UNIT-4

POWDER BED FUSION AND MATERIAL EXTRUSION

MATERIAL EXTRUSION

4.6 Basic Principles

There are a number of key features that are common to any extrusion-based system: –

- Loading of material
- Liquification of the material
- Application of pressure to move the material through the nozzle
- Extrusion
- Plotting according to a predefined path and in a controlled manner
- Bonding of the material to itself or secondary build materials to form a coherent solid structure
- Inclusion of support structures to enable complex geometrical features

4.7 Fused Deposition Modeling from Stratasys

By far the most common extrusion-based AM technology is fused deposition modeling (FDM), produced and developed by Stratasys, USA [7]. FDM uses a heating chamber to liquefy polymer that is fed into the system as a filament. The filament is pushed into the chamber by a tractor wheel arrangement and it is this pushing that generates the extrusion pressure. A typical FDM machine can be seen in Fig. 6.6, along with a picture of an extrusion head.

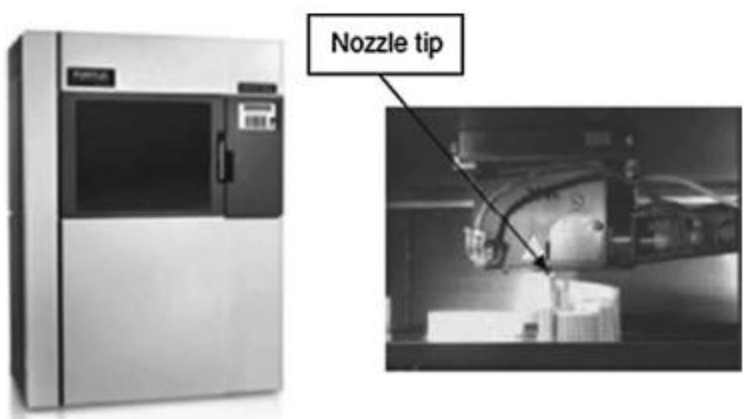

Fig. 6.6 Typical Stratasys machine showing the outside and the extrusion head inside (courtesy of Stratasys)

The initial FDM patent was awarded to Stratasys founder Scott Crump in 1992 and the company has gone from strength to strength to the point where there are more FDM machines than any other AM machine type in the world. The major strength of FDM is in the range of materials and the effective mechanical properties of resulting parts made using this technology. Parts made using FDM are among the strongest for any polymer-based additive manufacturing process.

The main drawback to using this technology is the build speed. As mentioned earlier, the inertia of the plotting heads means that the maximum speeds and accelerations that can be obtained are somewhat smaller than other systems. Furthermore, FDM requires material to be plotted in a point-wise, vector fashion that involves many changes in direction.

4.8 Materials

The most popular material is the ABSplus material, which can be used on all current Stratasys FDM machines. This is an updated version of the original ABS (acrylonitrile butadiene styrene) material that was developed for earlier FDM technology. Users interested in a translucent effect may opt for the ABSi material, which has similar properties to other materials in the ABS range. Some machines also have an option for ABS blended with Polycarbonate (PC). Table 6.1 shows properties for various ABS materials and blends

These properties are quite similar to many commonly used materials. It should be noted, however, that parts made using these materials on FDM machines may exhibit regions of lower strength than shown in this table because of interfacial regions in the layers and possible voids in the parts.

There are three other materials available for FDM technology that may be useful if the ABS materials cannot fulfill the requirements. A material that is predominantly PC-based can provide higher tensile properties, with a flexural strength of 104 MPa. A variation of this material is the PC-ISO, which is also PC-based, formulated to ISO 10993-1 and USP Class VI requirements. This material, while weaker than the normal PC with a flexural strength of 90 MPa, is certified for use in food and drug packaging and medical device manufacture. Another material that has been developed to suit industrial standards is the ULTEM 9085 material. This has particularly favorable flame, smoke, and toxicity (FST) ratings that makes it suitable for use in aircraft, marine, and ground vehicles. If applications require improved heat deflection, then an option would be to use the Polyphenylsulfone (PPSF) material that has a heat deflection temperature at 264 psi of 189 C. It should be noted that these last three materials can only be used in the high-end machines and that they only work with breakaway support system, making their use somewhat difficult and specialized. The fact that they have numerous ASTM and similar standards attached to their materials indicates that Stratasys is seriously targeting final product manufacture (Direct Digital Manufacturing) as a key application for FDM

