© 2016 IJSRSET | Volume 2 | Issue 2 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Investigation of the Effect of Fused Deposition Process Parameter on Compressive Strength and Roughness Properties of Abs-M30 Material

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ABSTRACT

The process parameters of FDM manufacturing technology are very important for obtaining high quality parts, good mechanical properties. Several optimization techniques used such as Response surface methodology, Taguchi method, FF, ANN etc. much research work has been carried out in ABS, PC, PPSF, Nylon-12, PC-ABS blend for optimizing process parameters to identify improved surface roughness, mechanical properties and built-up time.
Keywords: FDM, Taghuchi method, built up time

I. 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.

II. METHODS AND MATERIAL

A. Methods the Basic Process

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are:

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.

CAD Model Creation:

First, the object to be built is modeled using a Computer-Aided Design (CAD) software package. Solid modelers, such as Pro/ENGINEER, tend to represent 3-D objects more accurately than wire-frame modelers such as AutoCAD, and will therefore yield better results. The designer can use a pre-existing CAD file or may wish to create one expressly for prototyping purposes. This process is identical for all of the RP build techniques.

Conversion to STL Format:

The various CAD packages use a number of different algorithms to represent solid objects. To establish consistency, the STL (stereolithography), the first RP technique) format has been adopted as the standard of the rapid prototyping industry. The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles, "like the facets of a cut jewel." The file contains the coordinates of the vertices and the direction of the outward normal of each triangle. Because STL files use planar elements, they cannot represent curved surfaces exactly. Increasing the number of triangles improves the approximation, but at the cost of bigger file size. Large, complicated files require more time to pre-process and build, so the designer must balance accuracy with manageability to produce a useful STL file. Since then .stl format is universal, this process is identical for all of the RP build techniques.

Slice the STL File:

In the third step, a pre-processing program prepares the STL file to be built. Several programs are available, and most allow the user to adjust the size, location and orientation of the model. Build orientation is important for several reasons. First, properties of rapid prototypes vary from one coordinate direction to another. For example, prototypes are usually weaker and less accurate in the z (vertical) direction than in the x-y plane. In addition, part orientation partially determines the amount of time required to build the model. Placing the shortest dimension in the z direction reduces the number of layers, thereby shortening build time. The pre-processing software slices the STL model into a number of layers from 0.01 mm to 0.7 mm thick, depending on the build technique. The program may also generate an auxiliary structure to support the model during the build. Supports are useful for delicate features such as overhangs, internal cavities, and thin-walled sections. Each PR machine manufacturer supplies their own proprietary pre-processing software.

Layer by Layer Construction:

The fourth step is the actual construction of the part. Using one of several techniques (described in the next section) RP machines build one layer at a time from polymers, paper, or powdered metal. Most machines are fairly autonomous, needing little human intervention.

Clean and Finish:

The final step is post-processing. This involves removing the prototype from the machine and detaching any supports. Some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability.

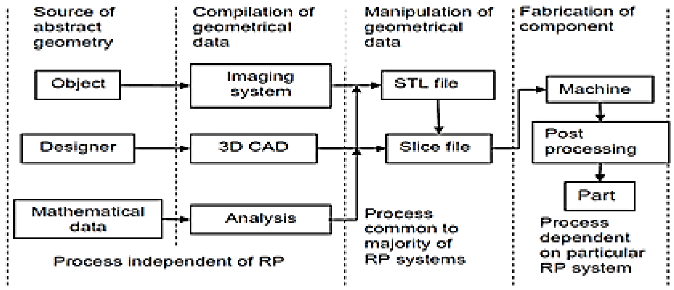

Figure 1

B. Rapid Prototyping Techniques

Most commercially available rapid prototyping machines use one of six techniques. At present, trade restrictions severely limit the import/export of rapid prototyping machines, so this guide only covers systems available in the U.S.

Selective Laser Sintering:

It was developed and patented by the University of Texas at Austin and wasinitially commercialized by DTM corporation which was later on owned by 3D systems, USA. In this process, a thin layer of thermoplastic powder is spread by a roller over the surface of a build cylinder and heated to just below its melting point by infrared heating panels at the side of the cylinder. Then a laser beam traces out the cross section of one slice of the part. Where the laser beam hits the powder, the affected particles fuse together (or sintered). The first fused slice descends one object layer, the roller spreads out another layer of powder, and the process continues until the part is built.

