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An Investigation into Fused Deposition Modelling Process with Emphasis on Fabrication of Minimum Internal Sized Features

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Abstract: The focus of industries has shifted from traditional product development methodology to accelerated or rapid fabrication techniques. Some of the latest developments within the automotive industry have shown how emerging rapid prototyping and manufacturing (RP&M) technologies can be used to reduce lead time in the prototype development process. More recent FDM systems include two nozzles, one for part material and other for support material. The support material is relatively of poor quality and can be broken easily once the complete part is deposited and is removed from substrate. In more recent FDM technology, water-soluble support structure material is used. Support structure can be deposited with lesser density as compared to part density by providing air gaps between two consecutive roads.

In this work the FDM process has been studied for its convenience to produce small features where critical internal features with dimensions in the range of 1-5 mm and it has been observed that the accuracy is mainly dependent on print direction. Also the problems with printing smaller sized features are discussed. This study can be useful in terms of selection of process and type of available machines among various available machines in market for particular requirement of ABS material prototype and the effect of post processing of chemical vapours on surface of model.

Keywords: Rapid Prototyping, FDM, ABS Material, 3-D Printing, Product Development etc.

I. INTRODUCTION

Reduction of product development cycle time is a major concern in industries for achieving competitive advantage. The focus of industries has shifted from traditional product developmentmethodology to accelerated or rapid fabrication techniques. Someof the latest developments within the automotive industry haveshown how emerging rapid prototyping and manufacturing(RP&M) technologies can be used to reduce lead time in the prototypedevelopment process. The term rapid prototyping (RP) relatesto a rapidly growing number of automated machines orprocesses like stereolithography (SL), Fused Deposition Modelling(FDM), selective laser sintering (SLS), laminated object manufacturing(LOM), etc. which fabricate three dimensional (3D) solidmodels from CAD data automatically without the use of toolingand minimum human intervention. In general, rapid prototyping(RP) machines utilize two common steps to automatically build apart model: (a) the CAD files are sliced into a series of 2D CAD files that represent the cross section of the part and (b) these 2D slicefiles are simple enough to automatically generate the needed vectorsto drive the 2 1/2 axis RP machine layer by layer. Each layer isbuilt on the preceding layer by each machine's particular materialfabrication technology until the 3D physical model is built.

A. Fused Deposition Modeling

In Fused Deposition Modeling (FDM) process a movable (x-y movement) nozzle on to asubstrate deposits thread of molten polymeric material. The build material is heatedslightly above (approximately 0.5 C) its melting temperature so that it solidifies within avery short time (approximately 0.1 s) after extrusion and cold-welds to the previous layeras shown in figure 8. Various important factors need to be considered and are steadynozzle and material extrusion rates, addition of support structures for overhanging featuresand speed of the nozzle head, which affects the slice thickness. More recent FDM systemsinclude two nozzles, one for part material and other for support material. The supportmaterial is relatively of poor quality and can be broken easily once the complete part isdeposited and is removed from substrate. In more recent FDM technology, water-solublesupport structure material is used. Support structure can be deposited with lesser density ascompared to part density by providing air gaps between two consecutive roads.

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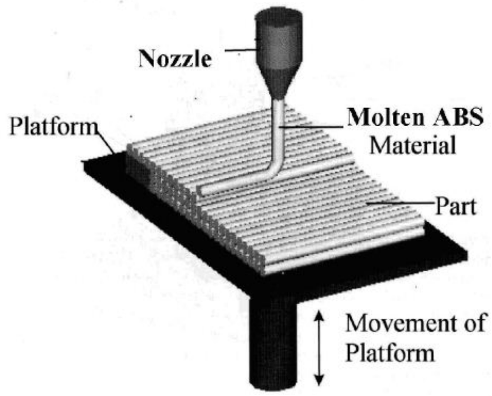

Fig. Fused Deposition Modeling Process [28].

FDM begins with a software process which processes an STL file (stereolithography file format), mathematically slicing and orienting the model for the build process. If required, support structures may be generated. The machine may dispense multiple materials to achieve different goals: For example, one may use one material to build up the model and use another as a soluble support structure,[3] or one could use multiple colors of the same type of thermoplastic on the same model.

The model or part is produced by extruding small flattened strings of molten material to form layers as the material hardens immediately after extrusion from the nozzle

A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. There is typically a worm-drive that pushes the filament into the nozzle at a controlled rate.

The nozzle is heated to melt the material. The thermoplastics are heated past their glass transition temperature and are then deposited by an extrusion head.

