FUSED DEPOSITION MODELING (FDM)

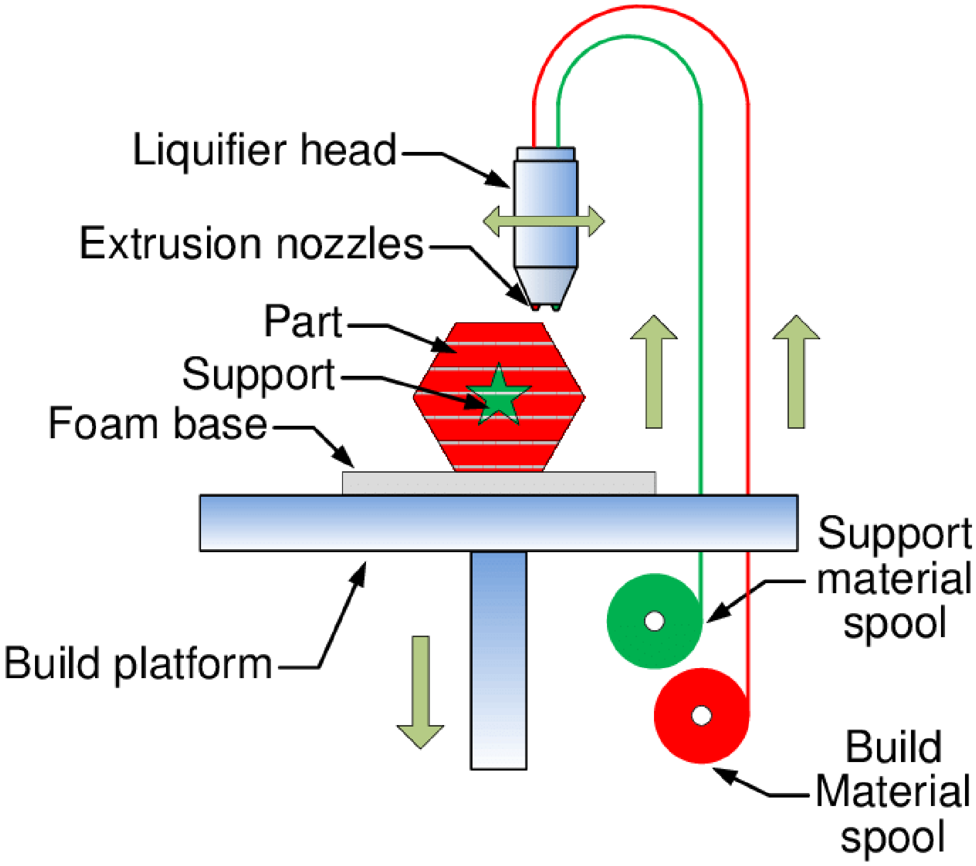

Fig.1.12: FDM Process Layout

Stratasys Inc. was founded in 1989 and has developed most of the company's products based on the Fused Deposition Modeling (FDM) technology. The technology was first developed by Scott Cramp in 1988 and the patent was awarded in the U.S. in 1992. FDM uses the extrusion process to build 3D models. Stratasys introduced its first rapid prototyping machine, the 3D modeler® in early 1992 and started shipping the units later that year. Over the past decade, Stratasys has grown progressively, seeing her rapid prototyping machines' sales increase from six units in the beginning to a total of 1582 units in the year 2000 [9]. The company's address is Stratasys Inc., 14950 Martin Drive, Eden Prairie, MN 55344-202, USA.

Principle

The principle of the FDM is based on surface chemistry, thermal energy, and layer manufacturing technology. The material in filament (spool) form is melted in a specially designed head, which extrudes on the model. As it is extruded, it is cooled and thus solidifies to form the model. The model is built layer by layer, like the other RP systems. Parameters which affect performance and functionalities of the system are material column strength, material flexural modulus, material viscosity, positioning accuracy, road widths, deposition speed, volumetric flow rate, tip diameter, envelope temperature, and part geometry.

