Parametric Analysis of Objects made by ABS Using Fused Deposition Modeling

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ABSTRACT

3D printers are considered an additive manufacturing process because they use raw materials to build an object layer by layer. It is also known as rapid manufacturing or rapid prototyping. Fused Deposition Modeling (FDM) has become extensively used for low-cost printers. Normally, commercial manufacturers of printers only provide information on layer thickness, but no information is given as to dimensional accuracy, and the surface characteristics obtained in manufactured components. Main disadvantages for the use of 3D printers in final product manufacturing are its lack of precision and poor dimensional accuracy. The aim of this study was to determine the dimensional accuracy, flatness, and surface texture obtained in FDM rapid prototype with ABS (Acrylonitrile Butadiene Styrene) material. Main three parameter (layer thickness, orientation, and infill pattern) are changed in fused deposition modeling carried out on Maker Bot Replicator 2x 3D printer. And different parameter like tensile strength, compressive strength, impact strength etc can be analysed. Optimum process parameters were found to improve dimensional accuracy on rectangular test specimens, minimizing changes in length, width and height. The goal of this prototype was to improve the energy efficiency and reduce the power consumption of a 3D printer by employing an innovative and validated heating circuitry or platform without compromising print quality.

Keywords*: 3d printer, ABS, Fused deposition modeling, tensile strength.*

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1. INTRODUCTION

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 airfoil in a wind tunnel to measure lift and drag forces. Designers have always utilized prototypes; RP allows them to be made faster and less expensively. In addition to prototypes, RP techniques can also be used to make tooling (referred to as rapid tooling) and even production-quality parts (rapid manufacturing). For small production runs and complicated objects, rapid prototyping is often the best manufacturing process available. Of course, "rapid" is a relative term. Most prototypes require from three to seventy-two hours to build, depending on the size and complexity of the object. This may seem slow, but it is much faster than the weeks or months required to make a prototype by traditional means such as machining. These dramatic time savings allow manufacturers to bring products to market faster and more cheaply. In 1994, Pratt & Whitney achieved "an order of magnitude [cost] reduction and time savings of 70 to 90 percent" by incorporating rapid prototyping into their investment casting process.

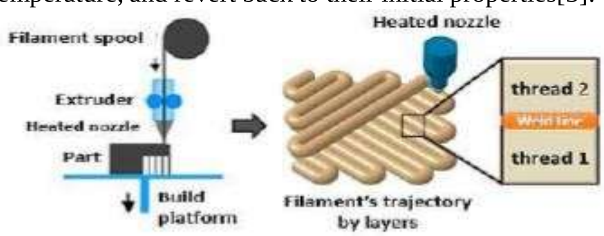
At least six different rapid prototyping techniques are commercially available, each with unique strengths. Because RP technologies are being increasingly used in non-prototyping applications, the techniques are often collectively referred to as solid free-form fabrication; computer automated manufacturing, or layered manufacturing.

The latter term is particularly descriptive of the manufacturing process used by all commercial techniques. A software package "slices" the CAD model into a number of thin (~0.1 mm) layers, which are then built up one atop another. Rapid prototyping is an "additive" process, combining layers of paper, wax, or plastic to create a solid object. In contrast, most machining processes (milling, drilling, grinding, etc.) are "subtractive" processes that remove material from a solid block. RP's additive nature allows it to create objects with complicated internal features that cannot be manufactured by other means. Of course, rapid prototyping is not perfect. Part volume is generally limited to 0.125 cubic meters or less, depending on the RP machine. Metal prototypes are difficult to make, though this should change in the near future. For metal parts, large production runs, or simple objects, conventional manufacturing techniques are usually more economical. These limitations aside, rapid prototyping is a remarkable technology that is revolutionizing the manufacturing process.

