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Analysis of Tool Life during Turning of En8 in Dry, Wet and MQL Environment – A Review

Miss. Sanjivanee P. Patil[1], Mr. Sharad S. Patil[2]
Department of Mechanical Engineering,
Karmaveer Bhaurao Patil College of Engineering, Satara, India.

Abstract— This paper presents a review on Analysis of tool life during turning of EN8 in dry, wet and Minimum Quantity Lubrication environment. Tool life is the most important parameter for assessing machinability. Since it is a direct function of cutting speed, a better machinable metal is one which permits higher cutting speed for a given tool life. With the rise of environmental friendly practices MQL is gaining popularity amongst machining industry, hence the tool life and surface finish can be improved. In this review, understand the effect of process parameters on tool life and surface roughness in turning operation and to investigate the effect of machining environment (Dry/MQL/Wet) on machining performance and tool life. RSM is employed to determine optimum value of cutting parameter as it offers more advantages over other design methods. It provides a systematic procedure to determine the relationship between input process parameter and output.
Keywords— Tool life, Minimum quantity lubrication(MQL), Machining, Work Piece material, Response Surface Methodology (RSM)

I. INTRODUCTION

Tool wear is one of the important factors affecting manufacturing process. The tool should be retracted and changed well before it wears out totally, otherwise the part to be machined will not comply with the specified accuracy. This also results in poor surface finish of the job, leading to an increase in overall production cost, rework and scrap.

Cutting fluids are used to facilitate the tool life and studies have shown that it improves the surface finish. However it poses the environmental concern due to its after use disposal issues. Strict regulations and their enforcement against using cutting fluids has therefore, been tightened. It is possible to reduce the use of coolant and achieve better tool life and surface finish with the use of new technique MQL.In this method minimum quantity of coolant with compressed air is applied during machining process. As the coolant gets evaporated due to higher temperature at tool work piece interface, coolant disposal problem will not arise. Thus it will help to make the manufacturing process environmental friendly.

In today's competitive manufacturing environment, the enhancement of productivity with improved product quality and reduced cost, as well as the maximization of the profit decides the sustainability of a manufacturing organization. The major problems in achieving high productivity and quality are caused by the high cutting temperature developed during machining, at high cutting velocity and feed rates, particularly when the work material is difficult to machine. In general, the condition of the cutting tools plays a significant role in achieving consistent quality, and also in controlling the overall cost of manufacturing.

Metal cutting is a complex process where many factors, such as machine tool, work material, tool material and machining conditions, have to be considered. Among the factors, tool wear is one of the most important aspects that affect product quality and cost in metal cutting process. Many research studies regarding of the tool wear have been carried out over 150 years. Several tool wear types have been reported in metal cutting including abrasion (Ramalingam and Wright [21]), adhesion (Wright and Bagchi [33]), diffusion (Trent[32]) and dissolution (Kramer and Kwon[14]). In general, abrasive and adhesive wears dominate at low cutting temperatures while the chemical wear such as diffusion and dissolution are dominant at high cutting temperatures (Stephenson and Agapiou [26]). Thus, the dominant wear mechanism at flank surface due to relatively low cutting temperature compared to rake surface is abrasion while the combination of abrasion and dissolution wears takes place at rake surface. In addition, the abrasion is strongly dependent upon the hardness of a tool material; therefore, a harder coating can improve the tool life if the abrasive wear is dominant. Analyzing machining process is a complicated task because of the large number of influencing factors. Such factors in cutting are the parameters that significantly affect are: work-piece material, tool material and geometry, machine, machining process, cooling and lubrication fluids properties and delivery, machining condition, etc. This study deals with the aspects that directly related to tool wear and surface finish, which are tool (coating) material, work material, lubrication and machining process because understanding these aspects can eventually improve the productivity.

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II. STUDIES ON TOOL WEAR AND TOOL LIFE

The performance of a cutting tool is normally assessed in terms of its life. Tool life can be defined as the total length of cutting time that a tool can be used until failure. There are a number of ways of expressing tool life such as:

A. Volume of metal removed

B. Number of work pieces machined, and

C. Usage time

The flank wear is an indicator for estimating the tool life as this parameter largely affects the stability of the cutting edge and consequently the dimensional accuracy of the machined work piece. The extent and rate of flank wear can be estimated using different methods. Figure 1 illustrates the estimation methods that can be used in estimating flank wear progress (Adesta et al.[1]). ISO (1993) dictates that the end of useful life of cutting tool is said to be over when it fails to produce the specified part size and surface quality.

