

INVESTIGATION OF MECHANICAL STRENGTHS ON 3D PRINTED ABS OBJECTS

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ABSTRACTS

The project work presents analysis of Mechanical behavior of 3D printed ABS parts. 3D printing technology - an additive manufacturing process is a method of making Three Dimensional solid objects from a digital file. The emergence of 3D printing technology is challenging many products that have been traditionally made. In this additive process an object is created by laying down successive layers of material until the entire object is created. In this work, the mechanical properties and behavior of a 3D Printed objects are studied by varying parameters such as Build (orientation) angle and Infill Density. Various tests such as compression test, flexural test and hardness tests are performed to determine failure characteristics of ABS materials. Based on experimental results, the object printed with 60° build angle and 80% infill density resulted in the highest compressive strength and object printed with 30° build angle and 60% infill density 60% has highest flexural strength and highest shore hardness value compared to other orientations.

Keywords: 3D printing, Rapid prototyping, FDM Process, STL file.

1. Rapid Prototyping:

The term rapid prototyping (RP) refers to a class of technologies that can automatically construct physical models from Computer-Aided Design (CAD) data. These "three dimensional printers" allow designers to quickly create tangible prototypes of their designs, rather than just two-dimensional pictures. Such models have numerous uses. They make excellent visual aids for communicating ideas with co-workers or customers. In addition, prototypes can be used for design testing. For example, an aerospace engineer might mount a model of airfoil in a wind tunnel to measure lift and drag forces. Designers have always utilized prototypes and RP allows them to be made faster and less expensively. The key idea of rapid prototyping technology is based on decomposition of 3-D computer models into thin cross-sectional layers, followed by physically forming the layers and stacking them up "layer by layer."

"Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data". Rapid Prototyping has also been referred to as solid free-form manufacturing; computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create molds for tooling, such as siliconerubber molds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP.

2. Methodology of Rapid Prototyping:

The basic methodology for all current rapid prototyping techniques can be summarized as follows:

- A CAD model is constructed, and then converted to STL format. The resolution can be set to minimize stairstepping
- The RP machine processes the STL file by creating sliced layers of the model.
- The first layer of the physical model is created. The model is then lowered by the thickness of the next layer, and the process is repeated until completion of the model.
- The model and any supports are removed. The surface of the model is then finished and cleaned.

3. The STL File:

The standard file format for rapid prototyping is called STL (Standard Triangulation Language), where the shape of the object is defined by a mesh of tiny triangles laid over the surfaces. The triangles must meet up exactly with each other, without gaps or overlaps, if the object is to be built successfully. The "slice files" which are used to build each individual layer are calculated from the STL file, and if there are any gaps between the triangles, then the edges of the slices are not properly defined.

STL is a standard output format from most CAD (computer-aided design) software, and the number of triangles used can be user-defined. Commonly the translation from the modeling format to STL leaves a few flaws, and so the integrity of STL files is usually checked using special software before the files are used to build an object. Small errors can be corrected automatically, but big faults or ambiguities may need "repairing" by an engineer. Figure 1.3 shows a sliced model using STL.

When creating an STL file from CAD, the resolution (also known as Tolerance, Chord Height or Facet Deviation) can be specified. Under-faceted STL files will affect the accuracy and may affect the appearance of the part. Over-faceted STL files will increase the time it takes to prepare the part, without improving the quality. There is therefore an optimum resolution for the STL file to give the best accuracy in the smallest file. The resolution is best set between 0.01 mm and 0.05 mm and the overall binary file size should not normally be more than 5Mbytes.