The nozzle can be moved in both horizontal and vertical directions by a numerically controlled mechanism. The nozzle follows a tool-path controlled by a computer-aided manufacturing (CAM) software package, and the part is built from the bottom up, one layer at a time. Stepper motors or servo motors are typically employed to move the extrusion head. The mechanism used is often an X-Y-Z rectilinear design, although other mechanical designs such as deltabot have been employed.

Although as a printing technology FDM is very flexible, and it is capable of dealing with small overhangs by the support from lower layers, FDM generally has some restrictions on the slope of the overhang, and cannot produce unsupported stalactites. The polymer material Acrylonitrile butadiene styrene (ABS- P430) is to be used for Model and (ABS- P400) is to be used for support of the FDM component. In Case of fused deposition modelling the polymer material may

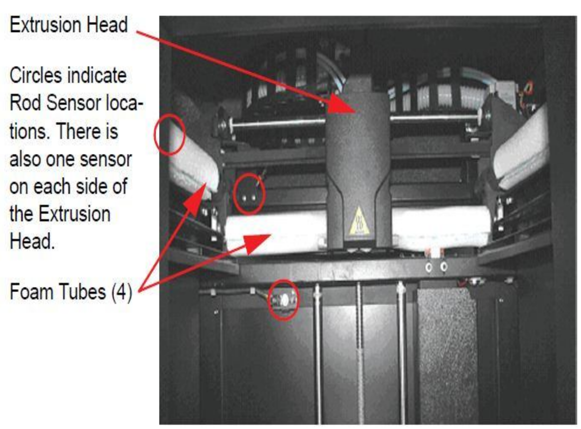

Fig. Extrusion heads for Model and support material

be available either in granular form or in the filament form which is available in different cartridges produced by machine suppliers.TheStratasys made Dimensions bst1200es / sst1200es is to be used as 3D Printer and for slicing and path generation software CatalystEx is to be used.

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II. EXPERIMENTAL METHODOLOGY