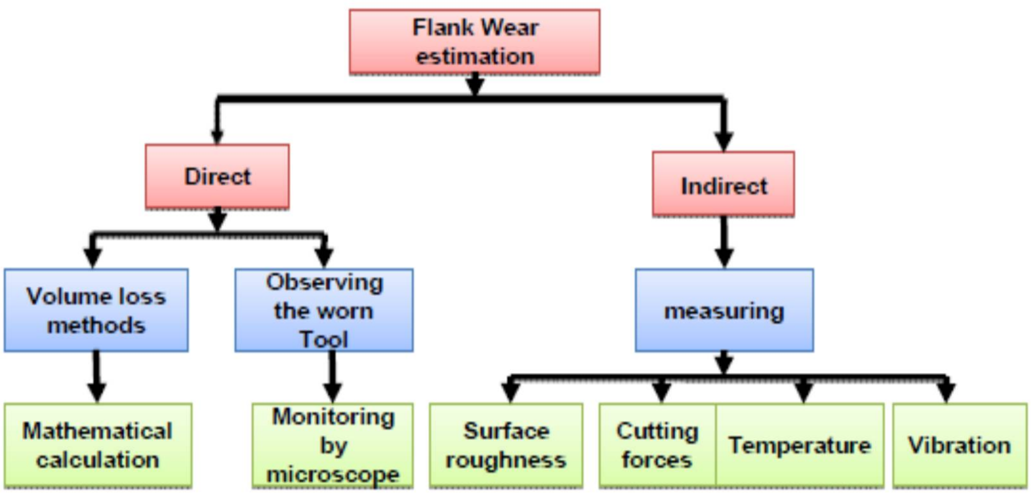

Figure 1. Flank wear estimation methods (Source : Adesta et al., 2010)

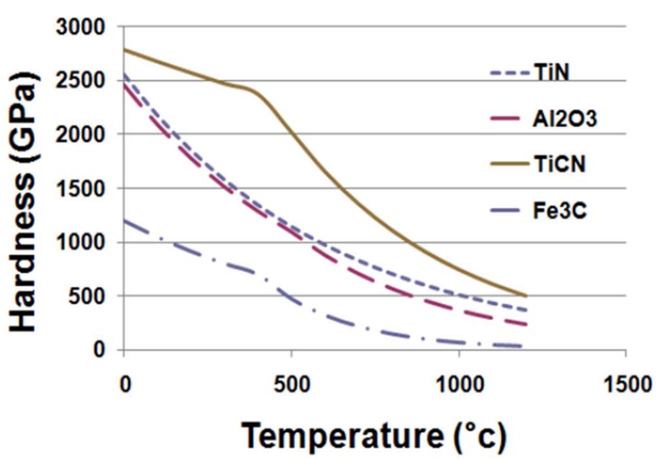

Figure 2. Hardness of cementite and coating materials (Source : Park, 2010)

While many ceramic materials such as TiC, Al2O3 and TiN possess high temperature strength, they have lower fracture toughness than that of conventional tool materials such as high-speed steels and cemented tungsten carbides. The hardness of the cementite and different coating material is shown in figure 2. The graph shows that with increased temperature the hardness of the tool material decreases rapidly and decreases the tool life. Thus it is important to keep the temperature of the tool and work material interface as minimum as possible to improve tool life.

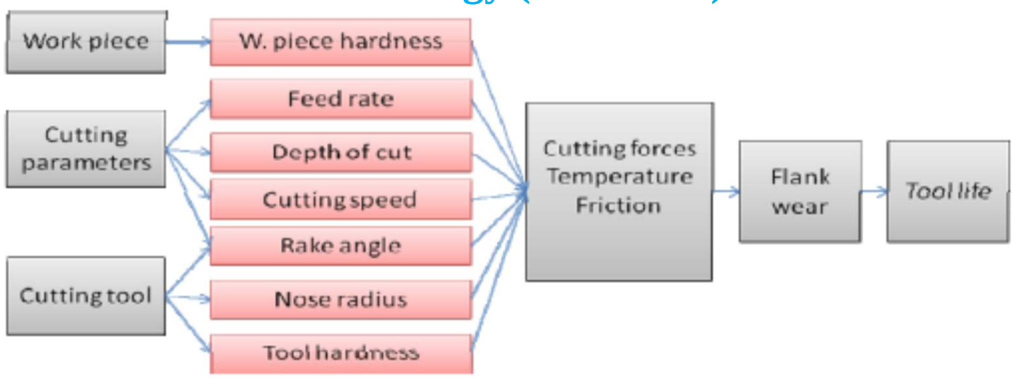

Figure 3. Effect of various parameter on tool life (Source : Adesta et al, 2010)

