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Commentary

Innovations in Additive Manufacturing: Transforming Materials, Techniques and Applications for a Complex Future

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ABOUT THE STUDY

Additive manufacturing, commonly known as 3D printing, represents a transformative approach to fabrication, allowing the creation of complex geometries that would be challenging or impossible with traditional manufacturing methods. This process involves building objects layer by layer from digital models, which allows unprecedented freedom in design and material utilization. Materials play an important role in additive manufacturing, determining not only the mechanical and thermal properties of the printed parts but also their appearance and application potential. The most commonly used materials in additive manufacturing can be categorized into polymers, metals, ceramics and composites. Polymers have been extensively used due to their versatility, cost-effectiveness and ease of processing. Thermoplastics like Poly Lactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS) and Poly Ethylene Terephthalate Glycol (PETG) are particularly popular because they can be melted and reshaped repeatedly, making them ideal for prototyping and low-load applications. Thermosetting polymers, which harden irreversibly, are used when higher strength and durability are required.

Metals in additive manufacturing have provided possibilities for high-performance applications, particularly in industries like aerospace, automotive and medical devices. Materials such as titanium alloys, stainless steels, aluminum and nickel-based super alloys are commonly used. The ability to fabricate parts with high strength-to-weight ratios, customized microstructures, and complex internal channels makes metal additive manufacturing highly preferable. Ceramic materials are another critical area of development, especially for applications requiring high-temperature resistance and excellent wear properties. Although more challenging to process due to their brittleness and high melting points, advancements in techniques have made ceramic additive manufacturing increasingly feasible.

Composite materials, which combine the properties of two or more constituents, have also generated a lot of awareness. By adding supports such as carbon fibers, glass fibers, or nanoparticles into polymer or metal matrices, composites achieve superior mechanical properties and functionality. This has expanded the applicability of additive manufacturing to fields such as aerospace and biomedical engineering, where specific performance attributes are important. The selection of materials is automatically linked to the techniques used in additive manufacturing. These techniques can be classified based on the type of material and the method of layer deposition and bonding. For polymers, Fused Deposition Modeling (FDM) and Stereo Lithography (SLA) are widely used. FDM involves extruding melted thermoplastic filaments through a nozzle and depositing them layer by layer. This technique is well-applicable for rapid prototyping due to its simplicity and cost-efficiency. SLA uses a laser to selectively cure liquid photopolymer resins, enabling the fabrication of highly detailed and smooth parts. Digital Light Processing (DLP) is similar to SLA but uses a digital light projector, providing faster build times and similar precision.

Selective Laser Sintering (SLS) and Multi-Jet Fusion (MJF) are important techniques for polymer powders. These methods involve selectively fusing or sintering powdered materials using a laser or heat source, allowing for greater geometric complexity and isotropic properties compared to FDM. For metals, Selective Laser Melting (SLM) and Electron Beam Melting (EBM) control the field. Both techniques involve melting metal powders layer by layer, with SLM using a laser and EBM employing an electron beam. These methods are capable of producing fully dense parts with excellent mechanical properties, suitable for high-performance applications. Binder jetting and material jetting represent alternative approaches that depends on using material droplets or liquid binders to produce platforms or powder beds. These techniques provide advantages in speed and material diversity but often require post-processing steps to achieve the required strength and functionality. Another advanced technique is Directed Energy Deposition (DED), which uses focused energy sources like lasers or electron beams to melt materials as they are being deposited. DED is particularly advantageous for repairing or adding material to existing components. Among the newer and evolving techniques is vat

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photo polymerization, which includes SLA and DLP, but also extends to Continuous Liquid Interface Production (CLIP). CLIP allows faster printing speeds and smoother finishes by maintaining a liquid interface during curing, thereby avoiding the layer-by-layer stepping effect. Similarly, advancements in Powder Bed Fusion (PBF) techniques have focused on improving precision, reducing material waste and allowing multi-material printing, which increases the range of achievable functionalities.