Fused Deposition Modeling is an additive manufacturing process that can quickly produce geometrically complex parts through the melting, depositing, and solidifying of thermoplastics, layer by layer. Due primarily to its many cost -effective applications, Fused Deposition Modeling has emerged the most popular 3D Printing method since its creation in the 1980s. On top of being affordable and widely applicable, its lead times are extremely short when compared to traditional manufacturers. Thus, the FDM technology has since been patented by Stratasys, a leading company in the world of Additive Manufacturing.

As stated by Stratasys, ―Fused Deposition Modeling is a 3D Printing method that makes durable objects under the same plastics used in every-day products. The affordable and industrial-grade thermoplastics used within this process have created several beneficial parts, including concept models, functional prototypes, and even production -grade components. The following sections describe exactly how Fused Deposition Modeling achieves these incomparable fabrications.

Fused Deposition Modeling revolves around a simple manufacturing process, called extrusion. The FDM technology utilizes this old-age process under specific conditions with specialized components. These components are:

Build Material

The build material is the polymer used to build the part. This material is usually a thermoplastic, meaning it can retain its mechanical microstructure through thermal manipulation. In other words, this plastic material can easily be melted and solidified without losing its structural integrity. The build material is stored as a filament wrapped around a spool and it is pulled to the extrusion head before depositing onto the build platform.

Support Material

The support material is the removable polymer used to support the build material, especially when complex geometries are being built. This support material is used to create support structures on the build platform, essentially acting as scaffolding for the build material. These structures are broken away from the final part during post-processing. The support material is also stored as a filament wrapped around a spool, and it is pulled to the extrusion head before depositing onto the build platform.

Extrusion Head

The extrusion head is essential to the FDM process in that it performs three of the most important functions. The extrusion head, pulls the materials from the spools, melts them, and accurately places them onto the build platform within a two-dimensional plane. This extrusion head uses two gripping drive wheels per material, pinching the filament and pulling it to the head. A heating element melts the filament as it is leaving the extrusion head and entering the build chamber. Finally, this nozzle assembly moves along the x and y of the build chamber by sliding along a two-axis rail system. These pre-programmed movements are known as the tool paths.

Build Chamber / Build Platform

The build chamber consists of the x-y-z manufacturing boundaries of the FDM machines. This temperature-controlled area instantly solidifies the melted thermoplastics as they are being laid onto the build platform. The build platform is the stage upon which the build and support materials are deposited it is where the part is being build. This platform moves vertically, in the z-direction, starting close to the extrusion head and slowly moving downward as the FDM process progresses

Often times, the build platforms are also temperature-controlled to prevent warping of the build part.

Proprietary Software

The proprietary software manipulates the CAD file for use by the FDM machines. This software slices the 3D models into hundreds/thousands of layers and it creates tool paths for each of these layers. These tool paths tell the extrusion head where and when to move in the x-y plane, as well as how much filament to deposit into the build chamber. The tool paths also tell the build platform where and when to move in the z-direction. This software also determines the temperature of the build chamber based on the specific material's critical thermal points.

The FDM Process

After the key components have been identified, the overall process can be broken down into just a few steps.

1. **Pre-processing**
   The pre-processing represents the very first steps in any additive manufacturing. This includes readying the CAD file for ―printing,‖ or building.

The proprietary software performs as described above, creating a code that translates into mechanical movements and thermal adjustments performed by the FDM machines.

2. **Building**

With the build chamber and build platform clean and empty, the building begins. The extrusion head heats up to the appropriate temperature. When thermally stable, the head pulls the build material and support material from their perspective storage Spools. These thermoplastic filaments melt at the extrusion head and deposit as a bead being laid onto the build platform. Simultaneously, the extrusion head moves along the tool paths that were pre-programmed for each layer. As the tool path of that specific layer is completed, the build platform descends vertically in a very small incriminate. This vertically aligns the extrusion head with the next layer.

