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A Review of FDM Based Parts to Act as Rapid Tooling

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Abstract: *Fused Deposition Modeling (FDM) is one from basic Rapid Prototyping (RP) technologies used in technical practice. In this contribution are presented basic information about parameters such as layer thickness, part build orientation, raster angle, raster width and air gap. This study provides insight into complex dependency of strength on process parameters. In this paper microphotographs are used to show the mechanism of failure. The major reason for weak strength is attributed to distortion within or between the layers.Developing a curved layer deposition methodology can improve part quality by reduced lamination, reduction in the staircase effect which leads to improved dimensional accuracy of the part. Less effort has been made to increase the range of FDM materials to include metals or metal based composites with the help of metal based composite direct rapid tooling will allow fabrication of injection moulding dies and inserts with desired thermal and mechanical properties suitable for using directly in injection moulding machines for short term or long term production runs.*
Keywords: *Rapid Prototyping; Fused Deposition Modeling; Rapid Tooling; Staircase Effect.*

I. Introduction

As a matter of fact the new market realistic require faster product development and reduced time to meet market demand (like: high quality, greater efficiency, cost reduction and a ability to meet environmental and recycling objectives) to reduce the product development time and cost of manufacturing, new technology of Rapid Prototyping (RP) has been developed. Rapid Prototyping Manufacturing (RPM) has been widely used in the modern industry, but it is difficult to achieve higher precision parts in FDM currently. Therefore, how to improve part quality can be said as hotspot in industrial applications of RPM, especially when rapid prototyping parts will be used as die, injection molding and EDM electrode, etc., the quality of which plays decisive role to that of final product in mass production. Stereo lithography (SL), selective laser sintering (SLS), fused deposition modeling (FDM) and laminated object manufacturing (LOM) is four relatively matured RPM processes that dominate the current commercial market [1-3], among which FDM, arepresentative rapid prototyping technology (RPT) with no use of toxic materials, has been increasingly widely used in offices. But now the FDM systems currently only fabricate parts in elastomers, ABS and investment casting wax using the layer by layer deposition of extruded materials through a nozzle using feedstock filaments from a spool [4]. Most of the parts fabricated in these materials can only be used for design verification, form and fit checking and patterns for casting processes and medical applications[5]. For FDM, the two concerns are how to develop new metal materials that can directly manufacture metal parts used in tooling, etc., and how to improve dimension accuracy. As to developing new metal materials, literature [6] presented the detailed formulation and characterization of the tensile properties of the various combinations of the nylon type matrix consisting of iron particles, and the feedstock filaments of this composite have been produced and used successfully in the unmodified FDM system for direct rapid tooling of injection moulding inserts, while literature [7] presented an investigation on thermal and mechanical properties of new metal-particle filled ABS (acrylonitrile-butadine-styrene) composites for applications in FDM rapid prototyping process. As to improving dimensional accuracy, literature [8] presented experimental investigations on influence of important process parameters viz. layer thickness, part orientation, raster angle, air gap, and raster width along with their interactions on dimensional accuracy of FDM processed ABS400 part, and it is observed that shrinkage is dominant along length and width direction of built part, while literature [9] presented a powerful tool, the Taguchi method, to design optimization for quality. In 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. Although great progress has been made in this field, most of the literatures focus only on improving dimensional accuracy. In fact, the part errors in FDM are classified into dimension error, shaped error and surface roughness. This paper, taking FDM for example, aims to analyze the reasons which lead to errors and propose corresponding measures to improve part accuracy.

II. Previous Work Done

2.1. FDM Machine Structure

FDM mainly involves a feeder role or coil which is perpetually fed into an extrusion head or nozzle. Before the material reaches the nozzle, it is heated to soften the material to a molten state when it can be deposited onto the platform [10]. This is done with the avail of heating elements in nozzle which melts the material. This nozzle is controlled by a computer availed manufacturing package which can be habituated to move the nozzle in horizontal, vertical directions. As the molten material ejects out of the nozzle, it is then spread onto the platform in the desired shape as a layer. The deposition platform is then lowered to a height equipollent to one layer height of the component and the deposition process is reiterated over the anteriorly deposited layer [11]. This process is reiterated layer by layer starting from the base and worked its way to the top to consummate the whole model

