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Eliminating the Stair Step Effect of Additive Manufactured Surface-A Review Paper

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Abstract**:** ***Additive technology is an advanced technique which enables fast and flexible manufacturing of forming tools. One of its disadvantages is the formation of stair steps in the tool radii. Generally in selective laser sintering there occurs two kind of stair stepping, eg-1) Horizontal stair stepping, 2) Vertical stair stepping. These two occurred due to granular structure of powdery materials are used in these layer by layer manufacturing process and also formation and joining of discrete layer in Additive manufacturing process . In this paper a new method to smooth this stair Steps is introduced. This includes studies on the general feasibility of the process and compares the result from literature survey. This study will open a new cross cutting technique in the field of reverse engineering and rapid prototyping.***
Keywords: ***Additive Manufacturing, stair steps, selective laser sintering, reverse engineering, rapid prototyping.***

I. INTRODUCTION

Prototyping or model making is one of the important steps to finalize a product design. It helps in conceptualization of a design. Before the start of full production a prototype is usually fabricated and tested. Manual prototyping by a skilled craftsman has been an age-old practice for many centuries. Rapid Prototyping (RP) by layer-by-layer material deposition started during early 1980s with the enormous growth in Computer Aided Design and Manufacturing (CAD/CAM) technologies. Additive manufacturing technologies have gained importance in the recent years for manufacturing prototypes of dies. These technologies directly build a 3D model of the die from its CAD model. One such technology is stereo lithography (STL), which was first introduced and patented by Hull [1]. Successive layers of the part are built by curing layers of photopolymer resin by ultraviolet light according to the 3D CAD Model. Another method is Layered Object Manufacturing [2] in which adhesive coated layers of paper or plastic are glued together and cut with a knife or laser. The methods discussed above helped in making prototypes faster and cheaper, but were not able to make actual dies which could be used in manufacturing. A logical progression from this idea was making actual tools using layered manufacturing for even faster production of sheet metal forming dies. This began with blanking tools which were produced by stacking metal sheets together and joining them. Yokoi [3] reports of different joining methods like clamping with bolts, welding, adhesive bonding or diffusion bonding. As a part of the Last form project [4], scientists at the University of Warwick have used a process similar to Layered Object Manufacturing to form tools for different processes like injection molding. In this method, they successively cut layers, applied adhesive, and stacked them together to form the die. Mueller et al. [5] investigated the Layer Milling process wherein thick layers of about 10-100 mm are joined and milled. Obikawa [6] successfully manufactured an open wrench and a miniature wheel by welding thin coated steel sheets by an induction heater. Another method for layered manufacturing is Selective Laser Sintering (SLS) which was first described by Housholder [7]. SLS is an additive manufacturing technique that successively builds layers using a laser to sinter powdered metal (Direct Metal Laser Sintering) at specific points [8] defined by the CAD model of the part. Walczyk and Hardt [9] compared different rapid fabrication methods for producing metal forming dies. They pointed out, that layered manufacturing has the advantages of lesser time of manufacturing, lower costs and the possibility to combine different materials in one tool.

The software that operates RP systems generates laser-scanning paths (in processes like Stereo lithography, Selective Laser Sintering etc.) or material deposition paths (in processes like Fused Deposition Modeling). This step is different for different processes and depends on the basic deposition principle used in RP machine. Information computed here is used to deposit the part layer-by-layer on RP system platform. Poor surface quality of RP parts is a major limitation and is primarily due to staircase effect. Further, the situation can be improved by finding out a part deposition orientation that gives minimum overall average part surface roughness (Singhal et al., 2005). However, some RP applications like exhibition models, tooling or master pattern for indirect tool production etc. require additional finishing improving the surface appearance of the part. This is generally carried by sanding and polishing RP models which leads to change in the mathematical definitions of the various features of the model.