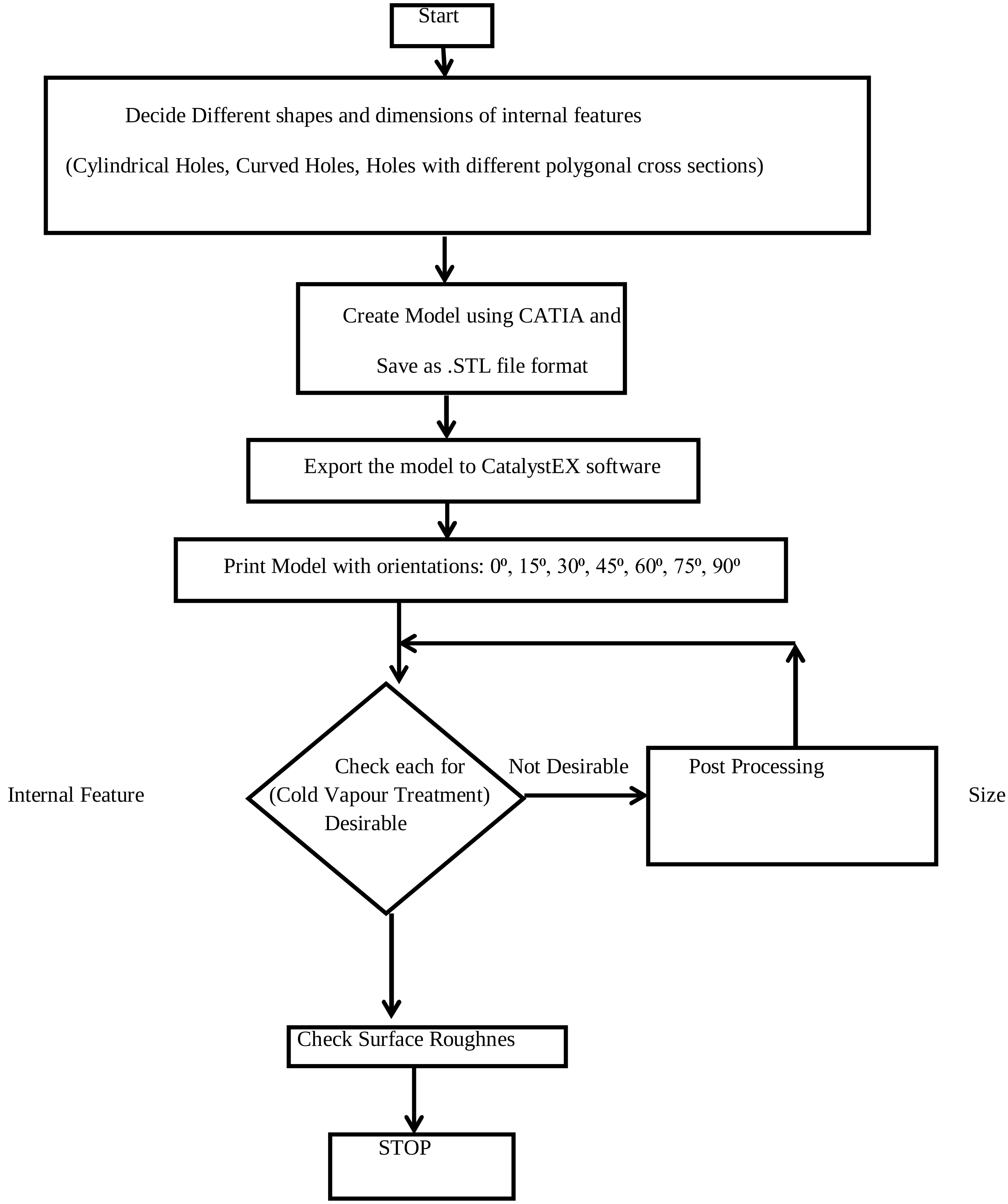


Fig. Experimental Methodology

A. Control Parameters

The FDM Process basically uses slicing and path generation software to process the 3D designed component into printable file. Since the software computes most optimized print path, user doesn't have control over path determination. Still we can control the process with available control parameters such as part density, support structure, layer resolution and orientation of part.

Table: Various print orientations of same component

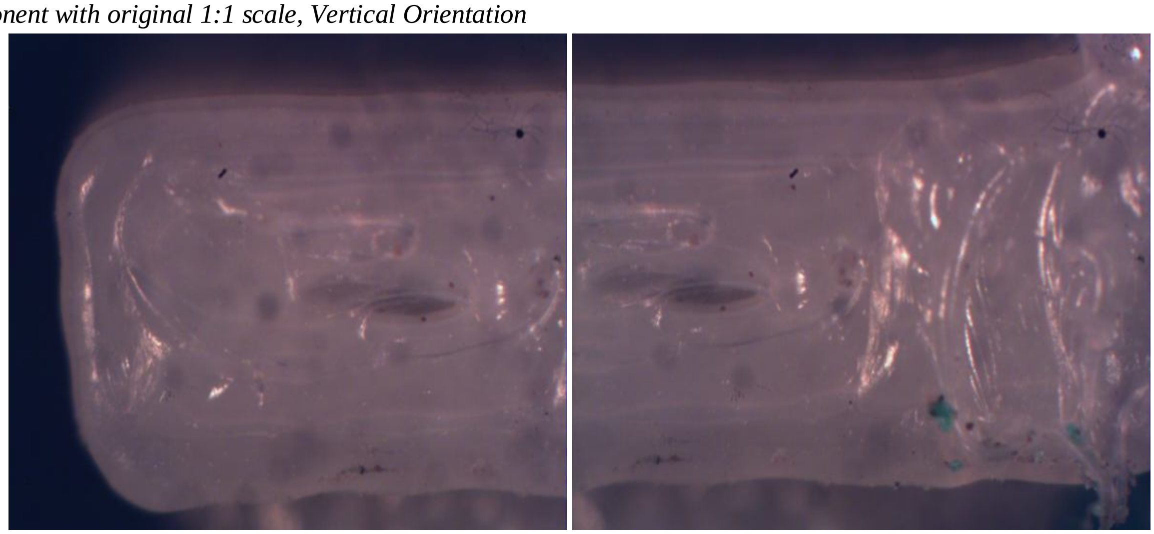
Sr. No	Scale	Inclination (wrt YZ plane)	Inclination (wrt XZ plane)
1	1	0°	0°
2	2	0°	0°
3	1	-15°	0°
4	1	0°	15°
5	1	-30°	0°
6	2	-30°	0°
7	1	0°	30°
8	2	0°	30°
9	1	-45°	0°
10	1	0°	45°