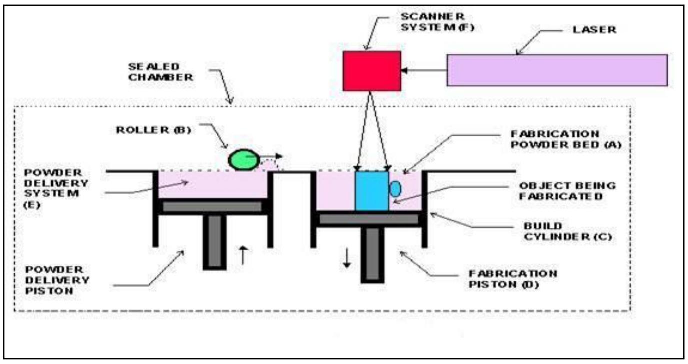

Figure 2. Selective laser sintering

Stereolithography (SL)

It is the first commercial RP machine introduced in mid 1980s by 3D systems, California, USA. It fabricates part from a photo curable liquid resin that solidifies when sufficiently exposed to a laser beam that scans across the surface of resin. The solidified layer is then lowered into a vat so that another layer of liquid can be exposed to the laser. This process is repeated until all cross sections are built into a solid model of the original CAD model. When all the slices have been traced by the laser, the platform is removed from the vat and excess liquid polymer is cleaned off the completed part. The completed part is then finally cured in an ultraviolet oven.

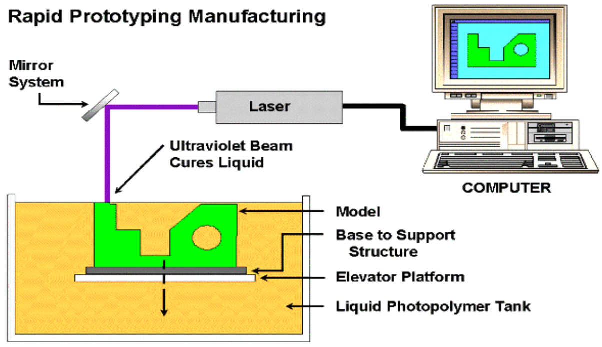

Figure 3. Stereolithography

Fused Deposition Modelling (FDM):

FDM was introduced by Stratasys, Minnesota, USA. A filament of material is extruded out of a fine nozzle in a semi liquid state and deposited onto a platform. The nozzle moves in the X-Y plane so that the filament is laid down to form a thin crosssectional slice of the part. As each layer is extruded, it bonds to the previous layer and solidify. The platform is then lowered relative to the nozzle and the next slice of the part is deposited on top of the previous slice. A second nozzle is used to extrude a different material in order to build-up support structures for the part where needed. Once the part is completed, the support structures are broken away from the part.

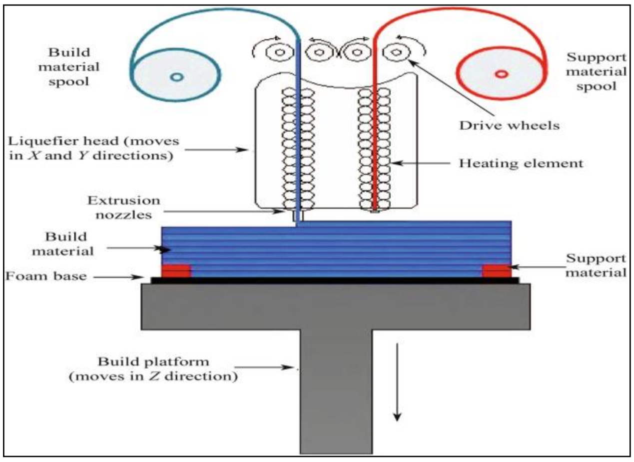

Figure 4. Principle of FDM process

C. Literature Review

Ahn et al [1]. Uses design of experiment method and concluded that the air gap and raster orientation affect the tensile strength of FDM processes part where as raster width, model temperature and colour have little effect. They further compare the measured tensile strength of FDM part processed at different raster angles and air gap with the tensile strength of injection moulded part. Material use for both type of fabrication is ABSP400. With zero air gap FDM specimen tensile strength lies between 10%-73% of injection moulded part with maximum at 0° and minimum at 90° raster orientation with respect to loading direction. But with negative air gap there is significant increase in strength at respective raster orientation but still it is less than the injection moulded part. All specimens failed in transverse direction except for specimen whose alternate layer raster angle varies between 45° and -45°. This type of specimen failed along the 45° line. Compression test on the specimen build at two different orientations revealed that this strength is higher than the tensile strength and lies between 80 to 90% of those for injection moulded part. Also specimen build with axis perpendicular to build table shows less compressive strength as compared to specimen build with axis parallel to build table. Based on these observations it was concluded that strength of FDM processed part is anisotropic.

