Applications of Additive Manufacturing Technologies

Subjects: Others

Contributor: Nicola Giannotta , Giada Sala , Claudio Bianchini , Ambra Torreggiani

The term “Additive Manufacturing (AM)” refers to those technologies of building layer upon layer from a 3D model in .STL format through seamless digital Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) integration; by varying the material used, the energy source and other macroparameters, different AM techniques can be specified and can be used for different applications. For the American Society for Testing and Standards (ASTM), there are seven types of AM: (1). Vat Photopolymerisation (VPP): the liquid photopolymer in a vat is selectively cured by light-activated polymerisation; (2).Material Jetting (MJT): the droplets of the build material are selectively deposited; (3). Binder Jetting (BJT): the liquid bonding agent is selectively deposited to join powder materials; (4). Material Extrusion (MEX): the material is selectively dispensed through a nozzle or orifice; (5).Powder Bed Fusion (PBF): the thermal energy selectively fuses regions of a powder bed; (6).Sheet Lamination (SL): sheets of the material are bonded to form an object; (7). Direct Energy Deposition (DED): focused thermal energy is used to fuse materials by melting as they are being deposited. Variable subclasses can also be identified for each of the previous seven main classes based on the materials with which they operate.

additive manufacturing electrical machines ferromagnetic materials

1. Additive Manufacturing (AM) for Polymers

Powder Bed Fusion (PBF) applied to polymeric materials includes “Multi Jet Fusion” (MJF) and “Selective Laser Sintering” (SLS). In MJF, the process begins with a layer of polymer powder. Then, liquid droplets are applied to the powder layer, and thanks to an infrared source, the material is melted. SLS exploits a movable laser beam, which sinters the polymer powder locally layer-by-layer. The component is generated by solidifying its cross-section in each layer.

MEX applied to polymers includes the “Fused Deposition Modeling” (FDM), used in [1] and the “Arburg PLstic Freeforming” (APF). FDM uses a hot nozzle unit to plasticise a polymer filament. APF, instead of a wire-shaped plastic, uses a plastic granulate.

The “Material Jetting” for polymers (MJ) applies locally and layer-by-layer small droplets of a photopolymer through many nozzles and, instantly, cures the viscous photopolymer by means of UV light.

“Stero Lithography” (SLA) and “Direct Light Processing” (DLP) are two examples of VPP applied to polymers. SLA cures selectively the viscous photopolymer in layers by means of a movable laser beam. DLP polymerises the exposed photopolymer layer-by-layer using a projector.

In [2], an interesting application, which used 3D-printed polymers, was presented for lightweight silicon photovoltaics technology.

2. AM for Metals

There is a schematic recap of the AM technologies that could be applied to metals. Regarding PBF, it is possible to recognise “Selective Laser Melting” (SLM) and “Electron Beam Melting”. SLM melts locally layer-by-layer the selected metal powder by means of a movable laser beam, thus solidifying a cross-section of the component. Compared to sintering, there is a higher density of the component and a different microstructure due to the different process of consolidation, which leads to greater mechanical characteristics for the same material used. The main challenges of this technology were deeply analysed in [3]. EBM works in the same way, but instead of a laser, it uses an electron beam to melt locally layer-by-layer the selected metal powder; for this reason, EMB can be used with only a few metals (e.g., titanium, tungsten, Co-Cr, Inconel 718, etc.).

The “Laser Engineering Net Shape” (LENS) [4], the “Metal Powder Application” (MPA), and the “Wire and Arc Additive Manufacturing” (WAAM) are DED technologies. LENS applies and melts the metal material simultaneously by a laser beam. The solidification of the melt generates new layers.

The MPA, also called “Cold Spray”, applies the metallic powder with very high kinetic energy layer-by-layer; in this way, the component is close to the final shape, and it is also possible to combine more materials. The WAAM applies locally and layer-by-layer the melted metal wire by means of arc welding; in this way, it is possible to quickly produce near-net-shape metal components. MEX for metals is called “Fused Deposition Modeling” (FDM), and it plasticises a metallic filament by means of a hot nozzle unit and doses selectively the material layer-by-layer. “Binder Jetting” for metals (BJ) applies selectively tiny binder droplets onto the metal powder by means of many nozzles to stick it together layer-by-layer. In the end, the MJT applied to metals is called “Nano Particle Jetting” (NPJ). NPJ doses selectively and locally a solvent fluid containing nano-metal particles; when the solvent evaporates, the nano-particles bond together. The components made by FDM, BJ, and NPJ must be sintered afterwards.