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II. LITERATURE SURVEY

One of the major disadvantages of layered manufacturing is the stair step effect. During layered manufacturing, Steps are formed at the work piece surface which requires finishing before use. CNC milling or lathe machines are most common for this purpose. Nakagawa [10] investigated the possibility to finish the surface by grinding. Pandey et al. [11] has used Hot Cutter Machining (HCM) for removing steps from the surface of a layer manufactured part, in which a heated cutting tool is used to machine the surface to reduce the cutting forces. Other most common methods to reduce stair step effect are to fill the steps with epoxy or some hard material, abrasive flow machining, or using very thin sheets. But thinner sheets reduce the compressive strength of the die. Furthermore, the edges can be cut by an angled cutting laser machine [12]. Kleiner and Krux [13] have formed deep drawing dies using metal sheets and reduced the effects of the steps by using an elastomer sheet between the die and the blank. Shi and Gibson [14] used a robot with six axis to machine an SLS product. The difficulty he faced was accessibility to complex geometrical features and undercuts. One of the disadvantages of the cutting processes used for surface finishing is the loss of material, excessive waste and time consuming.Lopez de Lacalle et al. [15] used this method to smooth the surface of forming tools which was characterized by the previous ball-end milling operation. Rodriguez [16] found that finishing of shafts by ball burnishing not only improved the surface finish, but also rendered the surface harder (strain hardening) with an improved fatigue life due to residual compressive stresses. A.E. Tekkaya [17] analyzed friction in thermally sprayed coatings, on deep drawing dies, finished by ball burnishing, and the results obtained were reduced friction and an increased drawing ratio.

III. METHODOLOGY

In this paper ball burnishing is used as an alternative finishing process to reduce the stair step effect in thin slicing layer to obtain a particular geometry. Ball burnishing (Fig.1) is a method for post processing of surfaces. Unlike cutting processes, in ball burnishing no material is removed. Due to a rolling contact between the roller and the surface, plastic deformation of the surface irregularities occur which results in a smoothing of the surface. The aim of this study is first of all to show the general feasibility of this new method to reduce the stair step effect of layer manufactured surfaces. Therefore, ball burnishing will be used as a bulk forming operation to smooth the edges of slicing layers. Furthermore, the influence of various ball burnishing parameters on the surface quality will be investigated by studying of various literatures on ball burnishing.

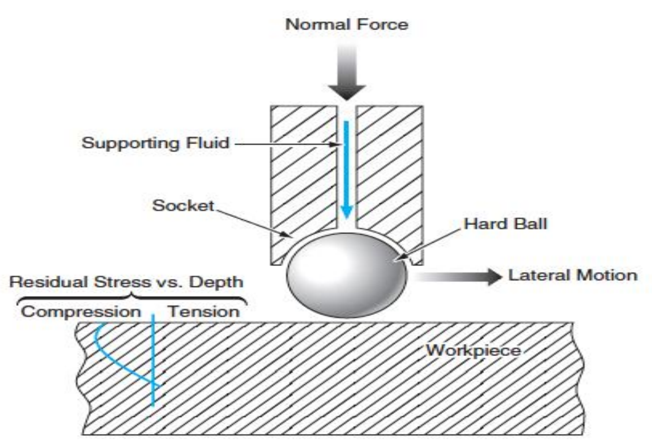

Fig. 1 Ball burnishing

IV. PROBLEM AND SOLUTION

Real error on slice plane is much more than that is felt, as shown in Fig.2. For a spherical model Pham and Demov (2001) proposed that error due to the replacement of a circular arc with stair-steps can be defined as radius of the arc minus length up to the corresponding corner of the staircase, i.e., cusp height (Fig. 2(b)). Thus maximum error (cusp height) results along z direction and is equal to slice thickness. Therefore, cusp height approaches to maximum for surfaces, which are almost parallel with the x-y plane. Maximum value of cusp height is equal to slice thickness and can be reduced by reducing it; however this results in drastic improvement in part building time. Therefore, by using slices of variable thicknesses (popularly known as adaptive slicing, as shown in Fig.3 (d) cusp height can be controlled below a certain value.

