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RESEARCH WORK ON FUSED DEPOSITION MODELING (FDM): A REVIEW

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ABSTRACT

Apart from the conventional manufacturing processes which are used for several years while manufacturing of a product, additive manufacturing processes have gained momentum in the recent years. The reason behind this is that these processes do not require special tooling and do not remove material which is very beneficial in the making of a part. Rapid-Prototyping (RP) is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional Computer Aided Design (CAD) data. Fused deposition modeling (FDM) is a process for developing rapid prototype (RP) objects by depositing fused layers of material according to numerically defined cross sectional geometry.

A review of the research work on FDM is presented in this paper. Some important research work of the recent years has been discussed. The review revealed that majority of the researchers have focused research work on performance parameters of the FDM process, multi objective optimization of the input and performance parameters, development of mathematical model of the process. Researchers have used different types of statistical methods for the analysis of the experimental results. Grey Relation analysis is used in some research work for the multi objective optimization. Taguchi method in combination with ANOVA is used to analyze the result data and significant effect of parameters on performance characteristics. The review relies on notable academic publications and recent conference proceedings.

Keywords :- FDM, RP, ANNOVA,Taguchi Method

INTRODUCTION

The FDM process was originally developed by Advanced Ceramics Research (ACR) in Tucson, Arizona, but the process has been significantly advanced by Stratasys, Inc. FDM is a non laser filament extrusion process that utilizes engineering thermoplastics, which are heated from filament form and extruded in very fine layers to build each model from the bottom up. The models can be made from acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyphenylsulfone (PPSF), and various versions of these materials. Furthermore, the models are tough enough to perform functional tests The extrusion-based process utilizes filaments of molten thermoplastic that are extruded from a heated tip to build up layers comprising the physical model. As shown in Figure the Extrusion head in which the material is pulled off the spool, heated just above the melting temperature, and deposited at the desired location. Application of FDM technology includes Conceptual modeling Fit, form applications and models for further manufacturing procedures, Investment casting and injection molding

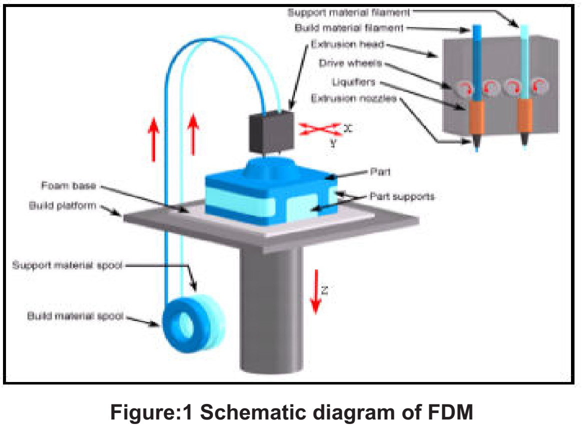

Figure:1 Schematic diagram of FDM

The key steps are:
1. Starting with the filament being fed into the drive wheels
2. The drive wheels force the filament into the liquefier
3. The heater block melts the filament
4. The solid filament is used as a linear piston
5. The melted filament is forced out through the tip.

The material used is fed into the head in solid wire form and then liquefied in the head and deposited through a nozzle in liquid form. The extrusion head is able to move in the X–Y plane and is controlled to deposit very thin beads of molten material onto the build platform to form the first layer. The platform is maintained at a lower temperature to ensure the deposited thermoplastic hardens quickly in 0.1 s. After the platform lowers, the extrusion head deposits a second layer upon the first. The material then cools and solidifies in place. The speed of the drive wheels can determine the width of the extrusion path that is controlled using the software. The build process lays down both modeling and support material in separate steps for one layer at a time. To switch between modeling and support material, one nozzle will raise up so it will not interfere with the material being laid down. The appropriate amount of Z-axis movement is determined by a setting within the software. The heads are moved in the X–Y plane by a set of linear motors to improve resolution, which hang from the machine ceiling.

This process is repeated and alternates between build and support materials until the part is completed. The support material is then removed and the part is cleaned. The selection of the material for support is important. Built materials used include ABS, Polycarbonate, Elastomers and Polyethylene

Main process parameters:-

1. **Layer thickness:** It is a thickness of layer deposited by nozzle and depends upon the type of nozzle used.

2. Orientation: Part builds orientation or orientation referrers to the inclination of part in a build platform with respect to X, Y, Z axis. Where X and Y-axis are considered parallel to build platform and Z-axis is along the direction of part build.

3. Part Fill Style: Determines the manner in which nozzle will deposit the material in a single layer of a part. There are two types of part fill methods:

(i)Perimeter Raster: Outer boundary is contour (perimeter) and internal is filled with raster.

(ii)Contours to depth: Other then the outer contour additional contours are provided to fill the inner region and remaining inner region is filled with raster. The number of additional contours is determined by the depth of contours value. By default depth of contour is twice the contour width to produce one contour.

