UNIT-5

OTHER ADDITIVE MANUFACTURING PROCESSES

5.1 Three-Dimensional Printing (3DP)

The original name for binder jetting was Three-Dimensional Printing (3DP) and it was invented at MIT and has been licensed to more than five companies for commercialization. In contrast to the printing processes described in Chap. 7, binder jetting (BJ) processes print a binder into a powder bed to fabricate a part. Hence, in BJ, only a small portion of the part material is delivered through the print head. Most of the part material is comprised of powder in the powder bed. Typically, binder droplets (80 μm in diameter) form spherical agglomerates of binder liquid and powder particles as well as provide bonding to the previously printed layer. Once a layer is printed, the powder bed is lowered and a new layer of powder is spread onto it (typically via a counter-rotating rolling mechanism) [1], very similar to the recoating methods used in powder bed fusion processes, as presented in Chap. 5. This process (printing binder into bed; recoating bed with new layer of powder) is repeated until the part, or array of parts, is completed. A schematic of the BJ process.

Because the printer head contains several ejection nozzles, BJ features several parallel one-dimensional avenues for patterning. Since the process can be economically scaled by simply increasing the number of printer nozzles, the process is considered a scalable, line-wise patterning process. Such embodiments typically have a high deposition speed at a relatively low cost (due to the lack of a highpowered energy source) [1], which is the case for BJ machines.

The printed part is typically left in the powder bed after its completion in order for the binder to fully set and for the green part to gain strength. Post-processing involves removing the part from the powder bed, removing unbound powder via pressurized air, and infiltrating the part with an infiltrant to make it stronger and possibly to impart other mechanical properties.

The BJ process shares many of the same advantages of powder bed processes. Parts are self-supporting in the powder bed so that support structures are not needed. Similar to other processes, parts can be arrayed in one layer and stacked in the powder bed to greatly increase the number of parts that can be built at one time. Finally, assemblies of parts and kinematic joints can be fabricated since loose powder can be removed between the parts.

Applications of BJ processes are highly dependent upon the material being processed. Low-cost BJ machines use a plaster-based powder and a water-based binder to fabricate parts. Polymer powders are also available. Some machines have color print heads and can print visually attractive parts. With this capability, a market has developed for colorful figures from various computer games, as well as personal busts or sculptures, with images taken from cameras. Infiltrants are used to strengthen the parts after they are removed from the powder bed. With either the starch or polymer powders, parts are typically considered visual prototypes or light-duty functional prototypes. In some cases, particularly with elastomeric infiltrants, parts can be used for functional purposes. With polymer powders and wax-based infiltrants, parts can be used as patterns for investment casting, since the powder and wax can burn off easily.

For metal powders, parts can be used as functional prototypes or for production purposes, provided that the parts have been designed specifically for the metal alloys available. Molds and cores for sand casting can be fabricated by some BJ machines that use silica or foundry sand as the powder. This is a sizable application in the automotive and heavy equipment industries.

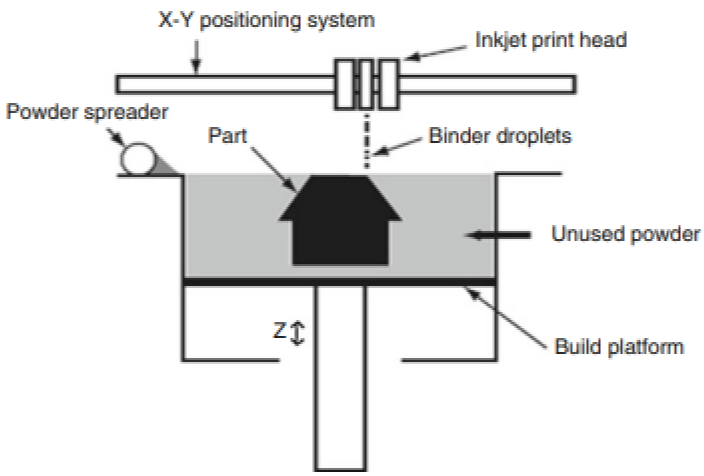

Fig. 8.1 Schematic of the binder jetting process

5.2 Materials

5.2.1 Commercially Available Materials

When Z Corporation first started in the mid-1990s, their first material was starch based and used a water-based binder similar to a standard house-hold glue. At present, the commercially available powder from 3D Systems is plaster based (calcium sulfate hemihydrate) and the binder is water based [2]. Printed parts are fairly weak, so they are typically infiltrated with another material. 3D Systems provides three infiltrants, the ColorBond infiltrant, which is acrylate-based and is similar to superglue, StrengthMax infiltrant which is a two-part infiltrant, and Salt Water Cure, an eco-friendly and hazard-free infiltrant. Strength, stiffness, and elongation data are given on 3D Systems' web site for parts fabricated with these infiltrants. In general, parts with any of the infiltrants are much stiffer than typical thermoplastics or VP resins, but are less strong, and have very low elongation at break (0.04–0.23 %)