Mohammad Hossain et al[3]. the focus was on improving tensile mechanical properties of FDM manufactured parts by adjusting FDM processing parameters. FDM processing parameters are specified by the user via Insight – the file preparation software for most FDM machines. Even though Insight gives the impression that adjacent roads are to be deposited and connected throughout, an optical imaging observation of the deposited material revealed that adjacent roads are not consistently connected forming voids that reduce mechanical performance. Therefore, this work reports the tensile mechanical properties of specimens built using three sets of parameters: standard/default parameters, an Insight revision method, and a visual feedback method. When compared to the default build parameters, the experimentally determined, visual feedback approach produced specimens, in some cases, exhibiting as high as 19% improvement in ultimate tensile strength. Future work may include the effect of build orientation as well as layer thickness in further improving mechanical properties of FDM parts. However, modifications in layer thickness may compromise building time. While visual feedback method does reduce the gaps in a part, it does not completely eliminate them. Therefore, measurements can be conducted in the future to determine how the changes in porosity of the samples, through the elimination of air gaps, affect density.

S.H.Masood et[2] al. Fused deposition modeling (FDM) is one of the most popular additive manufacturing technologies for various engineering applications. FDM process has been introduced commercially in early 1990s by Stratasys Inc., USA. The quality of FDM processed parts mainly depends on careful selection of process variables. Thus, identification of the FDM process parameters that significantly affect the quality of FDM processed parts is important. In recent years, researchers have explored a number of ways to improve the mechanical properties and part quality using various experimental design techniques and concepts. This article aims to review the research carried out so far in determining and optimizing the process parameters of the FDM process. Several statistical designs of experiments and optimization techniques used for the determination of optimum process parameters have been examined. The trends for future FDM research in this area are described. a large number of process variables that determine the mechanical properties and quality of fabricated parts. Much research work has been attempted to improve the mechanical properties and part quality for FDM fabricated ABS parts through statistical design optimization. However, modeling and optimization of FDM process with other leading FDM materials such as PC, PC-ABS, ABSM30i, PPSF, etc., have not been undertaken. Overall literature review shows that process parameters including air gap, layer thickness, raster angle, raster width and build orientations are the critical factors and these must be studied and analyzed in future research.

Constance Ziemian et al[7]. The mechanical properties of ABS specimens fabricated by fused deposition modeling display anisotropic behaviour and are significantly influenced by the orientation of the layered rasters and the resulting directionality of the polymer molecules. The presence of air gaps and the quantity of air voids between the rasters or fibers additionally influences the strength and effective moduli in regard to all of the tests completed in this study. Tension tests indicate that the ultimate and yield strengths are the largest for the 0° raster orientation, followed by the +45°/-45°, 45°, and 90° orientations in descending order.

The differences between mean ultimate tensile strengths are significant for all pairwise comparisons of different raster orientations. Fracture paths are affected by the directionality of the polymer molecules and the strength of individual layers. The longitudinal specimens benefit from the alignment of molecules along the stress axis. The results of both three-point bend and impact tests correlate well with tension test results, again indicating that the yield strengths are the largest for the 0° raster orientation, followed by the +45°/-45°, 45°, and 90° orientations in descending order. The 0° rasters offer the most resistance to bending due to the largest effective raster lengths. As raster angle increases, the effective length and associated flexural and impact strengths decrease. Mean flexural and impact strengths are significantly affected by raster orientations, with the pairwise comparison of 45º and 90º rasters as the only one with no statistical difference. The results of this project are useful in defining the most appropriate raster orientation for FDM components on the basis of their expected in-service loading. Results are also useful to benchmark future analytical or computational models of FDM strength or stiffness as a function of void density. Additional research currently in progress includes a thorough fatigue analysis of FDM specimens with varying raster orientations.