A key factor that affects the wear rate of tools is the temperature reached during the cutting operation along with the applied forces. Reduction in tool wear can be readily accomplished by using cutting fluids that can act both as lubricants and as coolants while machining. Theoretical and experimental studies were carried out by Luo et al [16] to investigate the intrinsic relationship between tool flank wear and operational conditions in metal cutting processes using carbide cutting inserts. A flank wear rate model, which combines cutting mechanics simulation and an empirical model, was developed to predict tool flank wear land width. Machining was done under different operational conditions using hard metal coated carbide cutting inserts. The results of the experimental studies indicated that cutting speed had a more dramatic effect, than feed rate, on tool life. The wear constants in the proposed wear rate model were determined by regression analysis using the machining data and simulation results. A close agreement between the predicted and measured tool flank wear land width was reported.
Özel & Karpat[18] studied the predictive modeling of surface roughness and tool wear in hard turning using regression and neural networks. The cutting tool used was cubic boron nitride. In this study, effects of cutting edge geometry, work-piece hardness, feed rate and cutting speed on surface roughness and tool wear were experimentally investigated. A four factor two level fractional factorial design was used. Tool wear prediction models were developed by Rao et al [23] using mathematical regression and neural network. Experimental data of measured tool flank wear was used to develop the models.
Insert coating plays important role on life of the tool. Various types of coating tools are available and used for machining different material. The effect of various parameters on tool life is shown in figure3. Coelho et al[4] found that coatings exhibit to the best tribological improvements when uncoated tools are compared. TiN coatings have shown the best tribological improvements compared to uncoated tools. Konyashin[13] examined the effect of TiN and TiC coating on the cemented carbide tools obtained by Physical Vapour Deposition (PVD).Investigation shows that the PVD-Chemical Vapour Deposition (CVD)coated carbide has longer tool life in turning as compared to conventionally coated inserts. PVD technology allows elimination of the decarburization or damage of the cemented carbide substrate and also used for depositing special barrier under layer before deposition of the conventional coating. Ghani et.al.[8] investigated the wear mechanism of TiN-coated carbide and uncoated cermets tools at various combinations of feed rate, depth of cut and cutting speed for hardened AISI H13 tool steel. They observed that the time taken for the cutting edge of TiN-coated carbide tools to initiate cracking and fracturing is longer than that of uncoated cermets tools, thus provides longer tool life.

III. STUDIES ON SURFACE FINISH

Surface finish is a important parameter which ascertains the quality of production during machining operation. It gives an aesthetic appeal to the product which gives maximum satisfaction to the customer. In a manufacturing industry surface finish will not suffice the completeness and if productivity adds to it, will give the total completeness (Suresh et al [29]). Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, etc. Before surface roughness, it is also necessary to discuss about surface structure and properties, as they are closely related. The surface roughness is generally evaluated by the mean roughness

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index R_a of the micro-irregularities as shown in figure 4. It is the arithmetic mean of the absolute value of the highest hi between the actual and the mean profile.