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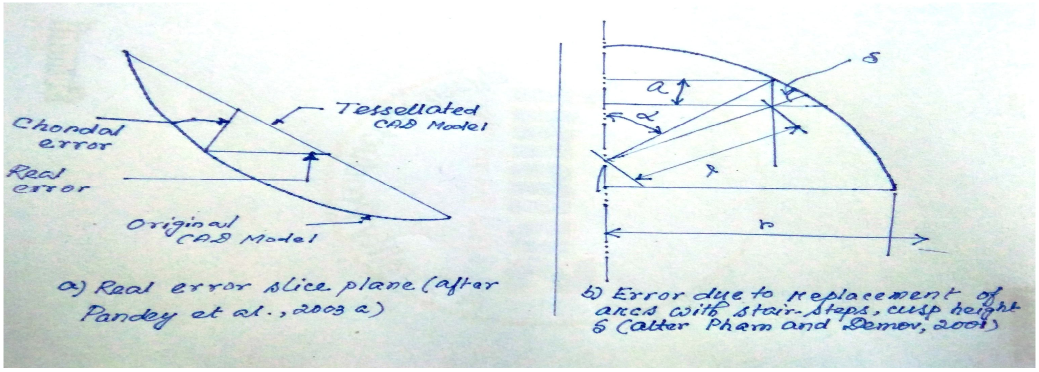

Fig. 2 Slicing error

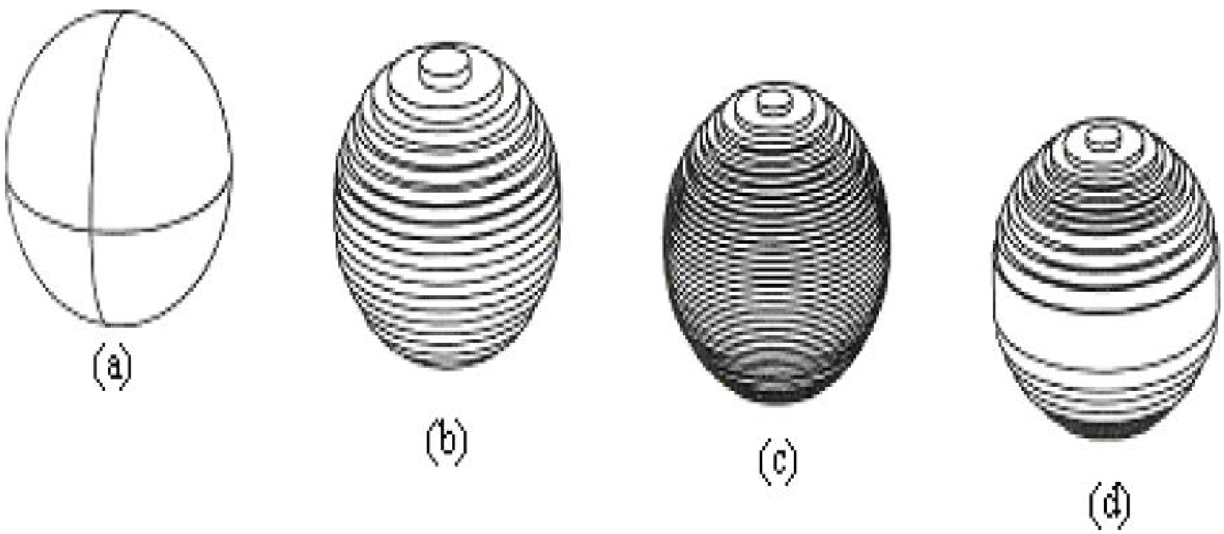

Fig. 3 Slicing of a ball (a) No slicing (b) Thick slicing (c) Thin slicing (d) Adaptive slicing

The ball tool is modeled to move along one peak, and then move on to the successive peak.