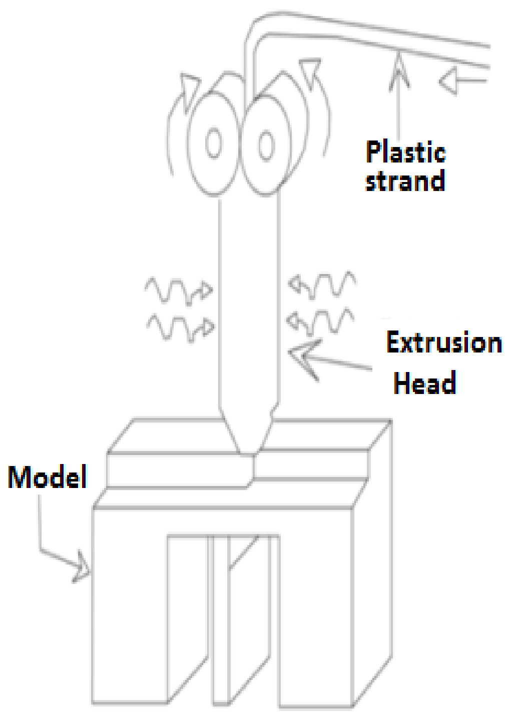


Fig. 2.1.1 FDM Schematic [12]

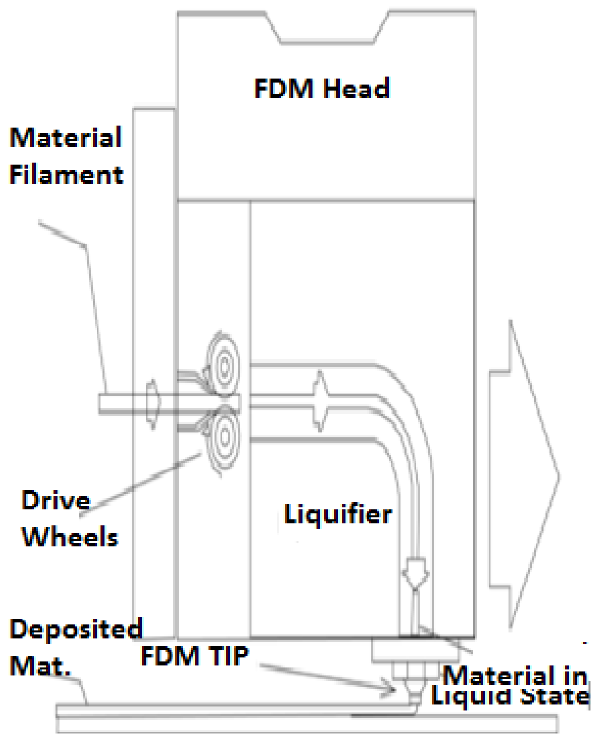


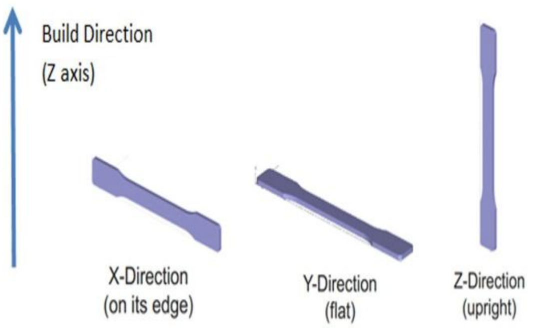
Fig. 2.1.2 Deposition Head [12]

The deposition head of the machine mainly consists of the drive block, the tip and the heating compartment. The raw material is fed into the machine with the avail of the drive blocks which contain wheels mounted on back of head [13]. These drive blocks are responsible for loading and unloading of the raw materials from the rolls and can be computer controlled for precision. A heating element is utilized as bubbles wrap for the heating compartment and withal blends in an L shape angle. This is done to divert the horizontal flow of the filament to a vertical direction which can be then utilized as an area to melt the material. External threading is done on the tips so that they can be screwed in with the internal screws on the heating compartment [14].

2.2. Process parameters

When preparing to build FDM parts many fabrication parameters are needed. To achieve optimum quality, parameters are set differently according to requirements of applications. Some parameters are -

a. 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.