Dr K.G.Dave et al[5]. Rapid prototyping (RP) refers to a class of technology that can automatically construct the physical models from computer aided design (CAD) data. Fused deposition modelling (FDM) is process for developing rapid prototype objects from plastic material by lying track of semi molten plastic filament on to a platform in a layer wise manner from bottom to top. The aim of this paper is to investigate the effect of process parameters on surface roughness of fused deposition modelling built parts. Response surface methodology (RSM) was used to conduct the experiments. The parameters selected for controlling the process are layer thickness, part built orientation and raster angle. Surface roughness of fused deposition modelling built parts is measured by surface roughness tester. From the results of the experiments, mathematical model have been developed to study the effect of process parameters on surface roughness. The effect of process parameters like layer thickness, part build orientation and raster angle on surface roughness has been studied. Experiments were conducted using response surface methodology (central composite design matrix) and mathematical model have been developed. The response plots are analysed to assess influence of each factor and their interaction on surface roughness. Experimental result analysis and surface plots concluded that part build orientation has the most significant effect onmsurface roughness followed by layer thickness. However raster angle has least significant influence on surface roughness.

S.Manikanandan et al[4]. RP parts are used in many organizations as concept models, functional or semi-functional components, master patterns and direct tooling. Fused Deposition Modeling (FDM) is one of the RP technologies. The mechanical properties of parts produced by FDM are affected by various process parameters. This project concentrates on the effect of process parameters of FDM 900mc machine on mechanical properties such as flexural strength and surface roughness for Polycarbonate-Acrylonitrile Butadiene Styrene (PC-ABS) blend material. The parameters considered are Contour style, Raster angle, Raster width, and Air gap. Testing is done for the mechanical properties such as flexural strength and surface roughness using the preferred standards. The results obtained were optimized using Taguchi method in order to have better mechanical properties. The results show that raster angle has greater effect on flexural strength. Raster angle of 45°/45° yields higher flexural strength when compared with other parameters considered. Similarly, for surface roughness, contour style is the most significant parameter, where the triple contour style gives better surface finish. The best combination of FDM process parameters, in order to have good flexural and surface roughness properties are identified for the material PC-ABS Blend. In the direction of having better flexural strength, single contour style, raster angle of 45°/45°, raster width of 0.6064 mm, and air gap of 0.00 mm are the best combinations. Raster angle is the parameter which has the most significant effect on flexural strength of PC-ABS component made by FDM process, when compared with the other parameters taken into account. The best parameter settings to obtain minimum surface roughness is given by triple contour style, raster angle of 45°/45°, raster width of 0.6064 mm, and air gap of 0.02 mm. Contour style is the parameter which has the most significant effect on surface roughness of PC-ABS component made by FDM process, when compared with the other parameters. The above parameter settings can be used for the fabrication of PC-ABS samples in FDM machine for various applications which focuses on flexural and surface roughness properties of the prototype. The material usage by the FDM machine can be optimized with the help of these parameter settings.

S.Dinesh Kumar et al[6]. Rapid Prototyping (RP) is the solid free form manufacturing process which enables the quick fabrication of physical models using three-dimensional computer aided design (CAD) data. Fused Deposition Modeling (FDM) is a solid-based rapid prototyping method that extrudes material, layer-by-layer, to build a model. Knowledge of the quality characteristics of FDM fabricated parts is vital. Quality extensively depends on process variable parameters. Hence, the Optimization of these process parameters of FDM is able to make the system more specific and repeatable and such progression can guide to use of FDM in rapid manufacturing applications rather than only producing prototypes. In order to understand this issue, this paper explains the results obtained in the experimental work on the cause of the main FDM process variable parameters namely, layer thickness (A), air gap (B), raster width (C), contour width (D), and raster orientation (E). The novel ABS- M30i biomedical material was used in this research work to build parts. Experiments were conducted using Taguchi's design of experiments with two levels for each factor. The results are analyzed statistically to determine the significant factors and their interactions. In this research, five FDM parameters: (A) layer thickness, (B) air gap, (C) raster width , (D) contour width , (E) raster orientation were examined at two variable settings for building test parts. Full factor design was used in this research to conduct an experimentation plan to determine the optimum parameters settings that affect the output characteristic response i.e., surface roughness (Ra). It has been found that not all FDM parameters have impact on the Surface roughness; also the FDM parameters vary in their influence on each proposed response characteristic. Air gap parameter has been proved statistically to influence the surface finish of FDM built parts, combined with layer thickness at (0.254 mm) and raster width at (0.508 mm). By applying negative air gap at (-0.01), the beads of ABS M-30i overlapped and the voids between the built beads were filled, this resulted in a smooth surface construction and a lower Ra value compared with other built parts with default settings. Hence, it has been found that the voids between the deposited layers caused a roughed surface. Building parts with thinner layers or narrower roads may reduce the surface roughness.

