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Response of the process variables and material on the mechanical properties of FDM processed part:- A Review

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Abstract —*Fused Deposition modeling technology is used for product manufacturing using advanced materials by Rapid Prototyping. Prototypes can be generated using RPT by various materials like Acrylonitrile Butadiene Styrene (ABS), polyamide, polycarbonate, polyethylene, and polypropylene. The subtractive fabrication can create a complete shape effectively, though at the expense of material being wasted.Alternatively, the final desired part is manufactured by adding multiple layers of material on top of one another in additive fabrication process. The innovative idea behind this method is that the three dimensional CAD model is sliced into many thin layers and this geometric data is used to build the material layer by layer. This "layered manufacturing" or "direct digital manufacturing" technique eliminates any fault caused by human skills and intervention in traditional fabrication of component and comparably is time saving.*

Keywords*-Rapid Prototyping; Fused Deposition Modeling; Direct Digital Manufacturing; Layered Manufacturing; Classification of RPT, Additive Manufacturing, fabrication*

I. INTRODUCTION

Conventionally components are manufactured using subtractive manufacturing processes like milling, shaping, grinding, etc. The material is removed from block or raw material and desired shape and dimensions can be effectively gained. Subtractive processes use carefully planned-controlled movements of tool or block to cut material. The NC machining is typically used in small model making machines. Alternatively, additive fabrication is a process in which the final desired part is manufactured by adding multiple layers of material on top of one another. The key idea of this innovative method is that the three dimensional CAD model is sliced into many thin layers and the manufacturing equipment uses this geometric data to build each layer sequentially until the part is completed. Hence, additive fabrication is often referred as "layered manufacturing", "direct digital manufacturing", "three-dimensional printing", or "solid freeform fabrication". Additive technology can be used to generate complex shapes with cavities and undercuts.

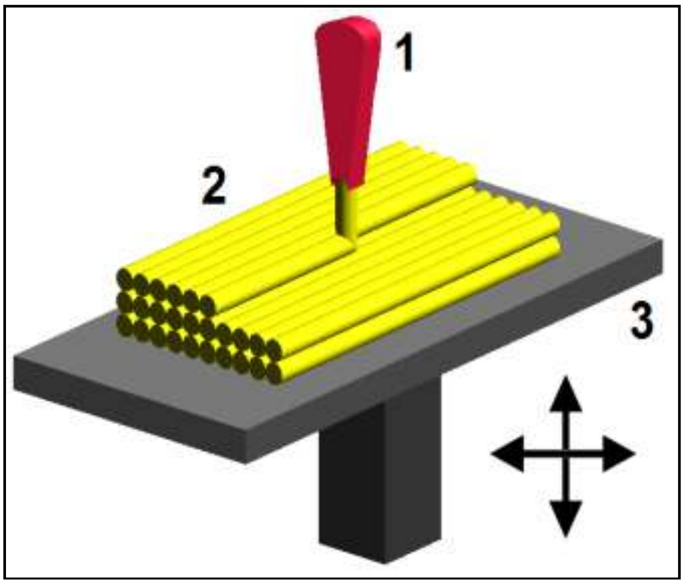

Fig. 1 Rapid Prototyping Process[5]

In rapid prototyping the part is fabricated by deposition of layers contoured in a x-y plane two dimensionally. The third dimension z results from single layers being stacked up on peak of each other, but as discontinuous z-coordinate. So, the prototypes are incredibly precise in x-y plane but have stair stepping result in z direction as shown in Fig-1. The technology can be used in design, engineering analysis and planning and manufacturing and tooling as shown in Fig-2. There are many applications such as automobile, aerospace, biomedical, consumer electronics, jewelry, etc.