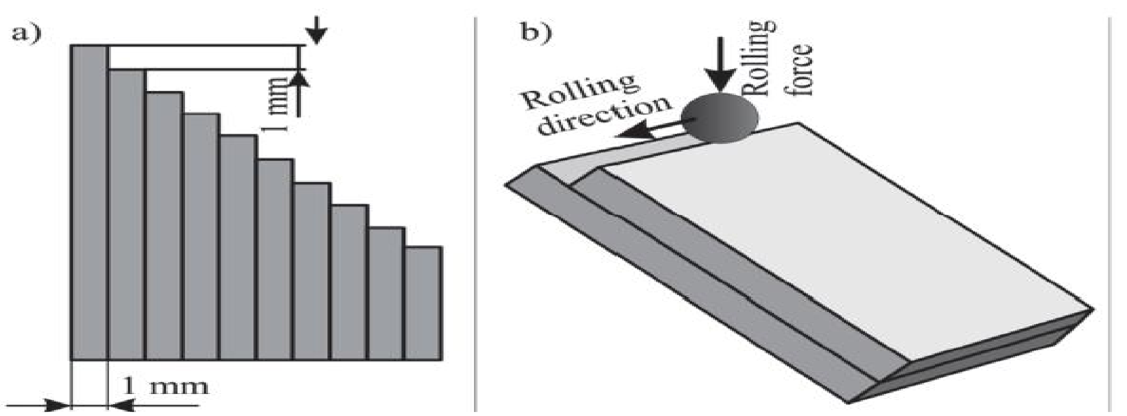

Fig. 4 Principle of rolling process

The peak of each slicing layer is rolled in a direction perpendicular to the stair steps (Fig. 5(a)).

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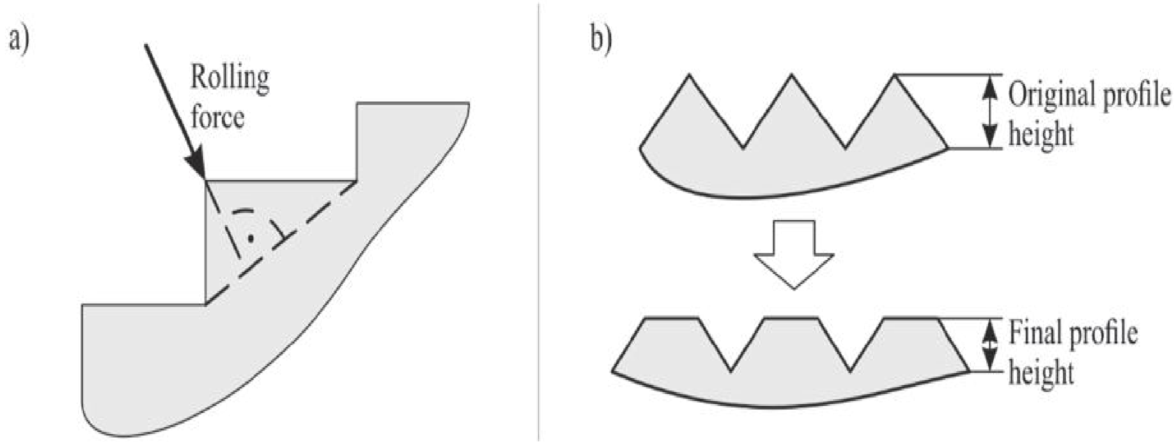

Fig. 5 Direction of rolling force (a) Profile before and after rolling (b)

Hardness can be increases with increasing rolling force. This can be explained by the strain hardening of the material. An increasing force results in higher plastic deformation of the edges and thus in greater strain hardening of the surface.