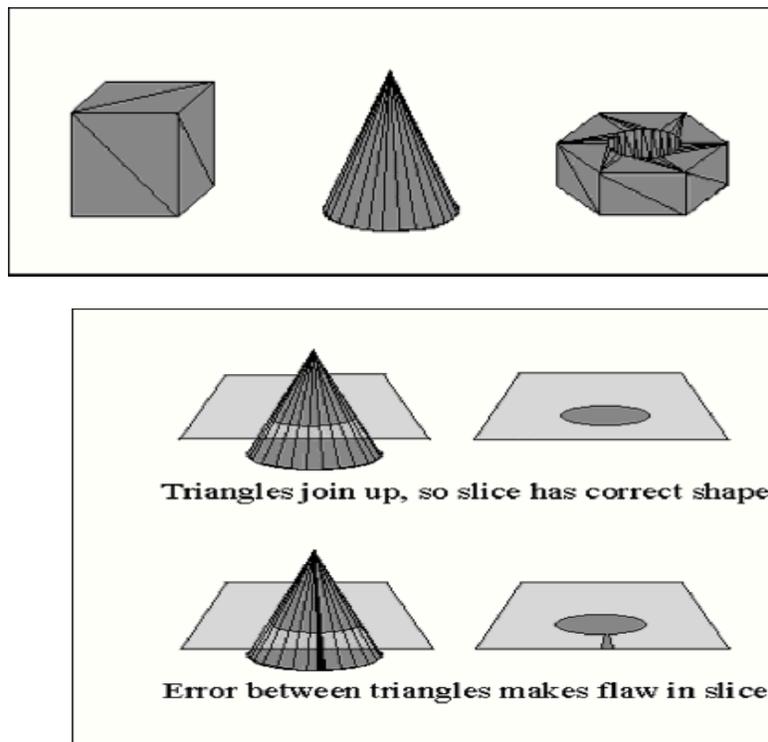


Figure 3. 1. A sliced model using STL

Improvements in rapid prototyping technology allow very accurate slice thicknesses, as low as 50 microns, to be achieved. As layers are of finite thickness, small degrees of errors can be tolerated within the Z axis. The final build process requires the merging of multiple STL files to produce the final build file and the building of the component can begin.

4. FUSED DEPOSITION MODELING

In this project we are using FDM technology which is one of the most widely used rapid prototyping systems in the world. FDM is today the second most common commercial layered manufacturing

system. The main reasons of its increasing popularity and use have been its reliability, safe and simple fabrication process, low cost of material and the availability of a variety of thermoplastics. Ever since the first FDM system was launched in early 1990s, the Stratasy Inc. USA has been marketing improved FDM systems on a regular basis. However, research has also been going on in universities and research institutions around the world to increase its applications, to develop new materials and to improve the FDM process. The FDM method forms three-dimensional objects from computer generated solid or surface models like in a typical RP process. Models can also be derived from computer tomography scans, magnetic resonance imaging scans or model data created from 3D object digitizing systems. The FDM 2000 system is shown in Figure 3.1.



Figure 4.1 Pramaan 200 3D-Printer

Product details:

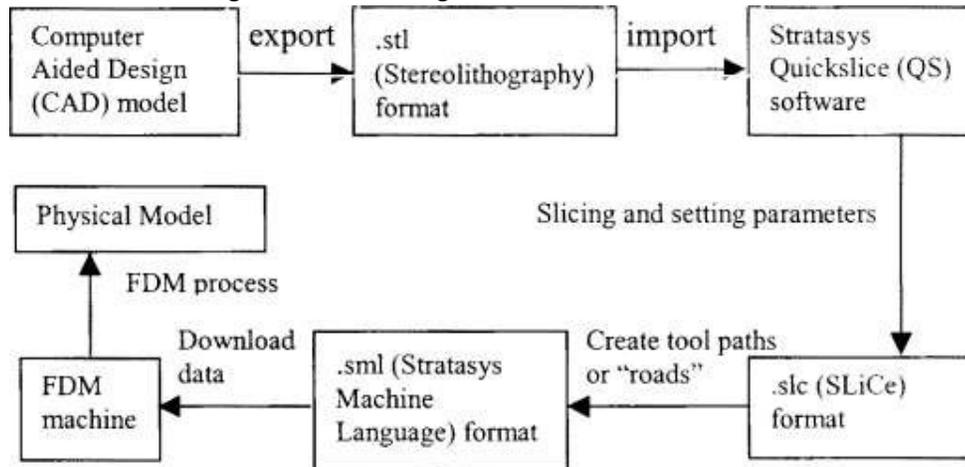
Build Volume	200 mm x 200 mm x 200 mm
Display	Digital
Input Format	G Code, STL
Operation Mode	Automatic
Size	38 cm x 37 cm x 48 cm
Voltage(V)	220 V
Build	Aluminium Extrusions
Cover	Powder Coated Sheet Metal Frame
Resolution	100 - 300 microns
Printable Materials	PLA, ABS, Nylon, TPU, Composites etc.
Number of Nozzles	1
Interface	Touch Screen
Connectivity	USB, SD Card, Ethernet, Wi-Fi