The thermoplastics solidify almost instantly upon entering the temperature-controlled build chamber, which builds the part layer by layer, from bottom to top. Support materials are built under overhanging sections of the part. These are visible in below the Figure shows FDM Process – Building a part. This stage can take a couple minutes to several hours, depending on the geometrical size and complexity of the build part.

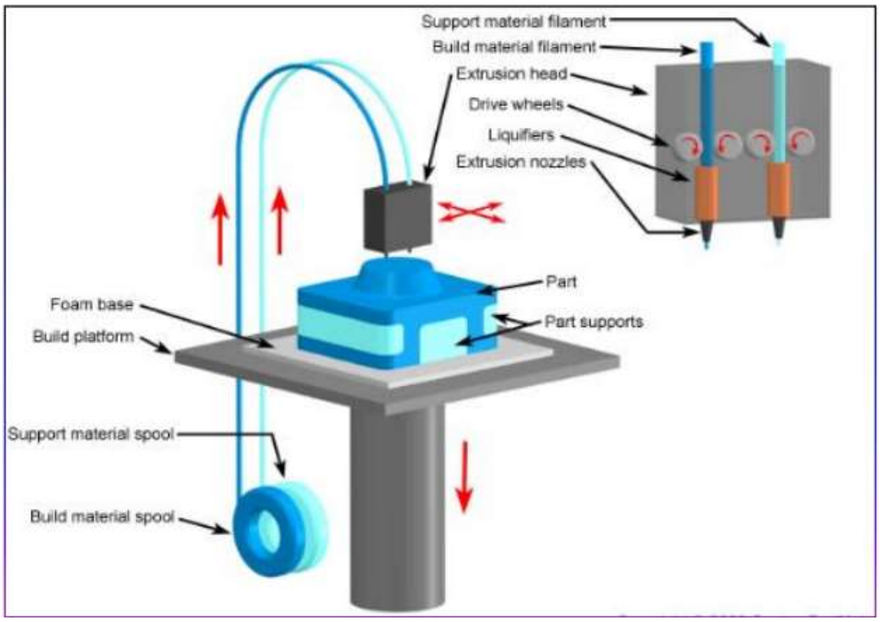

Fig.1.13: Stage wise SLA Process.

3. Post-processing

As the extrusion head finishes depositing material, the build chamber and build platform remain mechanically and thermally stable. This allows the build part and support structures to settle and cure with proper microstructures. After this cooling stage, the support structures are broken away and the final build part is cleaned. Thus, the fused deposition modeling process has come to a finish.

Detailed FDM Process (For making tea shape cup components)

The figure shows FDM process for making tea shaped cup component. In this patented process, a geometric model of a conceptual design is created on a CAD software which uses IGES or STL formatted files. It can then imported into the workstation where it is processed through the QuickSlice® and SupportWork™

Propriety software before loading to FDM 3000 or similar systems. For FDM Maxum and Titan, a newer software known as Insight is used. The basic function of Insight is similar to that of QuickSlice® and the only difference is that Insight does not need another software to auto-generate the supports. The function is incorporated into the software itself. Within this software, the CAD file is sliced into horizontal layers after the part is oriented for the optimum build position, and any necessary support structures are automatically detected and generated. The slice thickness can be set manually to anywhere between 0.172 to 0.356 mm (0.005 to 0.014 in) depending on the needs of the models. Tool paths of the build process are then generated which are downloaded to the FDM machine.

The modeling material is in spools — very much like a fishing line. The filament on the spools is fed into an extrusion head and heated to a semi-liquid state. The semi-liquid material is extruded through the head and then deposited in ultra thin layers from the FDM head, one layer at a time. Since the air surrounding the head is maintained at a temperature below the materials' melting point, the exiting material quickly solidifies. Moving on the *X–Y* plane, the head follows the tool path generated by QuickSlice® or Insight generating the desired layer. When the layer is completed, the head moves on to create the next layer. The horizontal width of the extruded material can vary between 0.250 to 0.965 mm depending on model. This feature, called ―road width‖, can vary from slice to slice. Two modeler materials are dispensed through a dual tip mechanism in the FDM machine. A primary modeler material is used to produce the model geometry and a secondary material, or release material, is used to produce the support structures. The release material forms a bond with the primary modeler material and can be washed away upon completion of the 3D models.