2. fused deposition modeling

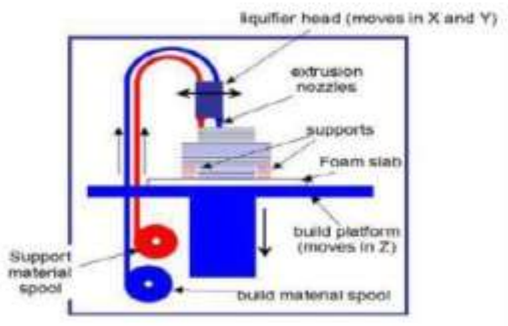
To present this work several papers are referred according to FDM. As there is mainly FDM is used in 3d printers to make complex objects by rapid prototyping. Recent advancements in 3D printing, sometimes referred to as additive manufacturing is considered a game changer relative to rapid prototyping. The industrial, military, commercial, aerospace as well as the automotive industry have made significant gains due to this technology.

Fused Deposition Modelling (FDM) has become extensively used for low-cost printers. Normally, commercial manufacturers of printers only provide information on layer thickness, but no information is given as to dimensional accuracy, and the surface characteristics obtained in manufactured components. The aim of this study was to determine the dimensional accuracy, flatness, and surface texture obtained in FDM rapid prototype with ABS-plus as the model material. The most frequently used materials are thermoplastics (polythene, polypropylene, polybutylene, polystyrene, polyvinyl chloride, ABS, ABS-plus, polyamide, among others), due to their excellent
mechanical, thermal, and chemical characteristics. These materials are particularly suitable for industrial applications since they are easily manageable in their pre-fusion state at low temperatures, gradually harden as they cool down at glass transition temperature, and revert back to their initial properties[3].



FDM and classical trajectory deposition

Fused Depositing Modeling (FDM) process begins with a 3D model in CAD or modeling software before
converting it in STL format file. This format is treated by specific software own to the AM technology which cuts the piece in slices to get a new file containing the information for each layer. This step implies a G-code language to traduce the slicing in trajectories and layers. During the manufacturing, a filament is extruded through a nozzle to print one cross section of an object, then moving up vertically to repeat the process for a new layer (Fig. 1). The most used materials in FDM are ABS, PLA, and PC (Polycarbonate). To predict the mechanical behavior of FDM parts, it is critical to understand the material properties of the raw FDM process material, and the effect that FDM build parameters have on anisotropic material properties[4].



Application Range

- Conceptual modeling
- Fit, form applications and models for further manufacturing procedures
- Investment casting and injection modelling

Advantages

- Quick and cheap generation of models
- There is no worry of exposure to toxic chemicals, lasers or a liquid chemical bath.

Disadvantages

- Restricted accuracy due to the shape of material used, wire is 1.27 mm diameter.

3. BASIC PROCESS

1. Create a CAD model of the design
2. Convert the CAD model to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer atop another
5. Clean and finish the model

4.ABS MATERIAL

Acrylonitrile Butadiene Styrene (**ABS**) chemical formula ((C8H8·C4H6·C3H3N)n) is a common thermoplastic used to make light, rigid, molded products such as piping (for example Plastic Pressure Pipe Systems), musical instruments (most notably recorders and plastic clarinets), golf club heads (used for its good shock absorbance), automotive body parts, wheel covers, enclosures, protective head gear, buffer edging for furniture and joinery panels, airsoft BBs and toys, including Lego bricks. ABS plastic ground down to an average diameter of less than 1 micrometer is used as the colorant in some tattoo inks. Tattoo inks that use ABS are extremely vivid. This vividness is the most obvious indicator that the ink contains ABS, as tattoo inks rarely list their ingredients.

It is a copolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The result is a long chain of polybutadiene criss-crossed with shorter chains of poly (styrene-co-acrylonitrile). The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The styrene gives the plastic a shiny, impervious surface. The butadiene, a rubbery substance, provides resilience even at low temperatures. ABS can be used between −25 and 60 °C. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix. Production of 1 kg of ABS requires the equivalent of about 2 kg of oil for raw materials and energy. It can also be recycling.