Table-4.1: Details of Pramaan 200 3D-Printer

5. Workingprinciple:

The FDM system consists of the main 3-D Modeller unit, slicing software and a workstation. The process starts with the creation of a part with a CAD) system as a solid or surface model. The model is then converted into a .STL tile and sent to the FDM slicing software. There, the STL file is sliced into thin cross sections of a desired resolution, creating a .SLC file. Supports are created if required by the geometryandslicedaswell. Theslicedmodelandsupportsareconvertedintoa.SMLtilethatcontains actual instruction codes for the FDM machine. The block diagram of FDM process is shown in Figure 3.2.

Figure 5.1 Block Diagram of FDM Process



The cross-section of the extrusion head is shown in Figure 3.3. Fused deposition modeling builds a 3D object, layer by layer from a CAD design. Spooled filaments are fed into a liquefier head via computer driven rollers. The motion of the extrusion system operates under three-dimensional computer numerical control. TheliquefierheadismachinecontrolledformovementinthehorizontalX-Yplane. To complete the three axis movement, a fixtureless build platform moves in the Z direction. In the commercially available FDM machines, a continuously wound spool of polymer is guided to the liquefier via a winding path before being fed into a pair of counter rotating rollers as shown in Figure 3.3

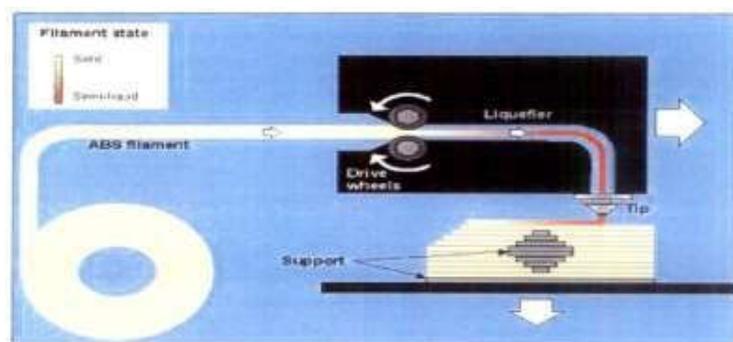


Figure 5.2 Working Principle of FDM Process

The filament softens and melts inside the liquefier to a temperature just above its melting point. The molten polymer is extruded out of a nozzle at the end of the liquefier. The positive force required for this extrusion is small and is provided by the rollers driving the incoming filament. A continuous positive displacement is provided in this manner.

It fabricates parts by extruding molten thermoplastic material or wax through a small, nozzle to form a thin bead or road that is deposited in a predetermined pattern to complete each build layer, bonding the extrudate to adjacent and previously deposited roads. The most common build material used with FDM systems is P400 ABS plastic and it is available in several stock colours, including white, red, blue, green, yellow and black. Inside the flying extrusion head, the filament is melted into liquid above its melting temperature by a resistant heater. The head traces an exact outline of each cross-section layer of the part. As the head moves horizontally in X and Y axes the thermoplastic material is extruded out a nozzle by a precision pump. The material solidifies in 1/10 second as it is directed onto the workplace. After one layer is finished, the extrusion head moves up a programmed distance in Z direction for building the next layer. Each layer is bonded to the previous layer through thermal heating. The designed object is fabricated as a three-dimensional part based solely on the precise deposition of thin layers of the extrudate. The deposition path and parameters for every layer are designated depending on the material used, the fabrication conditions, the application of the designed part and the preferences of the designer. The processing parameters of filling each layer depend on the earlier inputs into the slicing software. These include the FDM head speed, the rollers speed, the slice interval and the direction of deposition within each layer. Once built, the supports are removed after part building by breaking them away from the object.