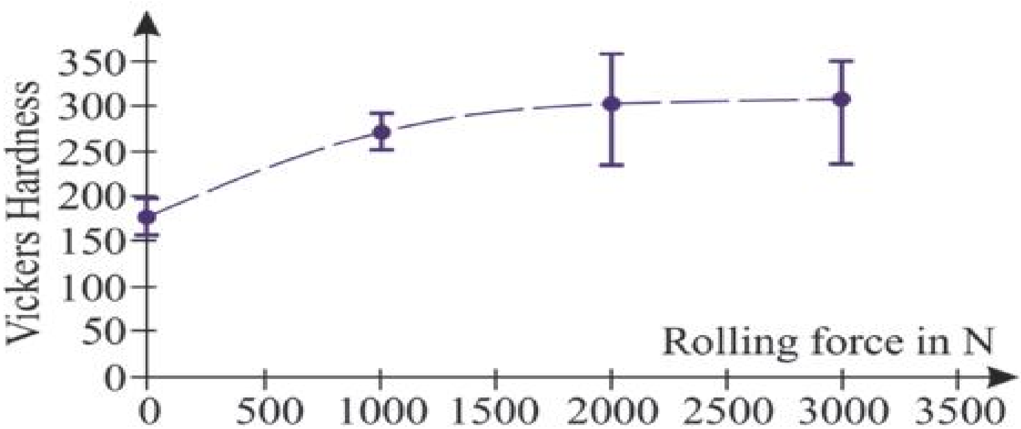

Fig.6 Hardness of rolled surface in dependence of rolling force

V. INFLUENCE OF BURNISHING PARAMETERS

A. Ball Diameter

The surface flattening increases with the increase of the ball diameter. This effect can be explained by the shape of the rolling ball. If the diameter is small, the ball forms a groove on the surface instead of flattening. In this case even an increase in pressure does not improve the surface flattening. Therefore, the ball diameter must be large relative to the slicing layer thickness to get a better surface better finishing.

B. Rolling Pressure

If a ball burnishing process is applied, an increase in the hydraulic pressure results in a better leveling of the surface. The best average leveling is in the range of 40 MPa with a remaining unevenness of 40 %.(Rodriguez [16]).

C. Slicing Thickness

The deformation required to smooth the edge of a thinner slicing layer is less than the deformation which has to be applied to smooth the stair steps of thicker slicing layer. Consequently, by using the same rolling force better leveling can be achieved for thinner slicing layer (Lopez de Lacalle et al. [15]).

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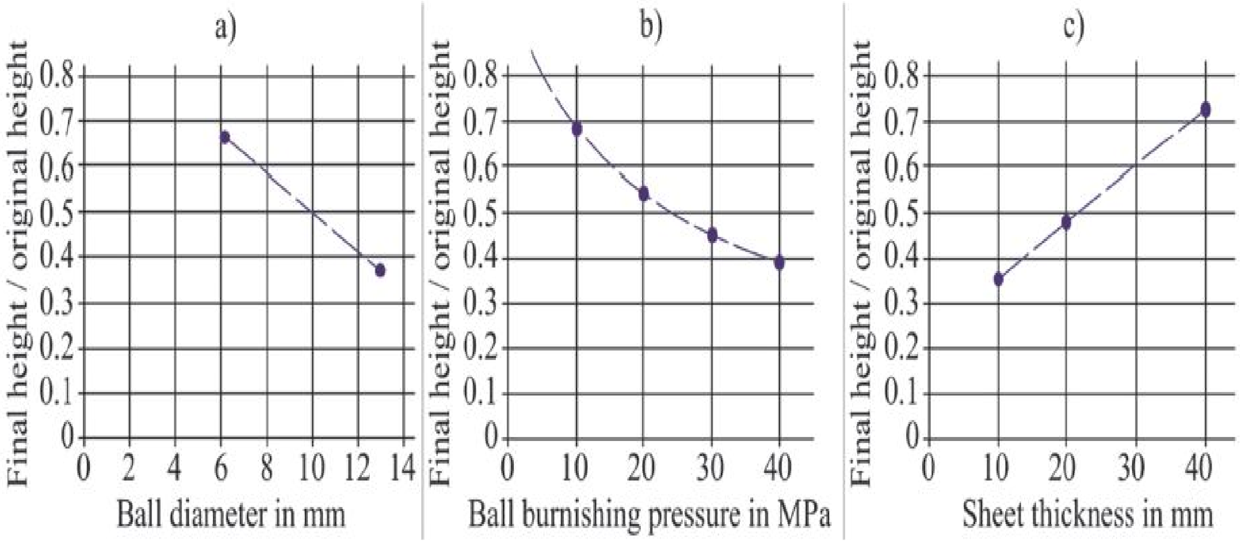

