, ABS or nylon (Colmenero,2020).

On the other hand, the fibers can be added to the most types of thermoplastics continuously to reach at a robust part. The carbon fiber is the main fiber used in the 3D printing technology, also other fibers like Kevlar or glass fiber (Mogan, 2021).

Carbon Fiber Reinforced Filament Spool

It has clearly noticed that large number of 3D printing companies are Using composites to create items. The significant question is why most desirable material in 3D printing is the composites materials?

Remarkably, the composite 3D printing market estimated to be more than $1.73 billion USD in the next decade as extraordinary growth.

New material combinations will likely create new applications. The first diamond composite shape was fabricated recently by Sandvik. Diamond is difficult to apply in 3D printing because it is very hard. The diamond composite, the material's properties can be useful for many resistant tools (drilling, mining, or cutting) and medical applications (Iftekar, 2023).

Hybrid Materials

There are a many kinds of hybrid materials that prepared by mix plastics by powders to obtain different color and finish or extra properties. Regularly depend on PLA; these materials are typically made of 30% hybrid material and 70% PLA. For instance, wood-based filaments variable from wood dust, cork, and bamboo are available. Moreover, several kinds of hybrid materials combine with metal to work with FDM machines, to provide items a metallic finish. They depend mainly on silver, bronze, copper,

and other metal (Al-Gawhari &Mohammed Ali, 2022).

3D filaments based on wood - Alumide

The Alumide plastic items are fabricated by a mix aluminum powder with polyamides by the SLS method. This polymer has a big and somewhat porous appearance surface, a sandy and rough appearance present and high thermal resistance (up to 170°C) and high strength. But, it is necessary to apply some post-processing treatments like, sanding, grinding, milling or coating (Stoia, et al.,2020) .

Soluble Materials

Soluble materials can be defined as materials had printed with the purpose of dissolve it in a forthcoming step of the work process. Commonly the most two solvable filament materials are PVA (Polyvinyl Acetate) HIPS (High Impact Polystyrene). HIPS is allied with ABS, and have ability to dissolve by mix it with limonene, while PVA relates to PLA and easy to dissolve in water (Tagami, 2019)

Also, there are BVOH filaments has been increasingly common, mainly in dual extruder 3D printers. This material has a higher solubility in water than PVA.

Resins (for Photopolymerisation-based 3D Printing)

There is type of 3D printing depend on photopolymerization use Ultraviolet sensitive resins to manufacture item layer by layer. That mean, a light source such as a LCD or laser screen to solid a liquid photopolymer by using techniques include, DLP, SLA, and Material Jetting (PolyJet) (Jasiuk el at, 2018). I this technology utilizing resins create high detail with smooth surface parts; however, the color variety is very limited by this method.

Conclusion

To clarify the features and benefits of different types of polymers including Acrylonitrile Butadiene Styrene (ABS), Polylactic acid(PLA), Acrylonitrile styrene acrylate (ASA), Polyethylene terephthalate (PET), Glycolized polyester(PETG), Polycarbonate (PC), Polypropylene (PP), Nylon, and Hybrid and composite materials has been clarified in this review. These polymers are used in several kinds of machines. Each type of polymer is suitable for a printer or more. Selecting a specific kind of polymer is important to understanding the specifications and features of the polymer. It is possible to compare the types to make the selection easier. Classifying the polymer regarding the type of printer and the required application in future work is recommended.

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