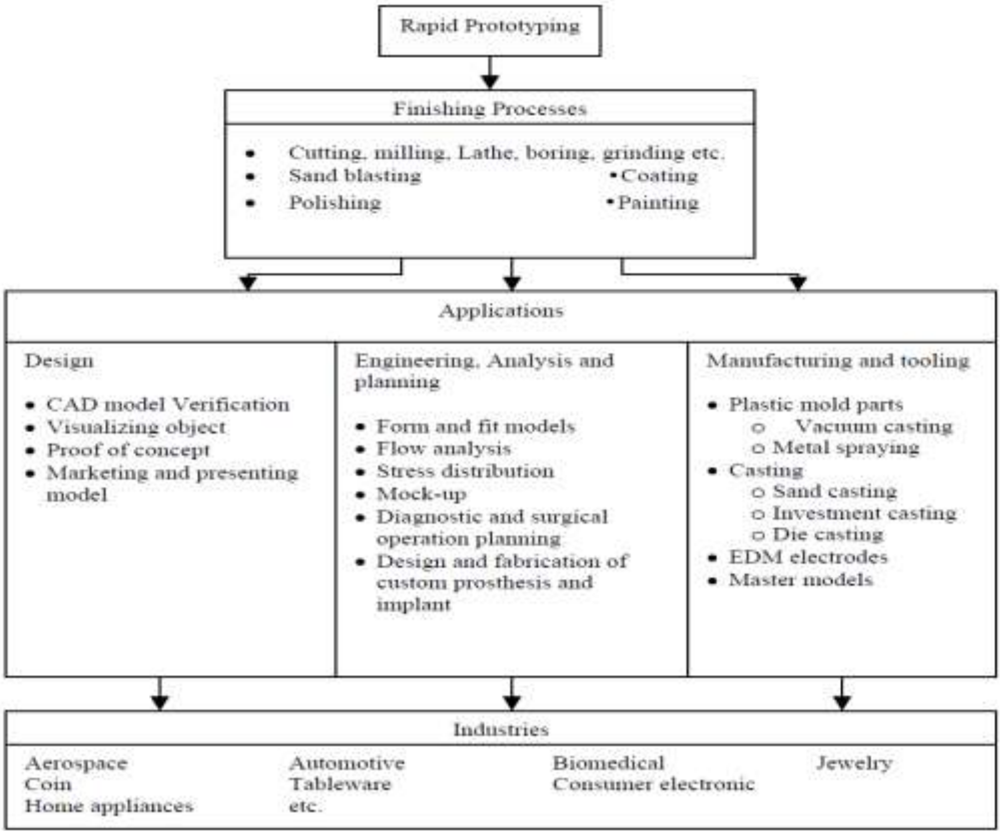

Fig. 2 RPT Application areas[3]

RP technologies is grouped according to their fundamental metal deposition, working principles as seen in Fig:3 FDM Technology was invented about two decade ago and has continued to lead RP revolution ever since. Even today FDM is most widely used RP technique.

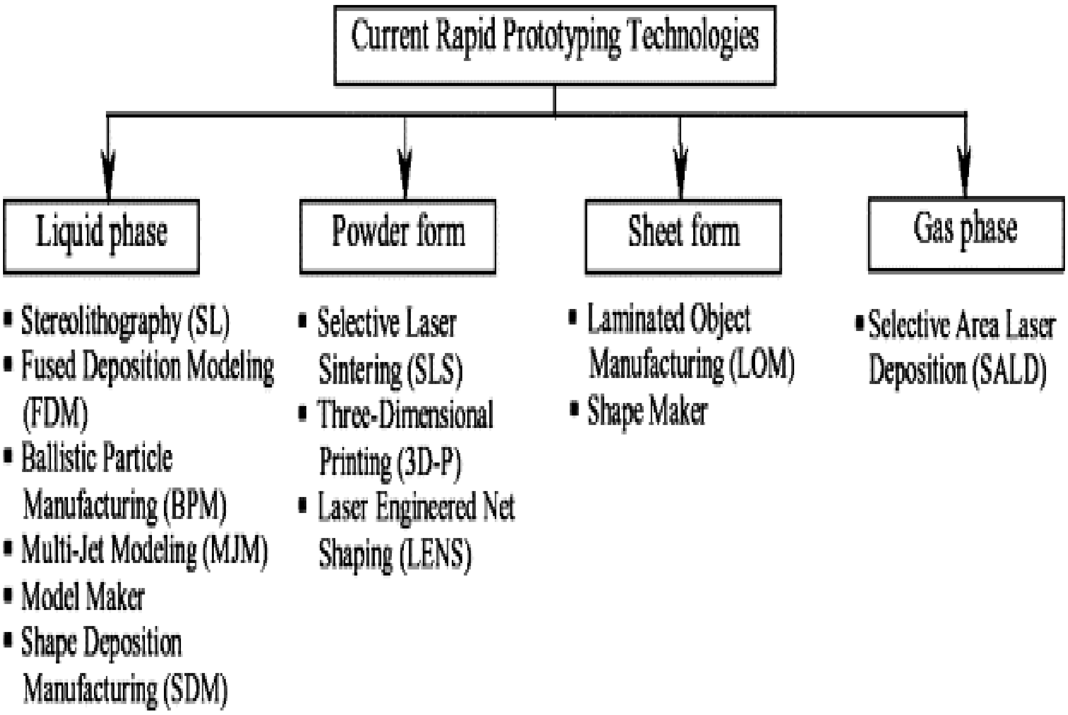

Fig. 3 RPT Types[3]