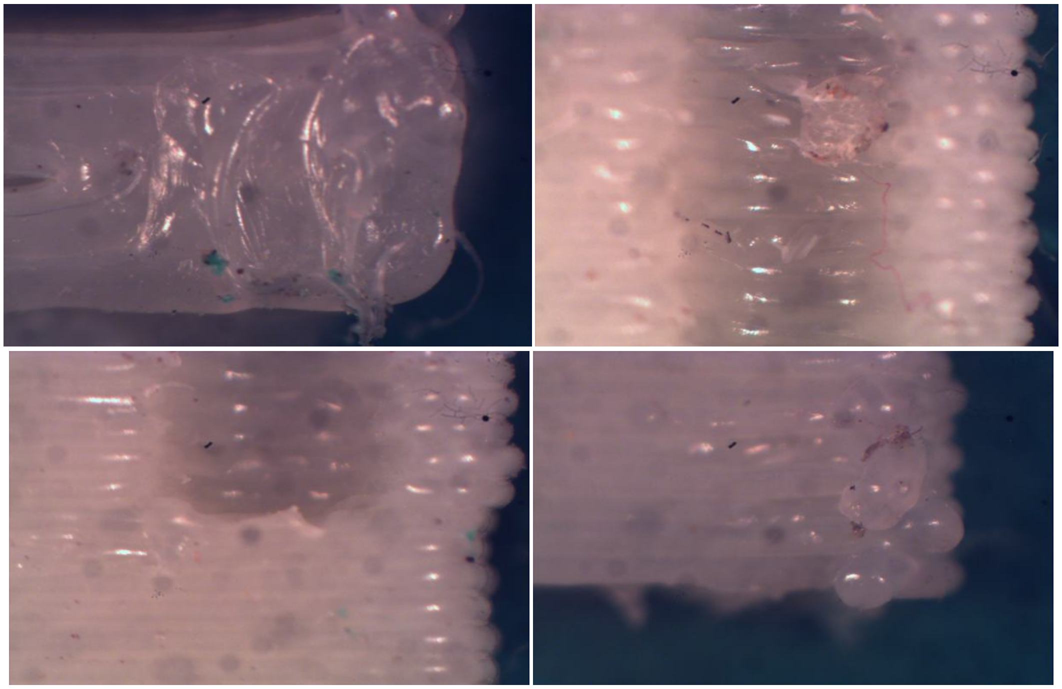
Fig: Photographic view of component printed in different orientation using FDM.

B. *Measurement of output variables*

The quality of 3D printed object depends on various parameters such as dimensional accuracy, surface roughness and strength of component. This work is focused on dimensional accuracy achievable and hence it is the primary output variable. It is measured with Mitutoyo toolmakers microscope. The surface roughness is considered as secondary response variable and measured with surface roughness tester Mitutoyosurftest SJ-301.

C. *Component with original 1:1 scale, Vertical Orientation*





III. RESULTS AND DISCUSSION

This chapter includes the details of the experimental work performed on FDM machine alongwith the results of the experimental work. The objective of the experimentation is to study theeffect of variation of input parameters to the overall quality of product. The overall quality has been determined on the basis of dimensional accuracy, surface roughness, and capability of FDM process to print internal features to near net shape. The further post processing is done to improve the quality and it is found that the improvement in surface finish is achieved to the certain extent. Evaluation of optimized process is done on the basis of experimental results obtained. The quality is evaluated by observing and analysing effect of input parameters on the output parameters. It is observed that change in one input parameter enhances quality of certain output parameter whereas it leads to compromise of quality of few other parameter.

A. Influence of Print Orientation on Internal Features

It is observed that vertical faces and bigger features generates with least amount of support material consumption when printed without inclination. But in the case of small features, there are certain voids remains in between adjacent paths of deposited material. Presence of such voids in the component leads to decrease its strength and dimensional inaccuracy also.

This occurrence of void spaces reasonably reduced when the printing orientation is changed and hence it can be concluded that the regular shapes and features can be printed in tilt position to obtain better homogeneity and isotropy.