3. AM for Other Materials

It is possible to add that MEX for a composite material is called “Continuous Filament Fabrication” (CFF) and uses a hot nozzle unit to plasticise selectively a wire-shaped plastic that is dosed layer-by-layer around continuously deposited reinforcing fibres. Another MEX technology is “Paste Extrusion Modeling” (PEM), which doses selectively layer-by-layer any pasty material by means of a piston nozzle.

BLT joins with a bonding agent sand or gypsum.

MJT is called “Drop on Demand” because it microdoses selectively, through many nozzles, heated wax droplets layer-by-layer.

SHL laminates composite or paper and is called “Selective Deposition Lamination” (SDL) or “Laminated Object Manufacturing” (LOM). Nozzles are devices that are designed to control the direction or characteristics of a fluid flow, usually to increase its velocity. In this application, they are used to guarantee a good level of precision to apply locally adhesive to the respective material layer. Each level can be stacked and laminated directly or subsequently, and then, the finished component can be cut out along the contour. Nozzles are devices that are designed to control the direction or characteristics of a fluid flow, usually to increase its velocity. In this application, they are used to guarantee a good level of precision to apply locally adhesive to the respective material layer. Each level can be stacked and laminated directly or subsequently, and then, the finished component can be cut out along the contour.

4. AM for EMs

Focusing on EM manufacturing, “Powder Bed Fusion” is the most-employed method: it melts or sinters particles of metal powder (e.g., aluminium and titanium alloys, electric steels, soft magnetic composites, etc.) using a laser or electron beam. It is possible to classify the following PBF techniques:

- Direct Metal Laser Sintering (DMLS);
- Electron Beam Melting (EBM);
- Selective Heat Sintering (SHS);
- Selective Laser Melting (SLM);
- Selective Laser Sintering (SLS).

After the previous general review of the AM technologies for metal, particular focus should be dedicated to the main ones among them that are used for fabricating permanent magnets, such as cold spray.

Cold spray, also called “Metal Powder Application”, has been recently applied to the fabrication of PMs. In a CS process, the fine magnetic particles, in a compressed gas stream, are hurled at high velocity, in general higher than 300 m/s, onto a substrate or backing plate; they deform plastically, so they can mechanically interlock and metallurgically bond, creating a layer.

The metallic powder remains in a solid state during the entire deposition process, and in this way, the thermal defects, e.g., oxidation and thermal stresses, are not seen in the PMs so made. Moreover, CS allows spraying on a metallic surface such as the rotor core. In this way, it is possible to obtain a complex near-net-shape geometry.

References

1. Benal, M.G.M.; GS, P.K.; Tambrallimath, V.; HR, G.; Khan, T.M.Y.; Rajhi, A.A.; Baig, M.A.A. Influence of Short Glass Fibre Reinforcement on Mechanical Properties of 3D Printed ABS-Based Polymer Composites. Polymers 2022, 14, 1182.
2. Budiman, A.S.; Sahay, R.; Agarwal, K.; Fajarna, R.; Gunawan, F.E.; Baji, A.; Raghavan, N. Modeling Impact Mechanics of 3D Helicoidally Architected Polymer Composites Enabled by Additive Manufacturing for Lightweight Silicon Photovoltaics Technology. Polymers 2022, 14, 1228.
3. Tiismus, H.; Kallaste, A.; Belahcen, A.; Rassõlkin, A.; Vaimann, T. Challenges of Additive Manufacturing of Electrical Machines. In Proceedings of the 2019 IEEE 12th International Symposium on Diagnostics for Electrical Machines, Power Electronics and Drives (SDEMPED), Toulouse, France, 27–30 August 2019; IEEE: Toulouse, France, 2019; pp. 44–48.
4. Sirisathitkul, C.; Sirisathitkul, Y. Recent Developments in 3D Printing of Rare-Earth-Free Permanent Magnets. Inventions 2022, 7, 71.