Hahn Schickard

Whitepaper Additive Manufacturing

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Tobias Vieten, Institute for Micro Integration, University of Stuttgart, Germany

ADDITIVE MANUFACTURING

Additive manufacturing (AM) describes a set of primary shaping techniques that are based around the concept, that a digital model of a three dimensional shape can be sliced into layers and subsequently manufactured layer by layer by adding material. The first additive manufacturing method, stereolithography (SLA), was invented in 1984 by Charles W. Hull. First thought of as a rapid prototyping method, today's market for additive manufacturing comprises rapid prototyping/rapid tooling as well as rapid manufacturing from one of a kind products to large scale production (e.g. in the automotive industry). Since "Chuck" Hull's stereolithography a large variety of diverse techniques has been developed. By and large all of these techniques are categorized by the ISO/ASTM 52900:2017 standard which differentiates between seven groups:

- vat photopolymerization (VPP)
- binder jetting (BJT)
- material jetting (MJT)
- material extrusion (MEX)
- powder bed fusion (PBF)
- sheet lamination (SHL)
- directed energy deposition (DED)

Vat photopolymerization techniques use light to selectively cure UV-sensitive thermoset resins. The aforementioned stereolithography belongs to this category. It uses a laser combined with a scanning mechanism to start the curing process (vector based). Another technique in this category is digital light processing (DLP) which is essentially the same as stereolithography only instead of a laser it utilizes UV-LEDs and a digital mirror device to cure the resin (image based). Parts made from vat photopolymerization techniques tend to have a good surface quality and a high level of detail. The resins can have a high content of various filler materials or additives so there is a wide range of material properties available. On the other hand, these techniques don't have multi-material capabilities and parts usually need support structures, which decreases surface quality and thereby increases necessary post processing efforts.

Binder jetting techniques use the drop on demand method also known from inkjet printing to selectively place droplets of a binding agent onto a powder bed. Due to the simple character of this method the powder can consist of almost any solid material (e.g. gypsum, sand, polymeric or metallic powders) as long as it can be combined with an appropriate binder. By using multiple print heads with different binder compositions parts can be produced with customized material properties or multiple colors and gradients thereof. Parts produced by binder jetting are usually brittle but often they can be sintered to get functional parts. During sintering the parts undergo a shrinking process which makes good dimensional accuracy somewhat difficult, although possible with enough experience. The surface of non-sintered parts is grainy because of adhering powder particles.

Material Jetting techniques, just as binder jetting, are typically based on the drop on demand technology, yet in this case the "ink" itself builds up on a build plate layer by layer to form the part. The jetted materials can be either liquids like UV-curing polymers or heat cured nanoparticle inks to produce parts e.g. from metal. By utilizing a second print head support material, e.g. wax, can be printed alongside the part. Often these supports can be removed afterwards by processing the part in a bath of heated water or oil. By adding even more print heads, gradient multi-material or multicolored parts can be manufactured. Due to the high resolution and small layer heights the dimensional accuracy and surface quality of the manufactured parts is very good compared to other AM techniques. Mechanical properties of polymer parts are limited due to the fact that materials filled with micro particles or fibers clog and wear the inkjet nozzles an thus cannot be processed.

Material extrusion techniques selectively dispense material through a nozzle or orifice. Probably the most commonly used AM technique is fused deposition modeling (FDM) due to the widespread use of low-cost machines by hobbyists and tinkerers worldwide. FDM machines feed a filament of meltable material through a heater into a nozzle which lays down the liquefied material onto a heated build platform to manufacture parts. The used materials are usually thermoplastics, quite often filled with one of many possible filler materials (e.g. wood, glass, metal, ceramics). With multiple nozzles or sophisticated feed systems more than one material can be processed quasi simultaneously to produce multi-material parts. Typically, the obtained surface quality, dimensional accuracy and resolution are not as good as obtained by MJT or VPP based technologies, yet with smaller nozzle diameters and thus much longer build times these characteristics can be improved. Parts with angles lower than 45° to the build surface have to be supported, which further lowers the part quality where they are attached to the part. For machines with multi-material capability there is the possibility of using water soluble support materials to improve part quality and reduce post processing time. Other technologies in the MEX category are for example machines that produce buildings by pumping concrete through a moving nozzle, or machines that feed hydrogels or sugar/chocolate from a pressurized reservoir through a moving dispensing needle to produce scaffolds for medical implants and novelty food products, respectively.

Powder bed fusion techniques use various forms of energy sources to selectively heat up regions in a powder bed and thereby sinter or melt the particles into a solid part. An integrated oven heats the powder bed to just below the sintering temperature of the powder to reduce the required energy of the selective energy source. Energy sources that are used in industrial machines are lasers, electron beams and heat lamps. In the latter case (HP multi jet fusion technology) the heat lamp is not selective, but every powder layer is inkjet printed with a thermal accelerator and an inhibitor to produce the correct shape. The applicable materials are mostly thermoplastics and metals but also machines for processing ceramic powders are being developed. The produced parts can be used as structural and functional parts and support structures are only necessary with some materials to suppress warpage. Especially with metals the support structures are hard to remove (e.g. by milling or cutting). Parts right out of the machine have a grainy surface from adhering or welded powder particles and laser sintered parts have a porous structure.

Sheet lamination techniques use rolls of metal or paper sheets as feedstock. The sheets are bonded together layer wise by means of ultrasonic welding (metal) or adhesives (paper). After a layer is bonded to the growing part, a laser cuts out the shape that is required to build up the current layer and separates the feedstock from the part. Sometimes in case of metallic feedstock, an additional milling process follows each layer-bonding step. The produced parts are (in case of paper feedstock) not suitable for functional or structural use but are often employed as visual models.

Directed energy deposition techniques are also layer by layer processes, but the layers don't have to be planar. A nozzle lays feedstock in form of powder or filament onto a surface where a laser or electron beam melts the material and welds it to the part, which makes it essentially an automated build-up welding process. By using 5-axis-concepts the substrate can be a freeform surface as long as there are no undercuts the nozzle cannot reach into. That is why these technologies, which usually work with metals, are commonly used to repair damaged parts by adding material and then milling or grinding everything to the final shape. DED techniques typically don't have a good dimensional accuracy and surfaces are dominated by welding runs.

Although the term "3D printing" is being used synonymic to additive manufacturing in the mainstream media and often also in scientific context, 3D printing and the abbreviation 3DP were originally trademarked by a Massachusetts Institute of Technology (MIT) research group specifically for the binder jetting technology developed by them. Today ISO/ASTM 52900:2017 defines the term 3D printing as the "*fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology*". ***In other words 3D printing as a technical term comprises only the binder jetting and material jetting technologies.***

Hahn-Schickard and the Institute for Micro Integration at the University of Stuttgart use additive manufacturing technologies to research the production of microsystems. Especially for producing 3D mechatronic integrated devices by laser direct structuring and electroless plating, substrate surfaces with low roughness and without pores are pertinent. Therefore, powder based technologies and sheet lamination are typically less suited than vat photopolymerization, material jetting and material extrusion.

For further information please contact:

Dr. Kerstin Gläser
Kerstin.Glaeser@Hahn-Schickard.de
Phone: ++49 711 685 84785
Hahn-Schickard-Gesellschaft für angewandte Forschung e. V.
Allmandring 9b, 70569 Stuttgart, Germany

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