

Chapter 4 - Materials used for 3D printing

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4.1 Polymers, Metals, Non-Metals, Ceramics

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Anisotropic Properties

- Isotropic means constant characteristic properties in any direction and identical values at any point in the part's volume.
- Isotropic material behavior therefore is a requirement for traditional tool-based production and consequently provides the basis for engineering design calculations.
- When a part is manufactured in layers it is not surprising that the part will exhibit recognizable property differences.
- Layer-oriented manufacturing by AM processes in fact produces anisotropic parts. The degree of anisotropy may vary: from barely recognizable to a degree that has a significant impact on the part's stability.
- Because of the layer manufacturing, the part's properties parallel to the build area and those perpendicular to it differ from each other.
- This effect can be theoretically compensated by simply changing the orientation of the part in the build chamber.
- As a design rule, the area of the highest load should be parallel to the build area.

Define Plastics / Polymers

Polymers are materials made of long, repeating chains of molecules. The materials have unique properties, depending on the type of molecules being bonded and how they are bonded.

Eg. PLA, Resin etc.

Properties of Polymers

- Low density: Many polymers have a low density, which makes them lightweight and easy to transport.
- High strength: Some polymers have a high strength-to-weight ratio, which makes them strong and durable despite their low density.
- Flexibility: Polymers can be flexible and have a degree of elasticity, making them useful for applications where they need to bend or stretch.
- Thermal and electrical insulation: Many polymers are good insulators of heat and electricity, making them useful for applications where insulation is important.
- Chemical resistance: Polymers can be resistant to many chemicals, making them useful for applications where they will come into contact with corrosive substances.
- Water resistance: Some polymers are water-resistant or waterproof, making them useful for applications where they will be exposed to moisture.
- Transparency: Certain polymers can be transparent, making them useful for applications where optical clarity is important.
- Biodegradability: Some polymers are biodegradable, meaning they can break down into harmless substances in the environment, making them useful for sustainable applications.
- Adhesion: Certain polymers can adhere well to other materials, making them useful for applications where bonding is important.
- Processability: Polymers can be easily processed into various shapes and forms, making them versatile for use in different manufacturing processes.

List different types of Materials used in 3D printing

- Thermoplastics: The most common materials used in 3D printing are thermoplastics, such as ABS, PLA, PETG, and Nylon.
- Photopolymers: These materials are used in SLA (Stereolithography) and DLP (Digital Light Processing) 3D printers. Photopolymers are cured using UV light and come in a range of colors and material properties.

- **Metals:** Metals like aluminum, stainless steel, and titanium can be 3D printed using processes like DMLS (Direct Metal Laser Sintering) and SLM (Selective Laser Melting).
- **Ceramics:** Ceramic materials like porcelain and glass can be 3D printed using powder-based 3D printing technologies.
- **Composites:** These materials are made up of a combination of different materials, such as carbon fiber or fiberglass, mixed with a polymer matrix.
- **Biomaterials:** These materials include living tissues, cells, and other biological materials, and are used in applications like regenerative medicine and tissue engineering.
- **Wax:** Wax is used in 3D printing to create molds for casting metal objects.
- **Food materials:** Some 3D printers can print food materials like chocolate, sugar, and dough, allowing for the creation of intricate and artistic culinary designs.
- **Paper:** 3D printers that use paper as a material are called 3D paper printers. They work by gluing layers of paper together to create a 3D object.
- **Concrete:** Large-scale 3D printers can print concrete to create architectural structures and buildings.

PLA (Polylactide)

PLA (Polylactic Acid) is a commonly used thermoplastic material in 3D printing. It is a biodegradable and compostable material made from renewable resources such as cornstarch or sugarcane.

Uses of PLA

PLA is a versatile material that can be used in a wide range of 3D printing applications. Some common uses of PLA in 3D printing include:

- **Prototyping:** PLA is commonly used for prototyping due to its ease of use, low cost, and availability in a wide range of colors and finishes.
- **Artistic applications:** PLA can be used to create artistic and decorative objects due to its ability to produce vibrant colors and fine details.
- **Education:** PLA is often used in educational settings, such as schools and universities, to teach students about 3D printing and rapid prototyping.
- **Toys and figurines:** PLA is a popular choice for creating toys and figurines due to its low toxicity and ability to produce intricate details.