Voxeljet [3], on the other hand, supplies a PMMA (poly-methyl methacrylate) powder and uses a liquid binder that reacts at room temperature. They recommend that parts stay in the powder bed for several hours to ensure that the binder is completely cured. For investment casting pattern fabrication, they offer a wax-based binder for use with PMMA powder that is somewhat larger in particle size than the powder used for parts. They claim excellent pattern burnout for investment casting

For materials from both companies, unprinted powders are fully recyclable, meaning that they can be reused in subsequent builds. A desirable characteristic of powders is a high packing density so that printed parts have a high volume fraction of powder and are strong enough to survive depowdering and clean up operations. High packing densities can be achieved by tailoring powder particle shape or by including a range of particle sizes so that small particles fill in gaps between larger particles. In practice, both approaches are used whenever possible.

Quite a few other infiltrant materials have been marketed by ZCorp and 3D Systems and many users have experimented with a variety of materials, so alternatives are possible that can produce parts with a wide range of mechanical properties

ExOne markets machines that use either metal or sand powders for metal parts or sand-casting molds and cores, respectively [4]. In the metals area, they currently market 3,166 stainless steel and bronze, 420 stainless steel (non-annealed), 420 stainless steel (annealed), bronze, and Inconel 625. For the stainless steel materials, bronze is used as an infiltrant so that parts are virtually fully dense. Polymer binders are used for the metals. In order to fabricate a metal part, the “green” part is removed from the AM machine, then is subject to three furnace cycles. In the first cycle, low temperature is used for several hours to burn off the polymer binder. In the second cycle, high temperature is used to lightly sinter the metal particles together so that the part has decent strength. If this cycle is too long, the metal particles more completely melt, causing the part to lose dimensional accuracy and its desired shape. After this cycle, the part is approximately 60 % dense. In the final cycle, a bronze ingot is placed in the furnace in contact with the part so that bronze infiltrates into the part’s pores, resulting in parts that are 90– 95 % dense

An exception to the light sintering and infiltration process is the new Inconel 625 material announced by ExOne in 2014. Although they use a binder, the Inconel material can be sintered to virtually full density (ExOne claims greater than 99 % dense) while maintaining acceptable dimensional accuracy. If this process can be extended to other metals, it could change the economics of metal AM significantly.

Both ExOne and Voxeljet market machines that use sand for the fabrication of molds and cores for sand casting. ExOne offers a silica sand and two-part binder, where one part (binder catalyst) is coated on a layer and the second part is printed onto the layer, causing a polymerization reaction to occur and binding sand particles together. They claim that only standard foundry materials are used so that resulting molds and cores enable easy integration into existing manufacturing and foundry processes. Voxeljet also offers a silica sand with an inorganic binder and claims that their materials also integrate well into existing foundry processes.

Finally, ExOne markets a soda-lime glass material for use in fabricating artwork, jewelry, or other decorative objects. Different colors and finishes are available. An organic binder is used that requires an elevated temperature curing cycle. Then, parts need to be fired at high temperature to sinter the glass particles and impart decent strength and stiffness.

5.3 Process Benefits and Drawbacks

The binder jetting processes share many of the advantages of material jetting relative to other AM processes. With respect to MJ, binder jetting has some distinct advantages. First, it can be faster since only a small fraction of the total part volume must be dispensed through the print heads. However, the need to distribute powder adds an extra step, slowing down binder processes somewhat. Second, the combination of powder materials and additives in binders enables material compositions that are not possible, or not easily achieved, using direct methods. Third, slurries with higher solids loadings are possible with BJ, compared with MJ, enabling better quality ceramic and metal parts to be produced. As mentioned earlier, BJ processes lend themselves readily to printing colors onto parts.

As a general rule, however, parts fabricated using BJ processes tend to have poorer accuracies and surface finishes than parts made with MJ. Infiltration steps are typically needed to fabricate dense parts or to ensure good mechanical properties.

As with any set of manufacturing processes, the choice of manufacturing process and material depends largely on the requirements of the part or device. It is a matter of compromising on the best match between process capabilities and design requirements.