2 Fused Deposition Modelling Process

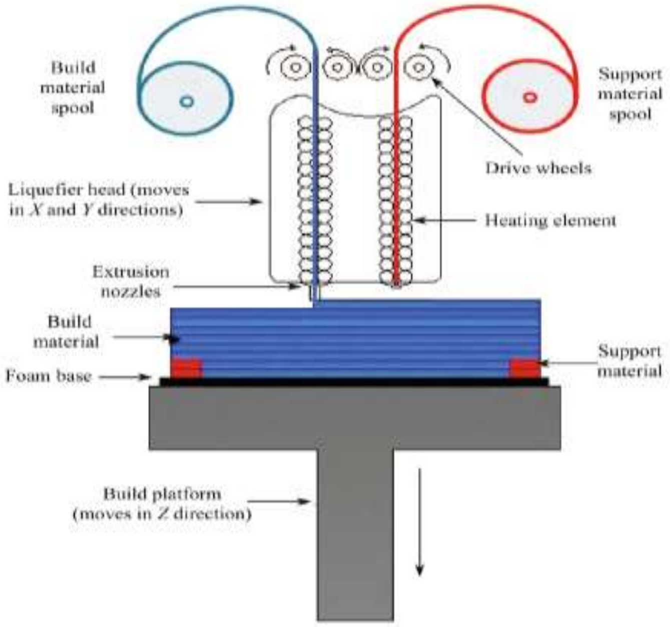

Fig-4 Principle of FDM Process[11]

As shown in Fig. 1, in this process, the material is melted into liquid state in a liquefier head and then selectively deposited through a nozzle that traces the parts cross sectional geometry to produce 3D parts directly from a CAD model in a layer by layer manner. A wide range of materials are available for this manufacturing process such as acrylonitrile butadiene styrene (ABS), polycarbonate (PC), and PCABS blend[11].

2.1 FDM process parameters

Nowadays, the additive manufacturing processes including FDM process are required to deliver superior part quality, high productivity rate, safety, low manufacturing cost, and short lead time. In order to meet the customer needs and satisfaction, the additive manufacturing process conditions must be established for each application. The key success of the additive manufacturing process depends upon the proper selection of process parameters. Determination of the optimum process conditions is an important task for production engineers. It plays an important role to ensure quality of products, improve dimensional precision, avoid unacceptable wastes and large amount of scraps, enhance productivity rates and reduce production time and cost. FDM is a complex process that exhibits much difficulty in determining optimal parameters due to the presence of a large number of conflicting parameters that will influence the part quality and material properties.[9] Figure 5 shows all the process variables that need to be studied and optimized in FDM process.