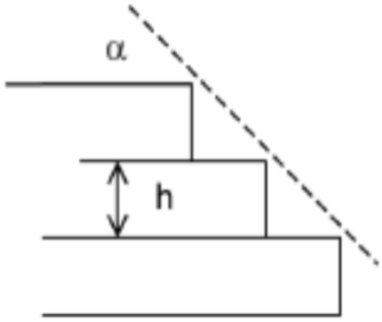
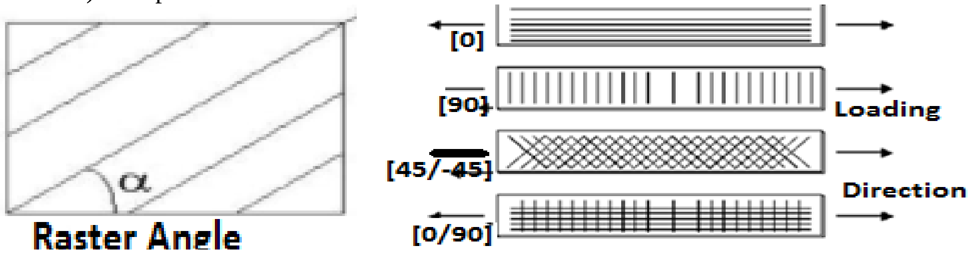


Fig. 2.2.1 Orientation [15] Fig. 2.2.2 Layer Thickness [16]

b. **Layer Thickness:** Slice height is the thickness of each layer measured in the vertical or Z direction as shown in fig. Varying the slice height would most likely have the same effect as varying the bead width of ABS plastic.
c. **Raster Angle:** Denotes the raster orientation which is measured from the X-axis on the bottom part layer as shown in figure 3.7. Also it refers to the direction of the beads of material (roads) relative to the loading of the part. The deposited roads can be built at different angles to fill the interior part. The effect of this filling according to the raster angle applied was also investigated, where using loose angles at (45o/90o) and tighter angles at (45o/-45o) of deposited roads.



(a) (b)

Fig. 2.2.3 (a) & (b) Raster Angle [17-18]

d. Part Raster Width (raster width): Denotes the raster width or road width which refers to the width of the deposition path related to tip size. Also refers to the tool path width of the raster pattern used to fill interior regions of the part curves as shown in figure 3.5. Narrow and wide filling pattern (roads) were considered to be examined [18].

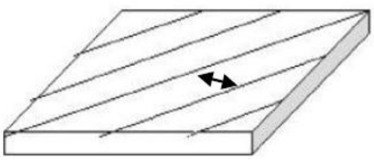


Fig. 2.2.4 Raster Width [17]

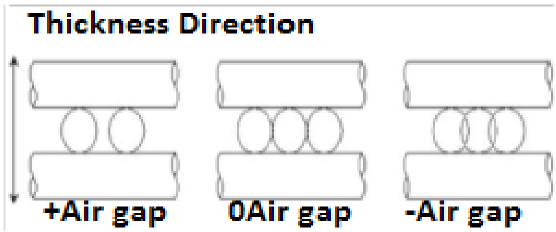


Fig. 2.2.5 Air gap [17]

e. Raster to Raster gap (air gap): Air gap is the space between the beads of FDM material as shown in Fig.2.2.5. The default is zero, meaning that the bead just touches. It can be modified to leave a positive gap, which means that the beads of material do not touch. The positive gap results in a loosely packed structure that builds rapidly. The air gap value can also be modified to leave a negative gap, meaning that two beads partially occupy the same space. This results in a dense structure, which requires a longer build time.