Anoop K. Sood et al[10] Fused deposition modelling (FDM) is gaining distinct advantage in manufacturing industries because of its ability to manufacture parts with complex shapes without any tooling requirement and human interface. The properties of FDM built parts exhibit high dependence on process parameters and can be improved by setting parameters at suitable levels. Anisotropic and brittle nature of build part makes it important to study the effect of process parameters to the resistance to compressive loading for enhancing service life of functional parts. Hence, the present work focuses on extensive study to understand the effect of five important parameters such as layer thickness, part build orientation, raster angle, raster width and air gap on the compressive stress of test specimen. The study not only provides insight into complex dependency of compressive stress on process parameters but also develops a statistically validated predictive equation. The equation is used to find optimal parameter setting through quantum-behaved particle swarm optimization (QPSO). As FDM process is a highly complex one and process parameters influence the responses in a nonlinear manner, compressive stress is predicted using artificial neural network (ANN) and is compared with predictive equation.

In the present work, an attempt has been made to study the effect of five processing parameters that is layer thickness, part build orientation, raster angle, raster width and air gap on the compressive strength of FDM built part. The experimental results establish the anisotropic and brittle nature of FDM processed ABSP400 part. The developed relationship between compressive stress (output) and process parameters (input) is able to explain the 96.13% of variability in the response and is suitable to explore the design space for future engineering applications. Effect of various factors and their interactions are explained using response surface plots

Dario Croccolo et al[12] Possible to rapidly generate even much complicated parts. Unfortunately, the Fused Deposition Modelling is affected by several parameters, whose setting may have a strong impact on the components strength. This paper is devoted to the study of the effects generated by the Fused Deposition

Modelling production parameters on the tensile strength and on the stiffness of the generated components, tackling the question from both the experimental and the numerical points of view. For this purpose, an analytical model was developed, which is able to predict the strength and the stiffness properties, based on the number of contours deposited around the component edge and on the setting of the other main parameters of the deposition process. The fundamental result of the paper consists in the possibility of predicting the mechanical behaviour of the Fused Deposition modelled parts, once the raster pattern(dimensions, number of contours, raster angle) has been stated. The effectiveness of the theoretical model has been verified by comparison to a significant number of experimental results, with mean errors of about 4%.

The present paper has dealt with the effect of contouring on the static strength and stiffness of FDM processed parts. The issue has been tackled both experimentally and analytically, with the development of a predictive model presented in a closed form. The FDM is a Rapid Prototyping technique that makes it possible to build 3D parts at low costs in a short time. The low strength can be compensated by good compliance properties. The analysis of the state of the art has showed that the effect of contouring on the mechanical behaviour has never been studied and, furthermore, predictive models, which significantly relate the process parameters to the final properties, are actually missing. The present study has been focused on ABS-M30, a widely used material for FDM processed parts. Specimens of five different types have been manufactured, taking two factors into account: the building direction and the number of contours. Experimental tensile tests have been performed according to the ASTM D638-10 Standard. The results have been processed for the determination of the Ultimate Strength and of the Young's modulus. Since a preliminary and simplified model, which relates the number of contours to the mechanical characteristics of the specimens, produced unacceptable errors if compared with the experimental results, it was decided to develop a new one, which considers all the beads sharing the applied load. The current model has been differentiated for the contours placed longitudinally with respect to the load direction, and those inclined having a fixed raster angle. The final algorithm, here presented and developed in closed form, is able to model the rupture event of every single bead and, consequently, to predict the failure of the whole part; moreover, it can be easily implemented in a calc-sheet.The numerical results have been calibrated and validated by comparing them to the experimental outcomes. A really good agreement has been highlighted and confirmed by very low errors in the prediction of the Ultimate Strength, of the Young's modulus and of the stiffness of the tested samples.

III. CONCLUSION

This paper presented literature review on "Investigation of the effect of fused deposition process parameter on compressive strength and roughness properties of absm30 material" different parameters have great impact on part quality of parts so that quality characteristic such as flexural strength, compressive strength, dimensional accuracy, tensile strength, surface roughness, are main concerns for manufacturer and users. Recent year, research has been targeting into finding optimal parameters to improve surface finish, mechanical properties and build-up time, etc. However most of the studies are mainly focused on optimizing process parameters of ABS parts, but remarkable works remain in PC-ABS blend, Nylon-12, ABS-M30, PPSF, in which ABS-M30 and it has to sustain against compressive loading during its application, therefore much study and research is needed in this direction.

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