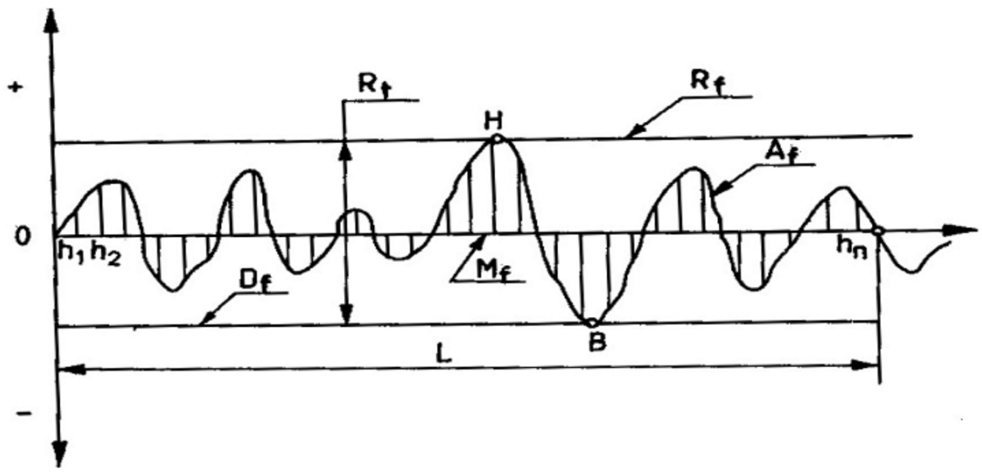

Figure 4. Surface undulation

Surface roughness and tolerance are among the most critical quality measures in many mechanical products. As competition grows closer, customers now have increasingly high demands on quality, making surface roughness become one of the most competitive dimensions in today's manufacturing industry(Feng [6]). Metal cutting is a common operation in many manufacturing systems. Roughness of the machined surface is an important quality measure in metal cutting, and it is important to monitor and control surface roughness over time during the machining operation. If the surface becomes too rough, the cutting tool has to be changed [34]. Surface finish is also an important index of machinability because performance and service life of the machined/ground component are often affected by its surface finish, nature and extent of residual stresses and presence of surface or subsurface micro-cracks, if any, particularly when that component is to be used under dynamic loading or in conjugation with some other mating part(s). Generally, good surface finish, if essential, is achieved by finishing processes like grinding but sometimes it is left to machining. Even if it is to be finally finished by grinding, machining prior to that needs to be done with surface roughness as low as possible to facilitate and economize the grinding operation and reduce initial surface defects as far as possible (Dhar et al [5]

Singh and Rao [24] investigated how surface roughness in bearing steel (AISI 52100) is effected by cutting condition and tool geometry. In this investigation mixed ceramic inserts which were made from Aluminum oxide and Titanium carbonitride (SNGA) which have different nose radius and different effective rake angle are used. In this study they concluded that Surface roughness is affected by feed significantly followed by nose radius and cutting velocity. Surface roughness is affected very less by effective rake angle but interaction effect of nose radius and effective rake angle is significant. RSM was used to develop mathematical model.

Singh et al.[25] depicts experimental study to investigate the effect of cutting parameters like spindle speed, feed and depth of cut on surface roughness and material removal rate on En 8. Taguchi methodology has been employed applied to optimize cutting parameters. The results showed that spindle speed affects most followed by depth of cut and feed rate. Jindal et.al.[11] observed that TiAlN coated tools showed the best metal cutting performance, followed by the TiCN and TiN coated tools According to Tawqif [30], (TiN,TiC) coated cutting tools gave best results for surface finish compared with TiN, TiC, Al2O3, TiN and all uncoated tool, for selected machining conditions. The experimental results also showed that, when the cutting speed is increased and feed rate is reduced, the values of surface roughness is decreased for uncoated tool insert, for single coated layer insert (TiN). Asri and Yusuf [2] analysed the performance of TiC coated carbide cutting tool in turning AISI 1045 steel. In his study he presented the flank wear characteristics of titanium carbide (TiC) as coated material on cemented carbide tool during machining AISI 1045 steel in dry machining. Silva et.al. [29] investigated the effect of cutting speed on cutting forces and surface roughness when dry precision turning AISI 1045 steel using coated and uncoated cemented carbide tools. The results showed, the turning force components tend to decrease or remain practically stable as cutting speed increased**.**

IV. STUDIES ON MINIMUM QUANTITY LUBRICATION

The analysis by many researches have shown that MQL is effective at low cutting speed also Gaitondea et al [7], Weinert et al [33] and Sredanovic et al [26].Techniques of lubrication on productivity and efficiency is shown in figure 5. Lakic et al [15] reported that

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with MQL it is possible to increase productivity with economy.

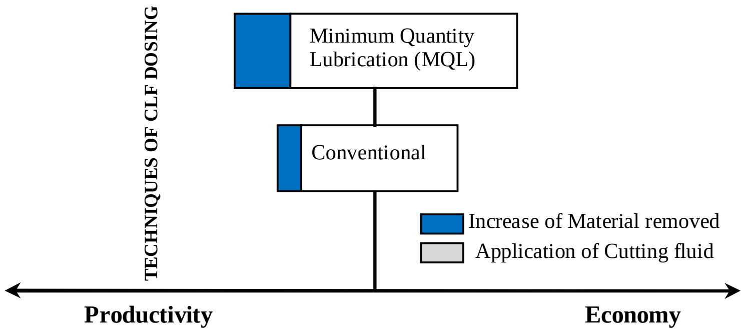

Figure 5. Influence technique of lubrication on productivity and efficiency
(Source: Lakic et al, 2013)

Dry machining is now of great interest and actually, they meet with success in the field of environment friendly manufacturing. This is sometimes less effective when higher machining efficiency, better surface finish quality, and severe cutting conditions are required. For these situations, semi-dry operations utilizing very small amounts of cutting lubricants are expected to become a powerful tool and, in fact, they already play a significant role in a number of practical applications. The concept of minimum quantity lubrication sometimes referred to as near dry lubrication. In another study Dhar et al.[5] used this technique in turning process and concluded that, in some cases, MQL has been shown to be better than flood cooling.