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- Household items: PLA can be used to create a variety of household items, such as organizers, planters, and vases.
- Cosplay and props: PLA is often used to create props and costumes for cosplay and theater productions due to its ability to produce detailed and lightweight objects.
- Medical models: PLA can be used to create medical models for training and simulation purposes due to its low cost and ease of use.
- Packaging and containers: PLA can be used to create biodegradable packaging and containers, reducing the environmental impact of disposable products.
- Aerospace and automotive parts: PLA can be used to create lightweight and durable parts for aerospace and automotive applications, particularly when combined with other materials in composite structures.
- Sustainable design: PLA is a sustainable material made from renewable resources, making it a popular choice for sustainable design and product development.

Types of PLA

There are several types of PLA (Polylactic Acid) available for use in 3D printing. Some of the most common types include:

- Standard PLA: This is the most commonly used type of PLA in 3D printing. It is easy to print with and produces high-quality prints with a smooth surface finish.
- High Temperature PLA: This type of PLA has a higher melting point than standard PLA, making it more suitable for printing objects that require higher temperature resistance.
- Tough PLA: Tough PLA is a blend of PLA and other materials that make it more impact-resistant and durable than standard PLA.
- Flexible PLA: This type of PLA is blended with other materials that make it more flexible and rubbery, suitable for printing objects that require flexibility.
- Conductive PLA: This is a special type of PLA that contains conductive particles, making it suitable for printing electrical components and circuits.

- **Glow-in-the-dark PLA:** This type of PLA contains phosphorescent particles that make it glow in the dark after being exposed to light.
- **Wood-filled PLA:** Wood-filled PLA is a blend of PLA and wood fibers, giving the printed object a wood-like appearance and texture.
- **Metal-filled PLA:** Metal-filled PLA is a blend of PLA and metal particles, giving the printed object a metallic appearance and texture.
- **Carbon Fiber PLA:** Carbon fiber PLA is a blend of PLA and carbon fibers, making it stronger and stiffer than standard PLA.
- **Color-changing PLA:** This type of PLA changes color based on the temperature, making it suitable for printing objects that require temperature-sensitive color changes.

Advantages of PLA

PLA (Polylactic Acid) is a popular material in 3D printing due to its many advantages, which include:

- **Easy to use:** PLA is easy to print with and does not require a heated bed, making it a great material for beginners.
- **Low warping:** PLA has low shrinkage and warping properties, meaning that it will not deform or warp during printing.
- **Biodegradable:** PLA is made from renewable resources and is biodegradable, making it an environmentally friendly choice.
- **Low toxicity:** PLA is non-toxic and does not produce harmful fumes when printed, making it safe to use in homes, schools, and other settings.
- **Wide range of colors:** PLA is available in a wide range of colors and finishes, making it suitable for a variety of applications.
- **Good surface finish:** PLA produces prints with a smooth surface finish, making it suitable for printing objects with intricate details and fine features.
- **Low cost:** PLA is a relatively low-cost material, making it a great choice for prototyping and other applications where cost is a concern.
- **Good dimensional accuracy:** PLA has good dimensional accuracy, meaning that printed objects will be very close to the intended size and shape.
- **Odorless:** PLA is odorless when printed, making it a good choice for printing objects that will be used in food or medical applications.

- Versatile: PLA can be used in a wide range of 3D printing applications, including prototyping, artistic creations, toys and figurines, household items, and more.

Disadvantages of PLA

While PLA (Polylactic Acid) has many advantages in 3D printing, it also has some disadvantages that users should be aware of:

- Low temperature resistance: PLA has a low melting point, which makes it unsuitable for printing objects that will be exposed to high temperatures.
- Brittle: PLA can be brittle and prone to cracking, especially when printed with thin walls or in cold environments.
- Limited strength: PLA is not as strong as some other materials used in 3D printing, such as ABS or nylon, making it unsuitable for printing objects that require high strength or impact resistance.
- Sensitive to moisture: PLA can absorb moisture from the air, which can cause problems during printing and affect the quality of the print.
- Limited chemical resistance: PLA is not resistant to some chemicals and solvents, which can cause it to degrade or dissolve.
- Limited lifespan: PLA is biodegradable, which means that printed objects may have a limited lifespan compared to those made from other materials.
- Difficulty with supports: PLA can be difficult to remove from support structures, which can result in damage to the printed object.
- Limited printability with complex geometries: PLA can be difficult to print with complex geometries or intricate designs, which can result in failed prints or poor quality prints.
- Can clog printer nozzles: PLA can sometimes clog printer nozzles due to its low melting point, which can cause printing problems and require maintenance to clear the clogs.
- Limited availability of high-performance variants: While there are many types of PLA available, high-performance variants with improved strength or temperature resistance can be difficult to find or more expensive than other materials.