5. TAGUCHI METHOD

Taguchi method is a statistical method developed by Taguchi and Konishi [12]. Initially it was developed for improving the quality of goods manufactured (manufacturing process development), later its application was expanded to many other fields in Engineering, such as Biotechnology [13] etc. Professional statisticians have acknowledged Taguchi's efforts especially in the development of designs for studying variation. Success in achieving the desired results involves a careful selection of process parameters and bifurcating them into control and noise factors. Selection of control factors must be made such that it nullifies the effect of noise factors. Taguchi Method involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyze the data and predict the quality of components produced. Here, an attempt has been made to demonstrate the application of Taguchi's Method to improve the surface finish characteristics of faced components that were processed on a lathe machine. Surface roughness is a measure of the smoothness of a products surface and it is a factor that has a high influence on the manufacturing cost. Surface finish also affects the life of any product and hence it is desirable to obtain higher grades of surface finish at minimum cost.

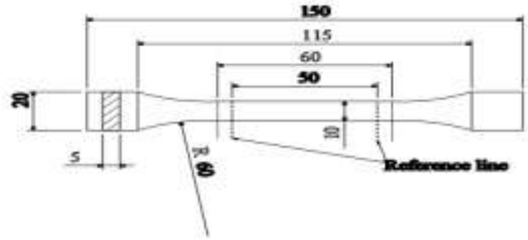
The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better.

FDM machines build prototypes on additive manufacturing technology.It has two nozzles, one for building of the prototype and other for building of support structure.The experiment is conducted for three parameter based model.Main process parameters used in the experiment are :

1. Layer thickness: It is the thickness of layer deposited by the nozzle and its configuration dependon the shape of prototype and type of nozzle.
2. Orientation: It refers to the inclination of the part in build platform with respect to X,Y,Z axis.The platform is taken as X and Y axis plane and Z axis is taken along build direction.
3. Infill pattern : The term "infill" refers to the structure that is printed **inside** an object. It is extruded in a
designated percentage and pattern, which is set in the slicing software. Infill percentage and pattern influence print weight, material usage, strength, print time and sometimes decorative properties.

Factors	**Symbols**	**Levels**		
		1	2	3
Layer thickness(mm)	A	0.100	0.200	0.300
Orientation (degree)	B	0	45	90
Infill pattern	C	Linear	Hexagonal	Diamond

Tensile test specimens having dimensions 60 mm x 20 mm x 5 mm. Infill pattern is an important parameter
for part strength, tests have been conducted by changing the infill patterns like linier, hexagonal and diamond for measuring Tensile strength (ASTMD 638). The part are modeled in CATIAV5 software and exported as STL file. STL file is imported to FDM software. Here, factors are set as per experiment plan. One objects per experiment are fabricated using fused deposition modeling vantage machine. The material use for part fabrication is ABS P400. Parts are modeled and experiment is conducted as per ISO R527:1966 for tensile test. And part made according to taguchi design 9 runs.



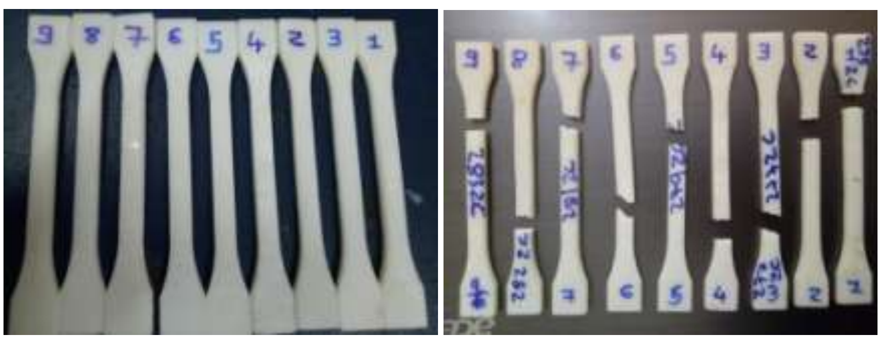
Line diagram of specimen for tensile test

6. RESULTS AND DISCUSSION

The most suitable orthogonal array for experimentation is L9 array as shown in table. Therefore, a total nine experiments are to be carried out and its tensile test value.