6. MATERIAL SELECTION

The material selection is the most important thing for printing, because we have different materials. The material has different working materials based on their properties.

There are different technologies that are used in 3D printing and so there are various material that are used in this process. Some printers support around 170 different types of material for printing this can broadly be categorized into four important heads.

- Plastic
- Powder
- Resins
- Other Material

6.1 PLASTIC

The FDM printers use thermoplastic filament which is heated till the melting point and then the molten plastic is placed layer by layer to form the model. These printers tend to use the following materials

Acrylonitrile Butadiene Styrene (ABS) /Home Printer

It is popularly known as Lego plastic and is considered to be the best material to work with as it is strong and very safe. It is made from spaghetti like filaments .it is available in a wide range of colours and is used for making of toys, bumper stickers etc.

6.2 Polylactic Acid (PLA)

It is probably the easiest to work as well as environment friendly. It is basically bio degradable plastic that has been derived from sources such as corn starch and sugar canes. This is available in soft and hard grades, with the increase in the popularity of PLA, this material is expected to overtake ABS in the near future.

6.3 Polylactic Acid (Soft PLA)

It belongs to the softer version of the PLA that was discussed in the earlier point. It is rubbery and quite flexible but is available in limited colours and sources

6.4 Polyvinyl Alcohol Plastic(PLA)

It is a type of plastic that is used as dissolvable support materials or is used for special applications.

6.5 Polycarbonate(PC)

It requires a high temperature nozzle design and is not widely used.

The right selection of the machining material is the most important aspect to take into consideration in processes related to the FDM process. From the observation the printed material that has been selected is ABS.

7. The material properties of ABS:

Glass transition temperature	105°C
Melt volume index (MVI)	9.7cm ³ /10min
Melting temperature	210-240°C
Printing temperature	230-250°C
Recommended print bed temperature	80-120°C (heated bed required)
Slumping temperature	110-125°C

7.1 Mechanical & physical properties:

ABS exhibits a superior layer bond. Object 3D printed this way will be stronger and more impact resistant. Therefore, it is better suited for mechanical parts and for objects that need to be weatherproof.

Moreover, ABS parts are more flexible than PLA parts and tend to bend rather than break when under pressure. Also, ABS is better malleable, post processing is easier: the printed object can be cut, filed, sanded, painted, and bonded. And they can be treated with acetone to get a smooth and shiny surface or to weld two objects together.

8. Selection of Process Parameters:

Process parameters are the defined variables that influence and control FDM process. A number of parameters, some user defined and others defined by geometry or material considerations affect the quality of parts fabricated. The process variables in FDM such as build orientation, speed, infill density are the most vital among the control parameters. The control parameters will affect the output of the process and are controllable in a run. When you are doing a 3D print of a model there are multiple parameters that you have control of and these parameters of the printing process can affect things like quality, durability and speed of the printing process. So you should know what and how to change in order to get a stronger model or a faster print or actually use a 3D printer if you are having trouble printing a 3D model.

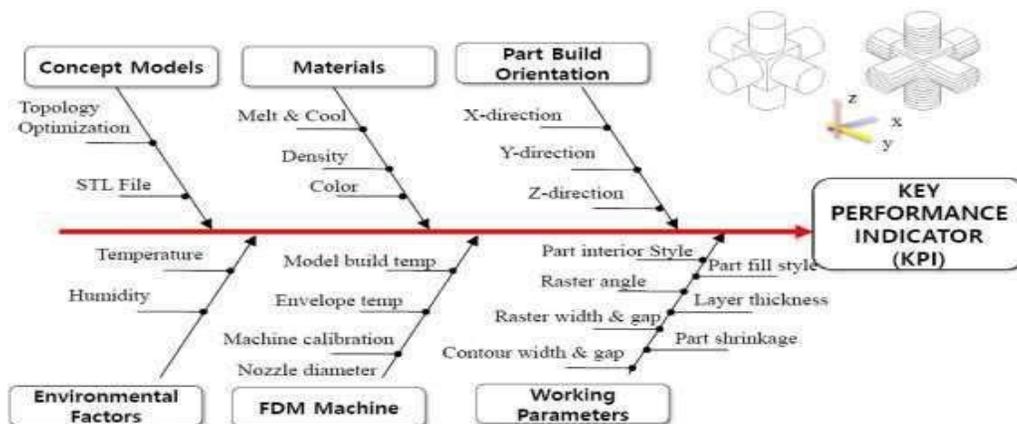


Figure 8.1 Ithikawa cause effect diagram for process parameters of FDM

9. Basic Object Sections

In general, a routine FDM object consists of four sections. The design criteria of each of these sections can be individually altered so that an optimized design is achieved. The sections are:

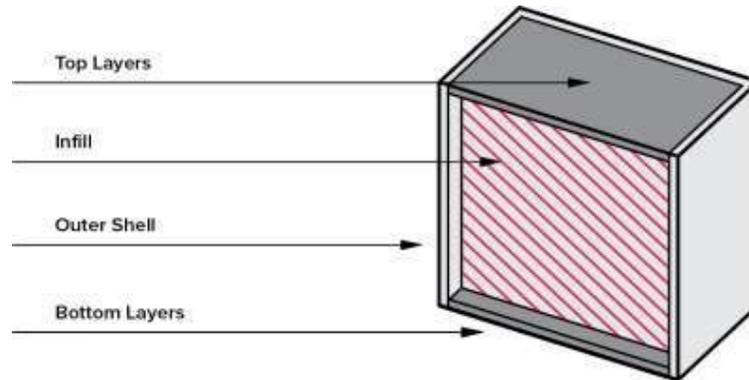


Figure 9.1 Basic object

Shell - The outside walls of an object, typically built up vertically along the z axis;

Bottom layers - A part of the shell comprised of an outside wall of an object, initially attached to the build plate;

Top layers - A part of the shell comprised of an outside wall of an object, facing upwards. Usually the last part of an object to print; and

Infill - The material that comprises the interior of the object between the shell or walls.

As you probably know, most FDM objects are not printed as solids. This is because printing a solid object would use a large amount of filament and take quite a long time to print. On the other hand, a printed object that was hollow and used only a thin outer shell would be cheap and quick to print.

However, for many applications this type of object would be impractical, as it would easily fail under the stress of normal usage. Infill is a compromise between these two positions.

Infill density is the amount of filament printed inside the object, and this directly relates to the strength, weight and printing duration of your print.

Different 3D print infill types or infill patterns can affect the object's final strength without changing the print's weight or filament used. We'll compare various infill designs and their uses below.

10. Using Shell Thickness to Reduce Infill Percentage:

The shell of an object consists of layers on the outside of an object. In many designs, the shell is often the first area that is printed in any layer. This means that shell thickness is intimately tied to infill amount and percentage.

When you increase the shell thickness of an object, you are also increasing its strength. This means that the object becomes sturdier and more capable of handling stress without the need for increasing the 3D printing infill density.

The majority of slicer programs will allow you to adjust the density of shell thickness in specific areas of the object, thereby offering localized strength where it is needed most.

Shell thickness is usually measured in print nozzle diameters. If you do decide to slightly increase shell thickness to reduce infill amounts, make sure that the thickness specified in your design is a multiple of your nozzle diameter. This will help reduce voiding in your walls, bottom and top layers.

10.1 Choosing Infill Density (%)

Infill density is one of the varying parameter in order to explore the Mechanical properties of 3D printing object we have varied two different varying infilling density which were 60% and 80%.

10.2 Part Orientation on the BuildPlate:

Once your part is created, it must be oriented on the build surface. Part orientation greatly influences the quality and the material properties of parts.