Applications of PLA

- PLA has a number of common uses, including for medical and food purposes. It is also widely used as a 3D printing feedstock for desktop fused filament fabrication 3D printers.
- PLA is popular for 3D printing as it can easily be sanded, painted or post processed.
- A user friendly material, this plastic works with low extrusion temperatures and there is no need for a heated bed, printer chamber or reinforced nozzle.
- Because PLA can degrade into lactic acid, it can be used for medical implants such as anchors, screws, plates, pins, rods or as a mesh.
- PLA, created with injection moulding, casting or by being spun, is also used as a decomposable packaging material, film or for cups and bags

Define ABS (Acrylonitrile Butadiene Styrene)

ABS (Acrylonitrile Butadiene Styrene) is a common thermoplastic material used in 3D printing. It is known for its strength, durability, and versatility, and is often used to create sturdy and long-lasting objects.

Features of ABS

1. High strength and durability: ABS is a strong and durable thermoplastic material that can withstand high impact forces, making it ideal for creating robust and long-lasting objects.
2. Good temperature resistance: ABS has a relatively high glass transition temperature (around 105°C), which means it can withstand exposure to heat without deforming or melting.
3. Flexibility: ABS has a degree of flexibility that allows it to bend and flex without breaking, making it ideal for creating objects that require some flexibility or resilience.
4. Smooth surface finish: ABS has a smooth surface finish that can be easily sanded, painted, or coated to achieve a high-quality appearance.
5. Chemical resistance: ABS is resistant to many chemicals, including acids, alkalis, and alcohols, which makes it ideal for use in applications where the object will come into contact with chemicals.

6. Good layer adhesion: ABS has good layer adhesion, which means the printed layers will bond well together, resulting in a strong and stable final object.
7. Easy to machine and post-process: ABS can be easily machined, drilled, or tapped after printing, and can also be smoothed or polished to achieve a better surface finish.
8. Versatile: ABS can be used in a wide range of applications, from creating small toys and household objects to larger mechanical parts and components for industrial use. It can also be printed using various 3D printing technologies, such as FDM, SLA, and SLS.
9. Availability: ABS is readily available and widely used in the 3D printing industry, making it easy to find and purchase.
10. Compatibility with support materials: ABS is compatible with a variety of support materials, which makes it easier to print complex geometries and structures.

List few of the strongest 3D printer materials available

There are several 3D printing materials that are known for their strength and durability, including:

- Carbon fiber reinforced nylon: This material is a blend of nylon and carbon fiber, which results in a strong, lightweight material with excellent strength-to-weight ratio.
- Polycarbonate (PC): This material is known for its high impact resistance and durability, making it suitable for printing objects that require toughness and strength.
- Ultem (PEI) Polyetherimide: This high-performance thermoplastic has excellent strength, stiffness, and high-temperature resistance, making it ideal for printing objects that require high strength and resistance to heat.
- Stainless steel: Metal 3D printing, such as Direct Metal Laser Sintering (DMLS), can produce parts made from stainless steel, which is a strong, corrosion-resistant material with high tensile strength.
- Titanium: Another metal commonly used in 3D printing, titanium is a strong, lightweight, and biocompatible material that is suitable for medical implants and aerospace applications.

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- Inconel: This nickel-based alloy has excellent high-temperature resistance, making it suitable for printing objects that will be exposed to extreme heat.

It is important to note that the strength of a 3D printed part depends on several factors, including the design of the part, the printing process, and the material properties.

Polycarbonate (PC) in 3D printing

Polycarbonate (PC) is a common thermoplastic material used in 3D printing. It is known for its toughness, high strength, and heat resistance. However, due to its high melting point and tendency to warp, PC can be difficult to 3D print with.