From the published literature on FDM it appears that the [19] heat is dissipated by conduction and coerced convection and the reduction in temperature caused by these processes forces the material to expeditiously solidify onto the circumventing filaments. Bonding between the filaments is caused by local remelting of anteriorly solidified material and diffusion. This results in uneven heating and cooling of material and develops non-uniform temperature gradients. As a result, uniform stress will not be developed in the deposited material and it may not regain its pristine dimension thoroughly. Speed at which nozzle is depositing the material may alter the heating and cooling cycle and results in different degree of thermal gradient and thus withal affects the component precision [20]. At lower slice thickness, nozzle deposition speed is more gradual as compared to higher slice thickness. Withal during deposition, nozzle ceases depositing material in arbitrary manner (in between depositing a layer and after consummately depositing a layer) and return to accommodation location for tip cleaning. While depositing the material at the turns near the boundary of part, nozzle speed has to be decremented and then increase to uniform speed [21]. If deposition path length is minuscule, this will result in non-uniform stress to build up especially near the component boundary. The pattern used to deposit a material in a layer has a consequential effect on the resulting stresses and deformation. Higher stresses will be found along the long axis of deposition line. Therefore, short raster length is preferred along the long axis of part to reduce the stresses [22]. Stress accumulation additionally increase with layer thickness and road width [23]. But the thick layer additionally designates fewer layers, which may reduce the number of heating and cooling cycles. Withal, a more minuscule road width will input less heat into the system within the designated period of time but requires more loops to fill a certain area. More loops betokens more time required for deposition of single layer and more non uniform nozzle speed. This will keep the deposited material above its desired temperature for regaining its pristine shape and in the mean time incipient material will be deposited and contraction of antecedently deposited material will be constrained. The gap between two rasters in a single layer and voids between rasters (Fig. 2.2.7) of two adjacent layers withal effect the heat dissipation and thus may decrease the residual stress. For the case of thickness, it seems that increase is mainly caused due to obviation of shape error and positive slicing method [24,25]. Consider (Fig.2.2.8) which shows that height of part (H) is function of its inclination (h) with reverence to base (build platform), length (L) and thickness (T). Diffusion of material between neighbouring rasters additionally engenders the bump (Fig. 2.2.9) because of overfilling at contact area which results in uneven layer.

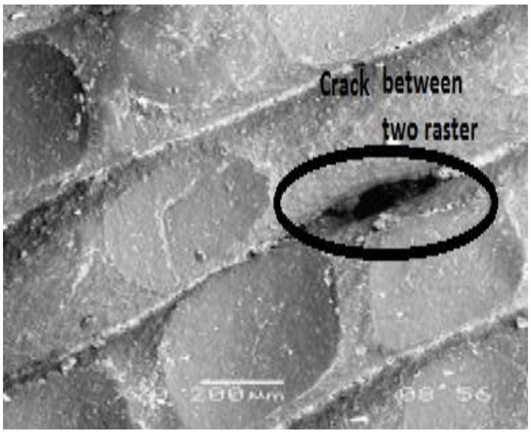


Fig.2.2.6. Crack between two rasters [9]

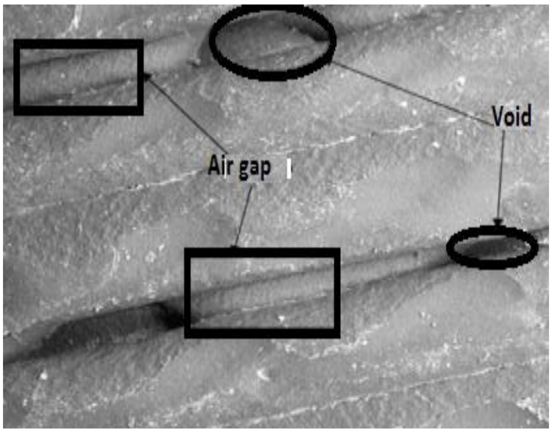


Fig.2.2.7. Air gap [9]

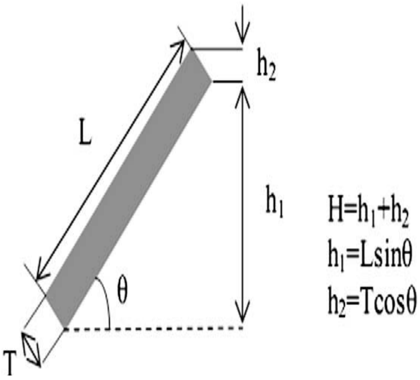


Fig. 2.2.8. Orientation of part with respect to the base (H is height of part) [9]