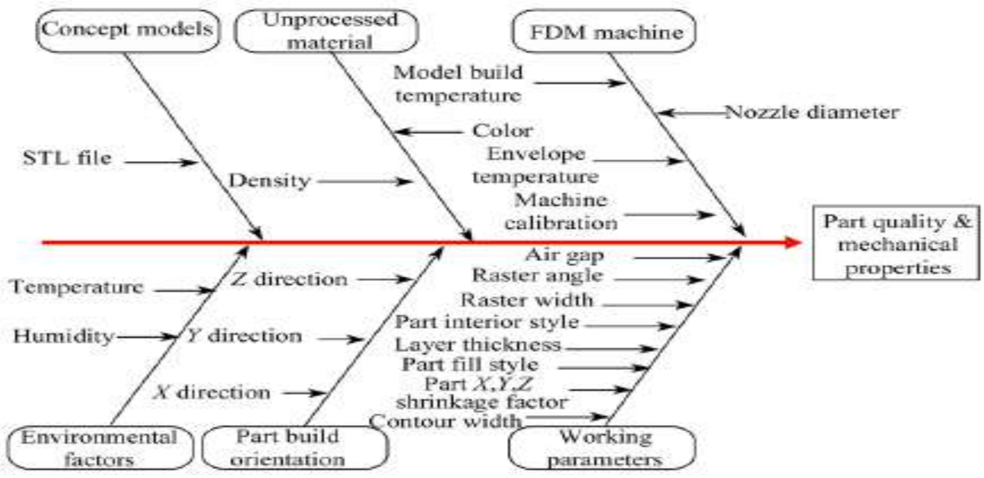

Fig 5 Cause and effect diagram of FDM process parameters

3.Literature Survey

Miguel Fernandez-Vicente et al. [1] studied the effect of pattern and infill density on tensile mechanical behavior in desktop 3D printing. In this study three levels of infill parameter were evaluated: 20%, 50% and 100% and three most widely used patterns were evaluated: line, rectilinear and honeycomb. The results of their investigation indicate that maximum tensile strength was obtained when pattern was rectilinear with infill density of 100%.

V.Dineshkumar,V.Nirmalkann et al.[2] done experimental work on The novel ABS- M30i biomedical material, 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). Experiments were conducted using Taguchi's design of experiments with two levels for each factor.Finally they concluded that 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 and raster width.

Anoop Kumar Sood, R K Odhar et al. [3] studied the effect of five FDM process parameters viz. slice thickness, raster width, raster angle, gap between two layers and part orientation on three mechanical properties viz. tensile, flexural and impact strength of ABS test specimen. A number of response surfaces were drawn which shows the following results (table 1):

Change inParameter	Effect on tensile strength	Effect on flexural strength	Effect on impact strength
Increment inlayer thickness	First decreases,then increases	Decreases	not defined
Increase in Raster width	Increases	Raises	Increases then decreases
Increase in Raster angle	Increases	Increases then decreases at higher values	not defined
Positive air gap	Increases	Increases	not defined
Increase in part orientation	Decreases	Decreases	Increases then decreases

Table-1 Effect of process parameters on mechanical properties[3]

S. Dinesh Kumar,V.Nirmal Kannanet al. [4] experimentally investigated the effect of FDM process parameters on surface roughness of the ABSM30i parts produced by FDM. Parameters taken in these experiments were slice height, raster width, raster angle, contour width and gap between two layers. A design of experiments was made having two levels for each process parameter to conduct experiments by using Taguchi method.They concluded that the surface roughness can be reduced by using slice height at low level,air gap at High level, Raster width and Contour width both at low level.

Vishal Patel, Kamlesh kapadiaet al.. [5]experimentally investigated the the effect of the main FDM process variable parameters of layer thickness (A), air gap (B), raster width (C), contour width (D), and raster orientation (E) on the mechanical properties viz. tensile, flexural, impact strength and hardness of part fabricated using fused deposition modelling (FDM) technology. the new ABS- M30 material was used in this experimental work to build parts. To conduct this study, a full factorial experiment was used to obtain the test runs. A number of analytical methods Analysis of Variance (ANOVA), used to determine the influence of the variable FDM process parameter settings.Results show that these process parameters have significant effect on the quality of finished products.

M Alhubail, D Aleneziet al.[6] doneexperimental work on the effect of the main fused deposition Modelling (FDM) process variable parameters such as layer thickness (A), airgap (B), raster width (C), contour width (D) and raster orientation (E) on the quality characteristics such as surface roughness (SR) and tensile strength (TS).They used New composite ABS- M30i biomedical material in this experimental work to buildparts. Taguchi design (L32) was used to obtain the experimentation runs. Numbers ofanalytical methods such as regression analysis, Analysis of Variance (ANOVA), Signalto Noise (S/N) ratio were used to determine the influence of the FDM process parameterssettings.They finally concluded that setting layer thickness andraster width at low level could minimize the surface roughness and maximize tensile strength in addition to the air gap at high level.

Godfrey C Onwubolu , Farzad Rayegani et al [7] experimentally investigated five important process parameters such as layer thickness, part orientation, raster angle, raster width, and air gap have to study their effects on tensile strength of test specimen of material acrylonitrile butadiene styrene (ABS P400) usingdesign of experiment (DOE).They finally observed that

(1) Minimum layer thickness improves tensile strength, although is more costly due to more material usage for manufacturing parts.