The curved features with diameter more than 5 cm doesn't get affected significantly by the change in print orientation

Table 4.1 Designed values of dimensions in featured component

Edge	Dimension (mm)	
	For Scale 1:1	For Scale 2:1
A	2.5	5
B	10	20
C	5.5	11
D	1	2
E	Ø 1.1	Ø 2.2

Table 4.2 Comparison of measured dimension

Sr. No	Scale	Inclination (w.r.t. YZ plane)	Inclination (w.r.t. XZ plane)	Measured Dimensions (in mm)				
				A	B	C	D	Ø E
1	1	0º	0 º	2.48	9.98	5.52	NA	NA
2	1	-15 º	0 º	2.4	9.96	5.58	NA	NA
3	1	0 º	15 º	2.5	9.98	5.54	NA	NA
4	1	-30 º	0 º	2.52	10.0	5.62	NA	NA
5	1	0 º	30 º	2.53	9.98	5.50	NA	NA
6	1	-45 º	0 º	2.54	9.97	5.52	NA	NA
7	1	0 º	45 º	2.60	9.90	5.54	NA	NA
8	2	0 º	0 º	4.99	19.97	10.98	2	2.2
9	2	-30 º	0 º	4.62	19.76	10.94	2	2.1
10	2	0 º	30 º	4.7	19.98	10.94	1.98	2.2

NA : Feature unable to print

From table 4.1 and table 4.2, it is observed that the external dimensions of smaller features in X and Y direction are closer to desirable value when printed in vertical orientation, but at the same time homogeneity of the object is not good due to presence of undesirable void pockets which can be seen from figure 3.10. Hence it can be concluded that to obtain minimum dimensional deviation of parts, surfaces of the FDM part should be orientated either in parallel or in perpendicular direction with respect to the axis of a part but it may be accepted on account of sacrifice of homogeneity.

It is also observed that the process has limitations to print the features such as pockets or extrusions below 2 mm dimension. Hence it can be concluded that the current FDM process is not capable to print the minimum sized internal features less than 2 mm correctly.

B. Direction Dependent Dimensional Accuracy

When trial was conducted to print larger size component to check the dimensional accuracy it was found that in X and Y direction the dimensional accuracy was upto 99.85% bur at the same time in Z direction it was found upto 99.5% correct. It may be on account that the X and Y movements of extrusion tip of machine has direct drive control whereas the printing progress in Z direction occurs by addition of layers.

When the filament falls on the previous layer or substrate, there is a restriction for its free flow. Furthermore, under the action of gravity, the filaments deposited do not remain cylindrical but become oval with flat bottom the cross section of which is shown in Figure. Since there will be overlap of filaments, there will be lateral restrictions too and hence the actual cross section in this case will be as shown in. The width of the filament deposited is called road width. It can be as small as the diameter of the nozzle to about twice its size. This variation can be achieved by controlling the values of the wire speed and the head speed which can be controlled independent of each other.[15]

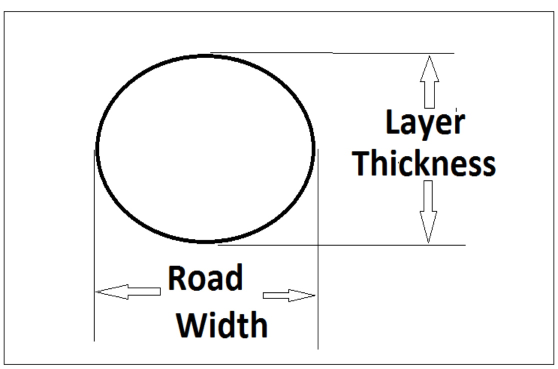


Fig. Cross section of filament deposited [15]

So it is advisable to orient the object in such a way that the most precise cross sectional dimension required is to be printed along XY plane.

C. Effect of Post Processing of Chemical Vapour on Surface Finish

Post-built treatment with coldvapours of acetone yielded a dramatic improvement insurfacefinish [6] due to reduction/elimination in staircaseeffect present on surfaces and as low as 2 micron surface roughness is possible to achieve. Chemicaltreatment of the specimen causes very minimal changein dimensional accuracy and in many cases reductionin dimensional deviation is achieved. Chemical treatmentalso leads to rounding of the corners andmajorly a radius less than 1mm is obtained. Thus,chemical treatment with cold vapour could as oneexcellentalternative for FDM parts to improve surfacequality without much sacrifice in dimensional orfeature geometry loss.

IV. CONCLUSIONS

Fused deposition modelling is one of the earliest developed rapid prototyping process and basically uses only ABS polymer for model making. Still it is widely spreading in various industries such as aerospace, bio implant model making, jewelry making, pattern making in foundry, educational model making etc. In this research work an attempt has done to produce the small sized components with few internal features, Also the dimensional deviations observed during 3D printing of large sized models are documented in second part of experiments. Since the FDM components shows poor surface finish, an attempt to increase the surface finish by post processing has been made and found some extent of enhancement in surface quality. The major observation from this research work brings us to the following conclusions

A. For printing of more critical shaped models on FDM machine, the use of soluble support is advisable.

B. The FDM process gives more accurate dimensions in X and Y (horizontal) direction than that of in Z (Vertical) direction

C. The stair stepping effect is observed in curved surface which can be reduced by re-orienting the object.

D. Internal homogeneity of small regular component in FDM can be can be increased by printing them with axis inclined but at the same time compromising with the surface finish of the model.