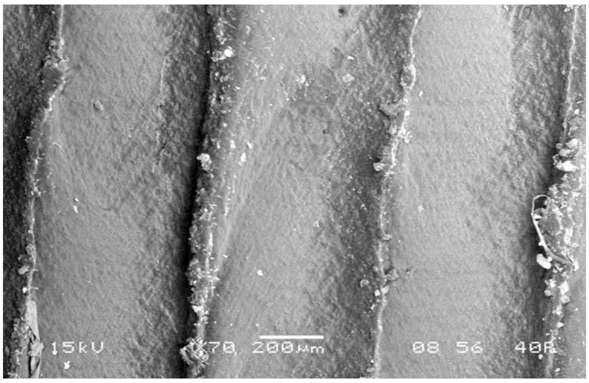


Fig.2.2.9. Overfilling at the contact of two raster [9]

2.3. Stair Case Effect

In FDM printing of components by stacking layer one on top of other. In this method rate of product development expeditious but bring some shortfalls additionally. One of the main areas of inhibition which particularly subsist in FDM is the “stair case effect”. This is mainly due to the deposition method of the process, printing of horizontal layers one on top of the other. The CAD model is first converted into the STL format which is then sliced in flat horizontal layers with each layer having its own shape. The STL file is fundamentally is one which consists of all the points which make up the shapes in each layer and all layers when put together stacks up as a model. The extrusion head, which is responsible for depositing the material on the surface layer by layer, follows the path information stored in the STL file and builds the whole part with an effect in which curved surfaces appear to be a little short or over shoot the genuine dimension of the component. "Stair case" effect, shown in the fig. 2.3.1

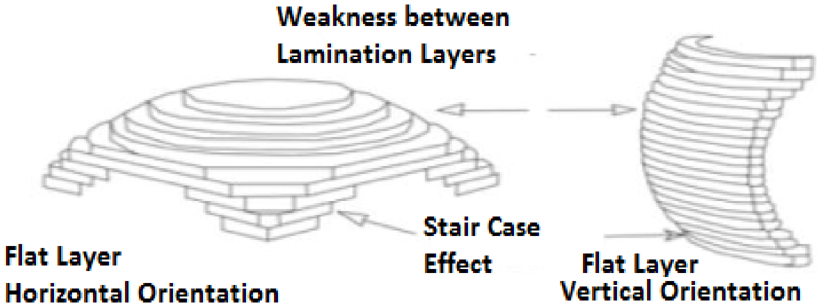


Fig.2.3.1 Stair case effect [12]

Stair case effect is more prominent when a more sizably voluminous diameter nozzle is utilized for material deposition. The straightforward solution to this situation would be to utilize low diameter nozzle which will print thin layers. In order to achieve more preponderant finish and reduced stair case effect, it would take more number of layers to print the same part which results in time consumption. To achieve high precision & surface finish prefer reduced layer thickness, as shown in the fig. 2.3.2 [12].

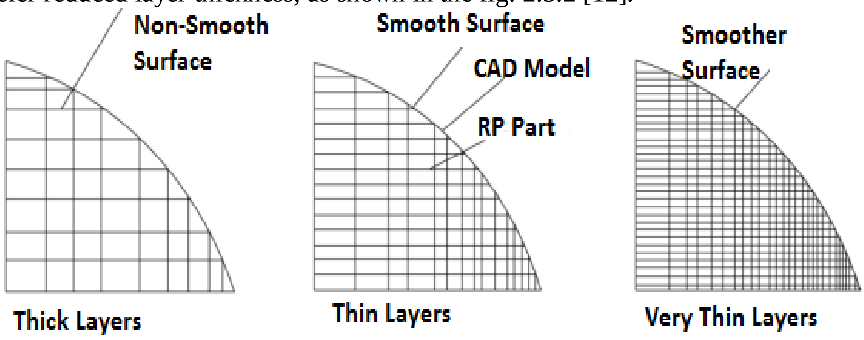


Fig. 2.3.2 Layers and finish quality [12]