Types of powdered materials used in 3D printing

There are several types of powdered materials used in 3D printing, each with their own unique properties and applications. Here are some common examples:

- Metal powders - These powders are used in metal additive manufacturing (AM) processes such as direct energy deposition (DED) and powder bed fusion (PBF) to produce metal parts with high strength and durability. Examples of metal powders used in 3D printing include stainless steel, titanium, aluminum, cobalt-chrome, and nickel alloys.
- Polymer powders - These powders are used in powder bed fusion (PBF) 3D printing technologies such as selective laser sintering (SLS) and multi-jet fusion (MJF) to produce parts with high accuracy and intricate geometries. Examples of polymer powders used in 3D printing include nylon, polyamide, polystyrene, and thermoplastic elastomers.
- Ceramic powders - These powders are used in ceramic additive manufacturing (AM) processes such as binder jetting and stereolithography (SLA) to produce parts with high stiffness, thermal resistance, and electrical conductivity. Examples of ceramic powders used in 3D printing include zirconia, alumina, and silicon carbide.
- Composite powders - These powders consist of a mixture of two or more materials, such as metal or ceramic particles embedded in a polymer matrix. Composite powders are used in powder bed fusion (PBF) technologies such as SLS and MJF to produce parts with unique properties, such as increased strength, stiffness, and wear resistance.

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State Powder bed fusion (PBF)

Powder bed fusion (PBF) is a type of additive manufacturing (AM) process that involves building 3D objects by fusing successive layers of powder material. In PBF, a thin layer of powder material is spread over a build platform, and a high-energy heat source is used to selectively melt or fuse the powder in the shape of the desired object. Once a layer is complete, the build platform is lowered and a new layer of powder is spread over the previous layer. This process is repeated until the entire object is complete.

Describe Resin 3D printing liquid

- Resin 3D printing, also known as stereolithography (SLA) or digital light processing (DLP), uses a liquid polymer resin that solidifies when exposed to light. The resin typically comes in a liquid form, and is stored in a resin tank.
- During the printing process, the build platform is lowered into the resin tank, and a light source, either a laser or a projector, is used to selectively cure the liquid resin in the shape of the desired object. This process is repeated layer by layer, with the build platform slowly moving upwards as each layer is cured, until the entire object is complete.
- Resin 3D printing offers several advantages over other types of 3D printing technologies, including high accuracy, smooth surface finish, and the ability to produce highly detailed and intricate geometries. It is also well-suited for producing small, delicate parts with intricate internal features, such as dental or jewelry applications.
- However, resin 3D printing also has some drawbacks. The liquid resin can be messy and requires careful handling and disposal, and the resin itself can be expensive compared to other 3D printing materials. Additionally, resin printing typically requires the use of a post-processing step to clean and cure the final part, which can add additional time and effort to the printing process.

Explain PETG in detail.

- PETG (Polyethylene Terephthalate Glycol) is a common thermoplastic material used in 3D printing. It is a modified version of PET (Polyethylene Terephthalate) that includes glycol in its chemical structure, which improves its properties for 3D printing.
- PETG is known for its high strength, durability, and flexibility, as well as its ability to be easily printed. It has a low shrinkage rate and does not require a heated bed to print, making it an attractive material for beginners.
- PETG is also a popular material for producing transparent or translucent parts, as it has excellent light transmission properties. Additionally, it is resistant to chemicals, weather, and UV radiation, making it a suitable material for outdoor applications.
- In terms of 3D printing settings, PETG typically requires a higher temperature than PLA, typically around 230-250°C. It also benefits from a slower print speed and a higher cooling fan speed, to improve layer adhesion and reduce stringing.
- Overall, PETG is a versatile and reliable material for 3D printing, suitable for a wide range of applications. Its combination of strength, flexibility, and ease of use make it a popular choice for both beginner and advanced 3D printing enthusiasts.

Explain the need of support materials used in 3D printing.

There are several reasons why support materials are necessary in 3D printing:

- Support materials prevent deformation: When printing objects with complex geometries or overhangs, the printer may not be able to print the object without additional support. Without support, the object may deform or sag, resulting in a final product that is not accurate or usable.
- Support materials prevent drooping: Similar to preventing deformation, support materials can prevent drooping or sagging of printed features like bridges, arches, or unsupported angles.
- Support materials improve print quality: By providing support during printing, support materials can help ensure that the final printed object has clean and sharp edges, and doesn't have any deformations or errors.

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- Support materials allow for the creation of more complex geometries: With the help of support materials, 3D printers can create objects with more complex and intricate geometries than would be possible without additional support. This allows designers and engineers to create objects that are more functional and aesthetically pleasing.

Questions:

- *List any four types of powdered materials used in 3D printing.*
- *State powder bed fusion*
- *Describe the following (i) Resin 3D printing liquid, (ii) PETG.*
- *Explain the need of support materials used in 3D printing.*
- *Explain the four different types of 3D printing materials with their applications.*
- *List and explain six different types of 3D printing materials with their applications.*
- *Define polymer. Explain properties of it.*
- *Features of ABS*