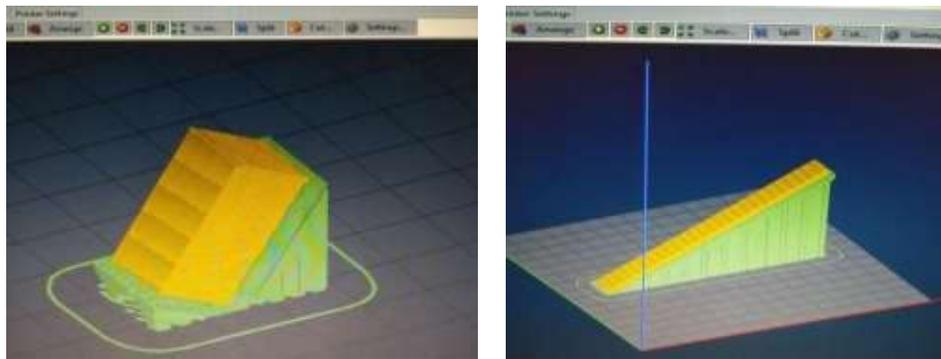


Fig. 10.1 Specimens with support material



Figure 10.2 Part Orientation

10.3 Positioning the part on the buildplate:

Centre parts on the build surface: The closer a part is to the center of the build plate the less it will warp because the build surface is leveled most accurately at its center. In addition, the heated build surface is cooler on the edges which increases warping near the edge.

Place parts directly on the platform: Make sure that the part is positioned on the build plate itself. You can check this by clicking on the “Move” button in Maker Ware and making sure the Z position is 0.

Place parts close together: When parts are positioned close together on the build platform, the printer head can move more quickly between parts, reducing build time. Arranging parts too close together can ruin multiple parts if one of the parts detaches. Parts should be placed 5-15 mm apart.

WARNING: Building multiple parts in the same build can cause other parts to print incorrectly if one of the part fails to print correctly. It is best to limit the number of parts per build and submit multiple jobs.

Selecting an appropriate orientation: Because 3D printers print parts layer-by-layer, the parts are weakest in the Z axis because layers can sometimes separate from one another. Also, the interior of parts is filled with a 10% dense honeycomb to reduce material use and build time, which also effects the material properties of parts.

Avoiding stair-stepping: Place curves or sloped surfaces so that they are printed in the XY plane. Curves printed in other planes have a stair-stepping effect. This stair-stepping effect can most easily be seen in parts with really shallow angles as shown in the picture below.

Avoid tall, thin features: Parts with small surface areas attached to the build surface are likely to become detached during printing due to the forces and moments exerted on them by the printer head. The taller the part, the larger the moments (or torques) it will experience at its base, which means the more likely it will detach while printing.

10.4 Post-processing Parts after Printing:

Some parts require post-processing after printing. If you printed your parts with rafts and supports they must be removed before your part will be useable. Using needle nose pliers to pry off supports can be effective. Metal spatulas have also been used successfully to remove rafts. It is best to add all holes to parts in CAD software prior to printing. Drilling holes into 3D printed parts can cause parts to collapse if nuts are tightened onto the holes because the interior of the parts is composed of a honeycomb structure to reduce material usage and print time.



Figure 10.4 Post Finishing process

S. No	BUILD ANGLE (DEGREE) X-Y PLANE	INFILL DENSITY (%)	LAYER THICKNESS (Microns)	SPEED (mm/sec)	INFILL PATTERN	UPPER AND LOWER PATTERN
1	0	60	200	60	Honeycomb	Rectilinear
2	0	80	200	60	Honeycomb	Rectilinear
3	30	60	200	60	Honeycomb	Rectilinear
4	30	80	200	60	Honeycomb	Rectilinear
5	60	60	200	60	Honeycomb	Rectilinear
6	60	80	200	60	Honeycomb	Rectilinear

Table 10.1 List of objects to be printed with varying Build Angle and Infill Density

11. MECHANICAL TESTS & RESULTS:



FIGURE 11.1: Before and After Testing of Compression Test Specimens

S.No	Build Angel (XY)	Infill Density (%)	Layer Thickness (Microns)	Speed (mm /sec)	Infill Pattern	Upper and Layer Pattern	Compression test	
							Ultimate load (KN)	Compressive strength (Mpa)
1	0	60	200	60	Honey Comb	Rectilinear	3.6	22.454
2	0	80	200	60	Honey Comb	Rectilinear	2.88	17.947
3	30	60	200	60	Honey Comb	Rectilinear	4.5	27.817
4	30	80	200	60	Honey Comb	Rectilinear	5.04	30.981
5	60	60	200	60	Honey Comb	Rectilinear	4.08	24.863
6	60	80	200	60	Honey Comb	Rectilinear	5.4	33.115