4. Contour width: The width of contour deposited by nozzle.

5. Part raster width (raster width)**:** Width of raster pattern used to fill interior regions of part curves.

6. Part interior style: Determine how the interior area in each layer is filled. There are two methods:

(i) Solid normal: Fills the part completely

(ii) Sparse: Semi hollow interior (honeycomb structure), minimize the amount of material used.

7. Visible surface: This feature improves the part external appearance.

8. Raster angle: It is a direction of raster relative to the x-axis of build table.

9. Shrinkage factor: Shrinkage factor applied in the x, y and z direction.

10. **Perimeter to raster air gap**: The gap between inner most contours and the edge of the raster fill inside of the contour.

11.Raster to raster gap (air gap): It is the gap between two adjacent rasters

Figure:2 Raster Details

REVIEW OF RESEARCH WORK IN FDM

1.Sung-Hoon Ahn *et al*, [1] have pointed out that process parameters such as air gap and raster orientation significantly affect the tensile strength of FDM processed part as compared to other parameters like raster width, model temperature and color through experimental design and analysis. In addition, built parts exhibit anisotropic properties as far as tensile strength is concerned depending on build orientation. They further compare the measured tensile strength of FDM part processed at different raster angles and air gap with the tensile strength of injection molded part. Material use for both type of fabrication is ABSP400. With zero air gap FDM specimens tensile strength lies between 10%-73% of injection molded 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 molded part. All specimens failed in transverse direction except for specimen whose alternate layer raster angle varies between 45° and -45°. This type of specimens failed along the 45° line. Compression test on the specimens 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 molded part. Also specimens build with axis perpendicular to build table shows less compressive strength as compared to specimens build with axis parallel to build table. Based on these observations it was concluded that strength of FDM processed part is anisotropic.

2. Es Said *et al*, [2] their observations indicate that raster ori-entation causes alignment of polymer molecules along the direction of deposition during fabrication and tensile, flexural and impact strength depends on orientation. Since semi molten filament is extruded from nozzle tip and solidified in a chamber maintained at certain temperature, change of phase is likely to occur. As a result volumetric shrinkage takes place resulting in weak interlayer bonding and high porosity; hence, reduces load bearing area.

3. Khan ZA *et al*,[3] In their study, the Taguchi method is used to find the optimal process parameters for fused deposition modeling (FDM) rapid prototyping machine that was used to produce acrylonitrile butadiene styrene (ABS) compliant prototype. An orthogonal array, main effect, the signal-to-noise (S/N) ratio, and analysis of variance (ANOVA) are employed to investigate the process parameters in order to achieve optimum elastic performance of a compliant ABS prototype so as to get maximum throwing distance from the prototype. Through this study, not only can the optimal process parameters for FDM process be obtained, but also the main process parameters that affect the performance of the prototype can be found. Experiments were carried out to confirm the effectiveness of this approach. From the results, it is found that FDM parameters, i.e. layer thickness, raster angle and air gap significantly affect the elastic performance of the compliant ABS prototype.

4. Lee CS *et al*, [4] have performed experiments on cylindrical parts made from three RP processes such as FDM, 3D printer and nano composite deposition (NCDS) to study the effect of build direction on the compressive strength. Experimental results show that compressive strength is 11.6% higher for axial FDM specimens as compared to transverse FDM specimens. When material is extruded from nozzle, it cools from glass transition temperature to chamber temperature causing inner stresses to be developed due to uneven deposition speed resulting in inter layer and intra layer deformation that appear in the form of cracking, de-lamination or even part fabrication failure. These phenomena combine to affect the part strength and size. These results explain that build direction caused the anisotropic behavior of RP parts, and eventually their compressive strength was changed by anisotropic behavior. FDM specimens failed along with build direction, but most of specimens fabricated by 3D printer and NCDS did not show failure modes clearly related to build direction.

5. L.M. Galantucci *et al*, [5] the influence on compressive mechanical behavior, manufacturing time and costs of the internal angle of the cones, of the raster width and of the shell width has been studied, demonstrating that the raster width is relevant only for the manufacturing time, while it has no influence on the maximum compressive stress. On the other hand, the internal angle and the shell width are very important for these aspects. The study has demonstrated the validity of the approach to achieve a cost, time and material reduction, contributing to a lower economic and environmental impact of these technologies.

6. Yizhuo Zhang *et al*, [6] have experimentally demonstrated that among the three parameters road width ,scan speed and layer thickness tested, the scan speed is the most significant factor to the residual stresses followed by the layer thickness. The simulation results show part distortions are related to the stress accumulation during the depositions. The simulations indicate that the stress accumulations increase with the increasing layer thickness, also increase with the increasing road width, to a less extent though. The distortion results from the experiment show a similar trend; distortions increase with both the road width and the layer thickness.