Fig.7 Ball Diameter (a) Burnishing Pressure (b) Sheet Thickness(c)

A combination of these averaged influencing parameters leads to an even much better leveling of the surface. By using the bigger burnishing tool (ball diameter), a small slicing layer thickness and a high burnishing pressure the surface can be smoothed to a desirable percentage of the initial profile height.

VI. CONCLUSIONS

This paper provides an overview of stair step effect of layered manufacturing techniques and how to eliminate this surface defect by applying adaptive slicing and very innovative ball burnishing process with very less cost effort. Furthermore, the increase of hardness due to strain hardening is favorable for the wear behavior of the surface and therefore a great advantage of the rolling process compared to machining processes. The amount of leveling depends mainly on the ball diameter of the rolling tool, the rolling pressure (and thus of the rolling force) and the slicing layer thickness. To achieve a good surface quality after rolling, the ball diameter should be as large as possible, the rolling pressure as big as possible and the slicing layer thickness should be chosen as small as possible. It can be used for the production and post treatment of layer manufactured deep drawing tools. The tool without post treatment with the resulting stair step effect and the tool whose surface was smoothed by rolling can be seen in Fig. 8. Ultimately, this smoothing of the surface makes a deep-drawing process without failure possible. Furthermore, it can be assumed that the higher surface hardness has a positive effect on the wear behavior of the tools. Furthermore, the material used will have an influence on the leveling. However, this has not been considered within this work and will be part of further studies.