E. The FDM machines which uses breakaway type of support material during building of component are poor to build internal features, irrelevant of size of component. Few regular internal features such as uniform cross sectional holes and pockets etc. with dimensions more than 2 mm and low aspect ratio can be printed on it when oriented with axis of such feature vertical.

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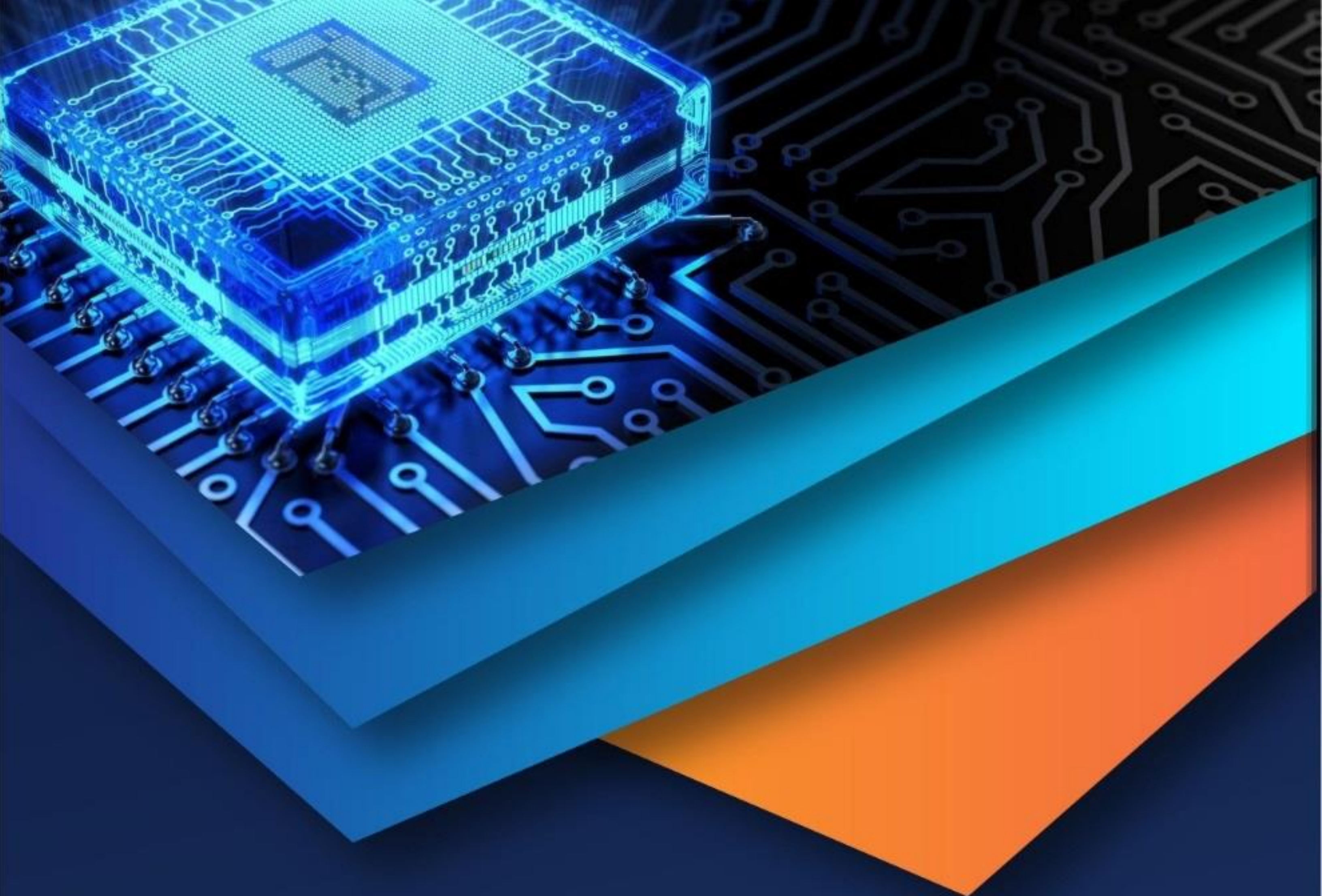

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