(2) Negative air gap significantly improves the tensile strength.
(3) Minimum raster widths also improve tensile strength.
(4) Part orientation plays a major role as could be observed from the results. For zero part orientation (with the part orientation coinciding with the direction of tensile loading), maximum tensile strength is obtained.
(5) Increased raster angle also improves tensile strength, although not very significantly.

Samir Kumar PANDA,Saumyakant PADHEE,et al [8] done experimental work on five important process parameters of FDM such as layer thickness, orientation, raster angle, raster width and air gap to study their effects on three responses viz., tensile, flexural and impact strength of test specimen Of material acrylonitrile butadiene styrene (ABS P400) by using central composite design (CCD) and empirical models relating each response and process parameters have been developed and models are validated using analysis of variance (ANOVA).After that they appliedbacterial foraging technique to suggest theoretical combination of parameter settings to achieve good strength simultaneously for all responses.They finally came to conclusion after experimental work thatIf number of layers is more, it will result in high temperature gradient towards the bottom of part. This will increase diffusion between adjacent rasters and strength will improve. Small raster angles are not preferable as they will results in long rasters which will increase the stress accumulation along the direction of deposition resulting in more distortion and hence weak bonding. Thick rasters results in high temperature near the boding surfaces which may improve the diffusion and may result in strong bond formation. And this study can also extended in the direction of studying compressive strength, fatigue strength and vibration analysis.

J.Santhakumar,Rishabh Maggirwar et al[9] done Experimental work on process parameter of FDM like layer thickness,build orientation,raster angle,raster width of polycarbonate material to investigate effect of these parameters on impact strength by using ANOVA.From the experiment they finally conclude that medium level of layer thickness and higher levels of other three parameters build orientation, raster angle and raster width provides maximum impact strength.From analysis of variance another outcome they conclude that layer thickness level influences impact strength most than other parameters.

AHN et al. [10] compared the tensile and compressive strengths of the FDM prototypes made of ABS P400, with the injection-molded parts of the same material. The factors considered in tensile strength measurements were raster orientation, air gap, bead width, color, and model temperature. On the other hand, build orientation was the factor that was considered in compressive strength measurement. It was shown that the build orientation significantly affects the compressive strength of the FDM specimens.

Wang et al. [11] used a statistical optimization methodto investigate the effects of control parameters such aslayer thickness, deposition style, support style, and depositionorientations on the surface roughness by integratingthe Taguchi method with the gray relational analysis. Itwas concluded that by using the optimum factor settings,the surface roughness was improved by 62.27%. This studyrevealed that optimal parameter combinations of surfaceroughness were obtained with less number of experimentationsusing Taguchi method compared to full factorialdesign which yielded similar results.

Kumar and Regalla [12] applied 2^5full factorial design to analyze the influence of each process parameter, such as layer thickness, raster angle, orientation, contour width and part raster width on support material volume and build time of FDM part. It was experimentally reported that the layer thickness and build orientation were important factors in the minimization of the build time. However, the study did not focus on the optimum process settings that minimize the build time and support material volume.

Laeng et al. [13] found the effects of air gap, raster angle, raster width and layer thickness on the elasticityperformance of ABS material for FDM by using Taguchi method and ANOVA procedure. Based on their study, the optimum combinations of process parameters were obtained for improving overall elasticity performance. However, the optimal settings are restricted to the experimental values only, where, in fact, the optimal settings are not exactly the same as the parameters' values. Thus the optimal parameter settings cannot be obtained using this approach. It can be obtained using response surface methodology (RSM) and empirical optimization techniques.

Arivazhagan et al. [14] investigated the effects of the FDM process parameters such as build style, raster width, and raster angle on the dynamic mechanical properties of PC processed part. Frequency sweep from 10 Hz to 100 Hz was used at three different isothermal temperatures. It was concluded that solid normal build style with raster angle of 45 degree, and the raster width of 0.454 mm led to the best dynamic properties than other build styles (double dense and sparse).

B.H. Lee et al.[15] have done optimization of influence of parameter for production of flexible ABS objects in FDM machine, here they have produced ABS compliant prototype .an orthogonal array, S/N ratio, and ANOVA are employed to investigate the process parameter in order to achieve optimum elastic performance of compliant ABS prototype to get maximum throw distance from prototype. Here four parameters such as air gap, raster angle, raster width and layer thickness each of at three level is selected for the study L9 orthogonal array was selected for design of experiments after the experimental work they have given out optimum combination of parameter for 10˚,15˚,20˚of displacement.

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