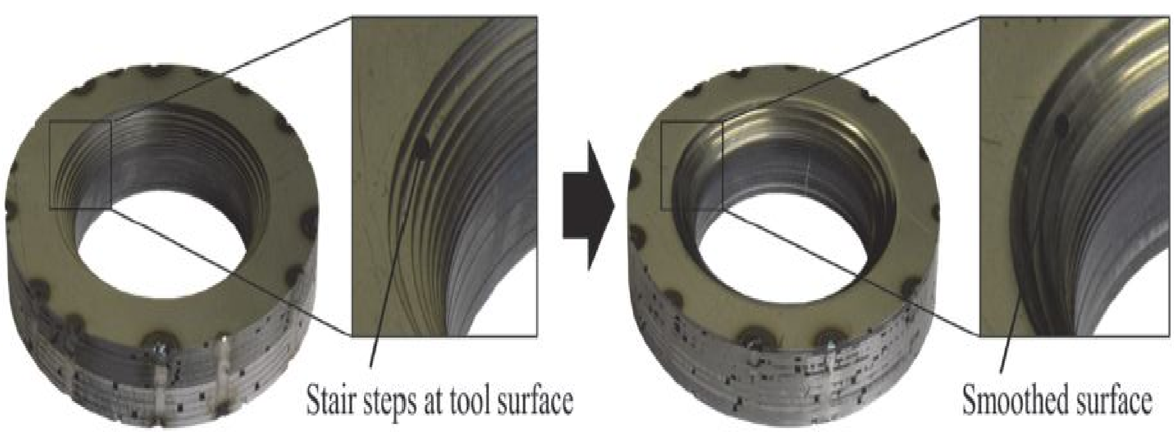

Fig.8 Layer manufactured deep drawing tools with and without post treatment

VII. ACKNOWLEDGMENT

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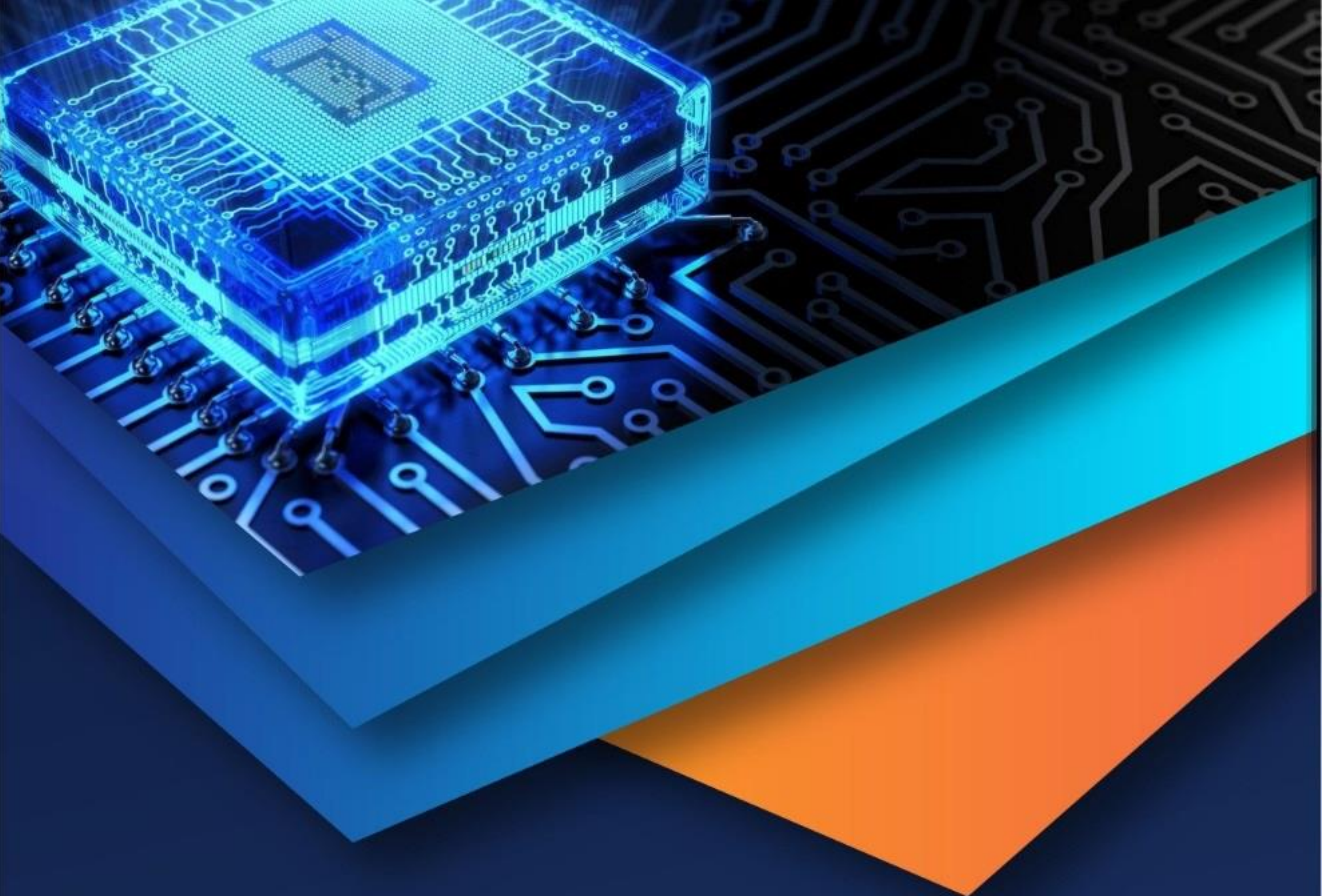

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