Note that FDM works best with polymers that are amorphous in nature rather than the highly crystalline polymers that are more suitable for PBF processes. This is because the polymers that work best are those that are extruded in a viscous paste rather than in a lower viscosity form. As amorphous polymers, there is no distinct melting point and the material increasingly softens and viscosity lowers with increasing temperature. The viscosity at which these amorphous polymers can be extruded under pressure is high enough that their shape will be largely maintained after extrusion, maintaining the extrusion shape and enabling them to solidify quickly and easily. Furthermore, when material is added in an adjacent road or as a new layer, the previously extruded material can easily bond with it. This is different from Selective Laser Sintering, which relies on high crystallinity in the powdered material to ensure that there is a distinct material change from the powder state to a liquid state within a well-defined temperature region

Table 6.1 Variations in properties for the ABS range of FDM materials (compiled from Stratasys data sheets)

Property	ABS	ABSi	ABSplus	ABS/PC
Tensile strength (MPa)	22	37	36	34.8
Tensile modulus (MPa)	1,627	1,915	2,265	1,827
Elongation (%)	6	3.1	4	4.3
Flexural strength (MPa)	41	61	52	50
Flexural modulus (MPa)	1,834	1,820	2,198	1,863
IZOD impact (J/m^2)	106.78	101.4	96	123
Heat deflection at 66 psi (°C)	90	87	96	110
Heat deflection at 264 psi (°C)	76	73	82	96
Thermal expansion (in./in./F)	5.60E – 05	6.7E – 6	4.90E – 05	4.10E – 5
Specific gravity	1.05	1.08	1.04	1.2

4.9 Limitations of FDM

FDM machines made by Stratasys are very successful and meet the demands of many industrial users. This is partly because of the material properties and partly because of the low cost of the entry-level machines. There are, however, disadvantages when using this technology, mainly in terms of build speed, accuracy, and material density. As mentioned earlier, they have a layer thickness option of 0.078 mm, but this is only available with the highest-cost machine and use of this level of precision will lead to longer build times. Note also that all nozzles are circular and therefore it is impossible to draw sharp external corners; there will be a radius equivalent to that of the nozzle at any corner or edge. Internal corners and edges will also exhibit rounding. The actual shape produced is dependent on the nozzle, acceleration, and deceleration characteristics, and the viscoelastic behavior of the material as it solidifies.

The speed of an FDM system is reliant on the feed rate and the plotting speed. Feed rate is also dependent on the ability to supply the material and the rate at which the liquefier can melt the material and feed it through the nozzle. If the liquefier were modified to increase the material flow rate, most likely it would result in an increase in mass. This in turn would make it more difficult to move the extrusion head faster. For precise movement, the plotting system is normally constructed using a lead-screw arrangement. Lower cost systems can use belt drives, but flexing in the belts make it less accurate and there is also a lower torque reduction to the drive motor.

One method to improve the speed of motor drive systems is to reduce the corresponding friction. Stratasys used Magnadrive technology to move the plotting head on early Quantum machines. By gliding the head on a cushion of air counterbalanced against magnetic forces attracting the head to a steel platen, friction was significantly reduced, making it easier to move the heads around at a higher speed. The fact that this system was replaced by conventional ball screw drives in the more recent FORTUS 900mc machine indicates that the improvement was not sufficient to balance against the cost.

One method not tried outside the research labs as yet is the use of a particular build strategy that attempts to balance the speed of using thick layers with the precision of using thin layers. The concept here is that thin layers only need to be used on the exterior of a part. The outline of a part can therefore be built using thin layers, but the interior can be built more quickly using thicker layers, similar to the cyclic build styles described in Chap. 4. Since most FDM machines have two extruder heads, it is possible that one head could have a thicker nozzle than the other. This thicker nozzle may be employed to build support structures and to fill in the part interior. However, the difficulty in maintaining a correct registration between the two layer thicknesses has probably prevented this approach from being developed commercially. A compromise on this solution is to use a honeycomb (or similar) fill pattern that uses less material and take less time. This is only appropriate for applications where the reduced mass and strength of such a part is not an issue

An important design consideration when using FDM is to account for the anisotropic nature of a part's properties. Additionally, different layering strategies result in different strengths. For instance, the right-hand scanning strategy in Fig. 6.5 creates stronger parts than the left-hand scanning strategy. Typically, properties are isotropic in the x–y plane, but if the raster fill pattern is set to preferentially deposit along a particular direction, then the properties in the x–y plane will also be anisotropic. In almost every case, the strength in the z-direction is measurably less than the strength in the x–y plane. Thus, for parts which undergo stress in a particular direction it is best to build the part such that the major stress axes are aligned with the x–y plane rather than in the z-direction.