Exp	Layer Thickness(A)	Orientation (B)	Infill pattern (C)	Time (min)	Weight (gm)	Load	UTS (Mpa)
1	1	1	1	45	9.9	1580	30.3
2	1	2	2	47	9.6	1190	23.9
3	1	3	3	55	8.3	770	14.5
4	2	1	2	21	9.2	1280	25.8
5	2	2	3	27	7.8	730	13.9
6	2	3	1	23	9.7	1580	30.4
7	3	1	3	16	10.6	1230	20.0
8	3	2	1	14	9.8	1620	30.8
9	3	3	2	15	9.2	1300	24.3

Total 9 runs ABS tensile specimen with after fracture is shown in figure.



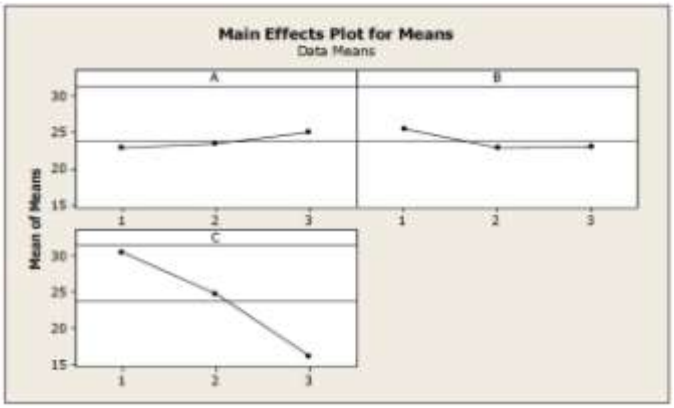
Test of tensile specimen

Response Table for Means (larger is better)

Level	A	B	C
1	22.90	25.37	30.50
2	23.37	22.87	24.67
3	25.03	23.07	16.13
Delta	2.13	2.50	14.37
Rank	3	2	1

Main affecting parameter - infill pattern

Main effects plot for the main effect terms viz. factors A, B and C are shown in Figure . From the main effect plots, it has been observed that tensile strength of FDM specimen dicreases with changing of infill pattern.



Main effects plot for means

ANOVA was developed by Sir Ronald Fisher in the 1930s as a way to interpret the results from agricultural experiments. ANOVA is statistically based, objective decision making tool for detecting any difference in average performance of groups of items tested.

ANOVA table consists of number of columns. One column consists of sources or parameters of the experiment, degree of freedom can be tabulated in other column, likewise sum of squares (SS), mean square (MS), Fisher test value (F ratio), and P value may be tabulated in others columns separately.

Parameter	DOF	SS	SS %
Layer thickness A	1	6.83	2.10
Orientation B	1	7.94	2.45
Infill pattern C	1	309.60	94.45
Total	3	324.37	100

It can be seen from this table that for the tensile specimen, the contribution of infill pattern (94.45%) is more significant than orientation which is (2.45%). These factors are more significant than the layer thickness (2.10%). It is clear that the effect of infill pattern on tensile strength of FDM specimen is very high.

7. Conclusion

- Infill pattern has the largest effect on the tensile strength of FDM specimen and the layer thickness has the smallest effect on the tensile strength of FDM.
- Tensile strength is maximum with slice orientation parallel to the loading axis.
- Low layer thickness slightly increase strength of specimen with compare to the infill pattern but it significantly increase the build time of specimen.
- Rapid prototyping providing simplness to study and analysing expensive processes.

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