7.Wang et al. [7], in their work, has mentioned that as extruded material from nozzle cools from its glass transition temperature to chamber temperature inner stresses will develop particularly due to uneven deposition speed. They concluded that as the total number of layers increase deformation will decrease rapidly but decreasing tendency will become slow after certain number of layers, higher stacking section lengths will produce large deformations and as chamber temperature will increase deformation will decrease and become zero at the glass transition temperature of material. Based on these results they propose that material use for part fabrication must have lower glass transition temperature and linear shrinkage rate. Also the extruded fiber length must be small.

8.Chou and Zang *et al*, [8] have simulated the FDM process using finite element analysis (FEA) and analyzes the effect of tool path patterns on residual stresses and part distortions. Their work reveals that the mechanical properties of FDM processed part exhibit anisotropy and are sensitive to the processing parameters that affect the meso-structure and fibre-to-fibre bond strength. Also un-even heating and cooling cycles due to inherent nature of FDM build methodology results in stress accumulation in the build part and these stress concentration regions will also affect the strength. It is also observed that all the researches in FDM strength modelling is basically devoted to study the effect of processing conditions on the part strength with no significant effort made to develop the strength model in terms of FDM process parameters so as to predict in advance the strength of component for practical application.

9.R.Anitha *et al*,[9] have conducted experiment and found that in their result, revealed several interesting features of the FDM process Only the layer thickness is effective to 49.37% at 95% level of significance. But on pooling, it was found that the layer thickness is effective to 51.57% at 99% level of significance. The other factors, road width and speed , contributes to 15.57 and 15.83% at 99% level of significance, respectively. The significance of layer thickness is further strengthened by the correlation analysis. Which indicates a strong inverse relationship with surface roughness. according to the S/N analysis, the layer thickness is most effective when it is at level 0.3556mm, the road width at level 0.537mm and the speed of deposition at level 200mm.

10.K. Thrimurthulu *et al*,[10] have concluded Two contradicting objectives, namely build time and average part surface roughness, are minimized by minimizing their weighted sum. It can be seen from the results obtained for different parts that there exist two limiting situations. One is minimum average part surface roughness with maximum production time and another is minimum production time with maximum average part surface roughness. The developed system of part deposition orientation determination also gives a set of intermediate solutions in which any solution can be used depending upon the preference of user for the two objectives. The present system can be used for any class of component, which may be a freeform or a regular object.

11.Anoop Kumar Sood et al,[11] In their work, they have analyzed effect of five factors viz., layer thickness, part build orientation, raster angle, raster to raster gap (air gap) and raster width each at three levels together with the interaction of part build orientation with all the other factors is studied on the dimensional accuracy of FDM build part. For this grey Taguchi method is adopted. Grey Taguchi method has the ability to combine all the objectives that is minimizing the percentage change in length, width and thickness into single objective known as grey relation grade. Maximization of grey relation grade shows that layer thickness of 0.178mm, part orientation of 0°, raster angle of 0°,road width of 0.4564 mm and air gap of 0.008 mm will produce overall improvement in part dimension.

SUMMARY

A review of the research work on FDM is presented in this paper. Some important research work of the recent years has been discussed. For each and every method introduced and employed in FDM process, the objectives are the same: to enhance the capability of machining performance, to get better output product, and to have better working conditions.

Majority of the researchers have focused their research on following aspects.
1. Effects of the process parameters on the Tensile strength, Compressive strength, Flextural strength and dimensional accuracy.

2. Multi objective optimization of the input and performance parameters.

3. Development of Mathematical model of the process to predict performance based on input parameters.

4. Analysis of the experimental results using different types of statistical regression methods. Statistical technique like design of experiments is used by few researchers to study multiple variables (factors or parameters) simultaneously.

5. Taguchi method in combination with ANOVA is used to analyze the result data and significant effect of parameters on performance characteristics.

6. Grey Relation analysis is used for multi optimization.

Important finding of these research work are as follows.
1. The weak interlayer bonding is responsible for decrease in strength because distortion occurs due to high temperature gradient towards the bottom layers. As the layer thickness increases, less number of layers will be required and distortion effect is minimized and hence, strength increases.

2. Total number of layers increases with increase in Part orientation and hence, distortion phenomenon dominates resulting in decrease in strength.

3. When raster orientation increases, their inclination producing rasters of smaller length and net effect is decrease in strength.

4. Small air gap helps to create strong bond between two rasters and hence negative air gap makes specimen more dense and thus, improves strength.

COMMENT

The reviews revealed that majority of the researchers have focused their research on the performance parameters of the FDM process and multi objective optimization of the input and performance parameters. The optimization allows us to get the most out of a given system. In a way it is the minimization of unwanted effects and maximizing the desired performance parameters. Considering the more number of control parameters and similarly more number of performance (output) parameters and complicated nature of the working mechanism of the FDM, multi objective optimization is the best technique to enhance performance of the FDM process.

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