2.4. Application of RP for Tooling

Today a great demand subsists on RPT-technologies to fortify product development by tooling or tooling inserts that sanction the engenderment of more astronomically immense series and at the same time enables the engenderment of those components in materials and with technologies akin to the ones used later for series engenderment runs. The most eminent advantage is the integration of engenderment orchestrating and testing within the product development period [26]. These processes can be relegated into two categories of Direct Rapid Tooling and Indirect Rapid Tooling, Fig.2.4.2 predicated on the number of intermediate steps taken along with the mundane RP operations to build the final implement. Direct Rapid Tooling involves fabrication of rapid tooling inserts directly from CAD model on an RP machine whereas Indirect Rapid Tooling method uses RP master patterns to build a mould, which requires adscititious downstream work [27]. Rapid prototyping-predicated tooling techniques (RPT) sanction the fabrication of engenderment implements offering a high potential for a more expeditious replication to market demands and engendering an incipient competitive edge. The purpose of RPT is not the manufacture of final components, but the development of the expedient to engender final components i.e. mass engenderment implements including moulds, dies, etc with the most eminent advantage of integrating engenderment orchestrating and testing within the product development cycle [28].

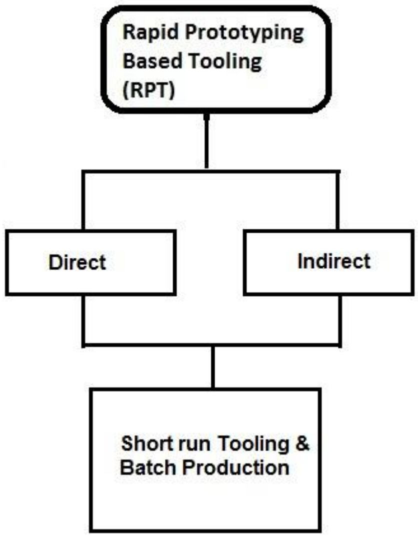


Fig. 2.4.1 Classification of the current RP-based Tooling [29]

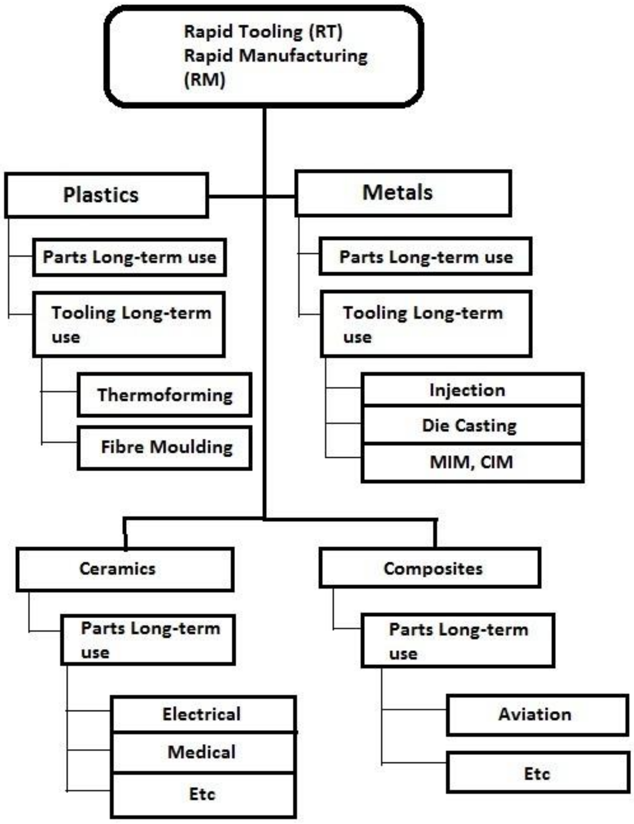


Fig. 2.4.2 Material-dependent Rapid manufacturing and Tooling [29]

III. Conclusions

It can be seen from above study there exit many factors that influence part's accuracy rapid prototyping. Among those factors process parameters are also significant factors.

Increasing slicing thickness, stair stepping errors increase number of layers in a part depends upon the layer thickness and part orientation. If number of layers is more (due to decrease in layer thickness or increase in orientation) high temperature gradient towards the bottom of part is resulted. This will increase the diffusion between adjacent rasters increase the bonding of rasters and improve the strength.

Lot of scope is expected to increase the range of FDM materials to include metals or metal based composites. With the help of metal based composite direct rapid tooling will allow fabrication of injection molding dies and inserts with desired thermal and mechanical properties.

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