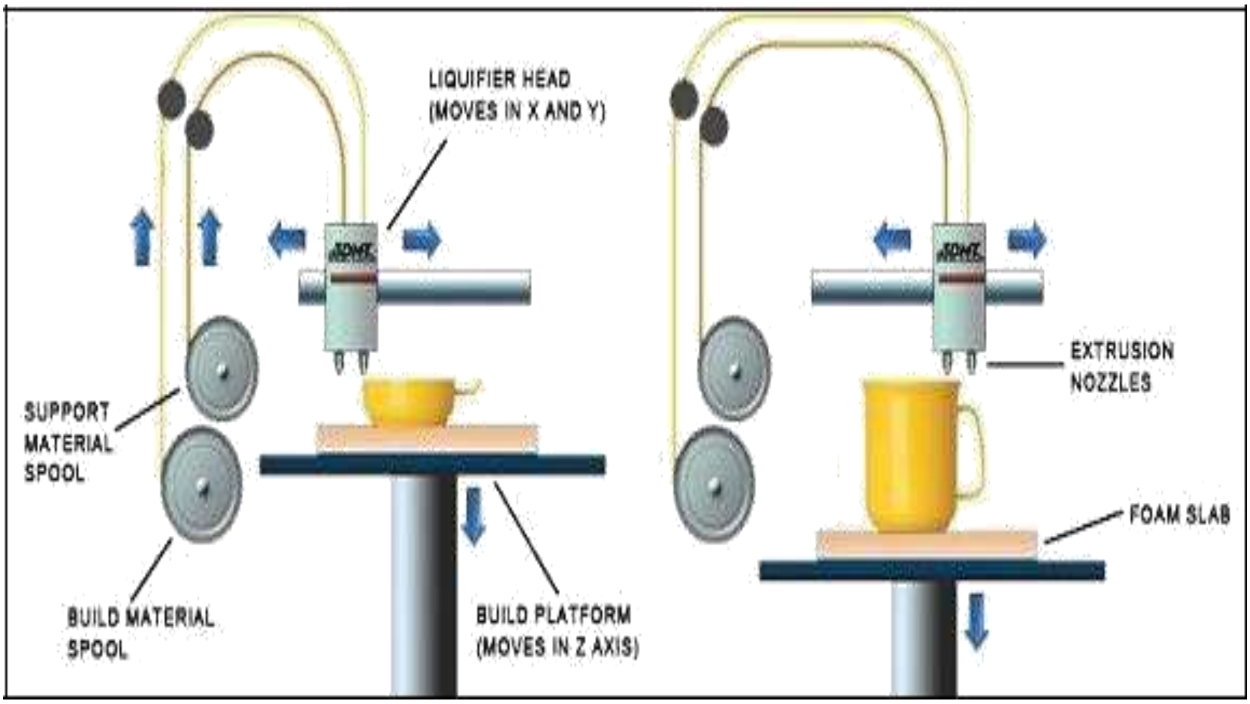

Fig 1.14: Fused Deposition Modelling for making tea cup shape product.

Table 1.4: FDM Material Properties

Material	Tensile Strength (Mpa)	Tensile Modulus (Mpa)	Flexural Strength (Mpa)	Flexural Modulus (Mpa)
ABDP	35.2	1535	66.9	2626
Medical Grade ABSP 500	38	2014	58.9	1810
Investment casting wax (ICWo6)	3.6	282	49.6	282
Elastometer	6.55	282	49.6	141

Advantages and Disadvantages

The main advantages of using FDM technology are as follows:

(1) *Fabrication of functional parts*. FDM process is able to fabricate prototypes with materials that are similar to that of the actual molded product. With ABS, it is able to fabricate fully functional parts that have 85% of the strength of the actual molded part. This is especially useful in developing products that require quick prototypes for functional testing.