Table 11.1: Results Obtained from the Compressive Tests

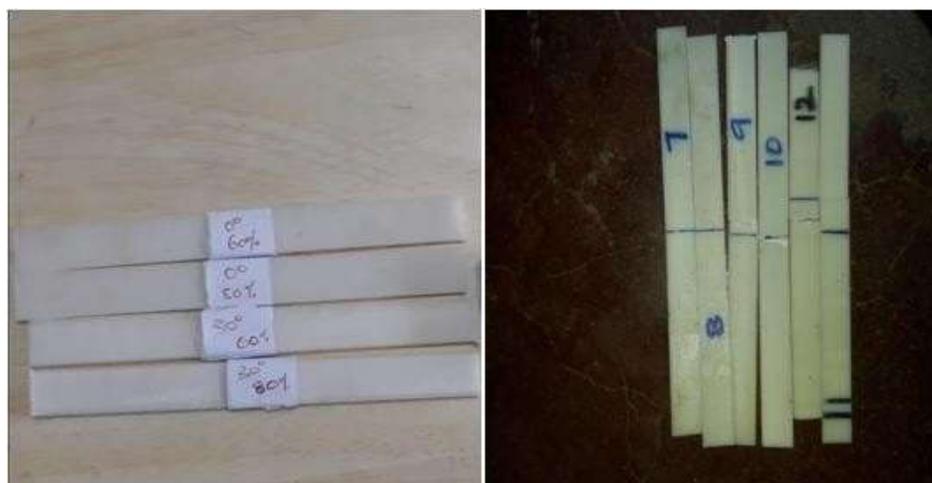


FIGURE 11.2 Before and After Testing of Flexural Test Specimens

S. No	Build Angel (XY)	Infill Density (%)	Layer Thickness (Microns)	Speed (mm /sec)	Infill Pattern	Upper and Layer Pattern	Flexural Strength (N/mm ²)
1	0	60	200	60	Honey Comb	Rectilinear	343.01
2	0	80	200	60	Honey Comb	Rectilinear	358.37
3	30	60	200	60	Honey Comb	Rectilinear	363.52
4	30	80	200	60	Honey Comb	Rectilinear	283.46
5	60	60	200	60	Honey Comb	Rectilinear	253.48
6	60	80	200	60	Honey Comb	Rectilinear	216.73

Table 11.2: Results Obtained from the Flexural Test

11.3 Testing

The specimen is first placed on a hard flat surface. The indenter for the instrument is then pressed into the specimen making sure that it is parallel to the surface. The hardness is read within one second (or as specified by the customer) of firm contact with the specimen.



FIGURE 11.3 Before and After Testing of Shore Hardness Test Specimen

S.No	Build Angel (XY)	Infill Density (%)	Layer Thickness (Microns)	Speed (mm /sec)	Infill Pattern	Upper and Layer Pattern	Shore Hardness Test
1	0	60	200	60	Honey Comb	Rectilinear	64.666
2	0	80	200	60	Honey Comb	Rectilinear	64.66
3	30	60	200	60	Honey Comb	Rectilinear	66.33
4	30	80	200	60	Honey Comb	Rectilinear	65.33
5	60	60	200	60	Honey Comb	Rectilinear	62.33
6	60	80	200	60	Honey Comb	Rectilinear	62.66

Table 11.3: Results Obtained from the Shore Hardness Tests

12. Conclusion:

The objects were printed on 3D-Printing FDM Machine, with ABS as printed material. Total 18 Samples were printed by varying process parameters Build Angel (0° , 30° , 60°) and Infill Density (60% and 80%). To Analyze the mechanical strength of these 3D printed ABS objects Mechanical Tests (Compressive, Flexural & hardness Tests) were performed. We observed that the object with 60° Build Angel, 80% Infill Density has high Compressive Strength 33.115 MPa with Ultimate load 5.400 KN and the object with 30° Build Angle and 60% Infill Density has high Flexural Strength 363.52 N/mm² and Hardness of 66.33. By this we conclude that, depending on the application, build orientation and Infill Density can and does make a difference in the strength, hardness, and Stiffness of the Object.

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