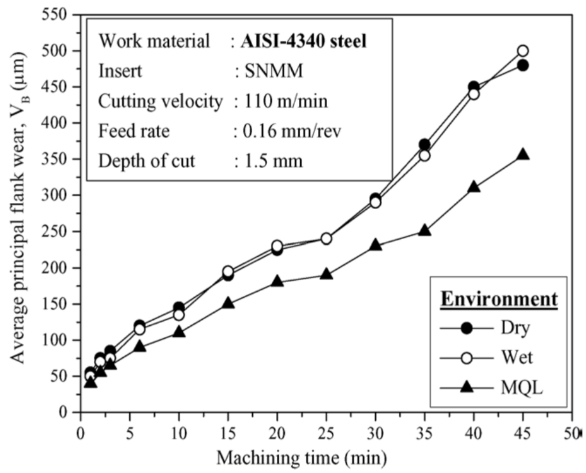

Figure.6 Growth of average principal flank wear with machining time under dry,wet and MQL condition(source:Dhar et al [5])

Ramana et al.[22] studied the Effect of dry, flooded and MQL in turning of Ti-6Al-4V alloy. It was observed that, the surface roughness is low for MQL compared to dry and flooded conditions. It was also noted that, the surface roughness increases as the cutting speed increases from low to moderate speeds for dry, flooded and MQL conditions, but from moderate to high cutting speeds, the surface roughness decreases for dry and flooded conditions, where as the surface roughness continuously increases for MQL conditions. This was explained by the reason that, surface roughness increases due to temperature, stress and wear at tool tip increases. In comparison of MQL with dry and flooded lubricant conditions, the cutting fluid supplied at high pressure and velocity, which penetrates minute particles into tool-chip and tool-workpiece surfaces, causes reduction in friction leads to less surface roughness.

In MQL condition, it provides both cooling and lubrication effectively and cooling occurs convective as well as evaporative heat transfer, hence less surface roughness was observed in MQL Gaitonde et al[7]. In flooded condition effective penetration of the cutting fluid into tool-chip and tool- work surface is not possible and also heat transfer takes place only with convective heat transfer. Hence, high surface roughness was found in flooded compared to MQL condition, whereas in dry machining, no cutting fluid is supplied, which results into high friction, high tool wear and low heat transfer leads to high surface roughness. The increasing and decreasing pattern of surface roughness in dry and flooded conditions was observed.

V. STUDIES ON RESPONSE SURFACE METHODOLOGY

RSM is a statistical method for heuristic optimization, which is basically a combination of design of experiments, regression analysis and statistical inferences. It is very useful technique for modeling and analysis of problem in which a response of interest is influenced by several variables and the objective of this approach is to optimize the response. By using this approach RSM models will be developed based on experimental results. Some stages in the application of RSM as an optimization technique are as follows: (1) the selection of independent variables of major effects on the system through screening studies and the delimitation of the experimental region, according to the objective of the study and the experience of the researcher; (2) the choice of the experimental design and carrying out the experiments according to the selected experimental matrix; (3) the mathematic–statistical treatment of the obtained experimental data through the fit of a polynomial function; (4) the evaluation of the model's fitness; (5) the verification of the necessity and possibility of performing a displacement in direction to the optimal region; and (6) obtaining the optimum values for each studied variable.

If the variables forms continuous range of values, RSM is useful for developing, improving and optimizing the response variable. Let y is the response variable, and it is a function of x1,x2, x3…… . Using RSM it can be expressed as

$$y = f(x1, x\ 2, x3 \ldots\ldots) + \in \ldots\ldots\ldots\ldots \text{i)}$$

The variables x1, x2, x3 ….. are independent variables and the response y depends on them. The dependent variable y is a function of x1, x2,x3 …….. and the experimental error '∈'. A first order model with two independent variables using RSM can be expressed as

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \in \ldots\ldots\ldots\ldots \text{ii)}$$

Nilrudra Mandal et al[33] investigated on the optimization of machining parameters in turning AISI 4340 steel. The Zirconia toughened alumina inserts were selected to machine the selected work-piece. The machining experiments were performed based on Response Surface Methodology (RSM) design called Central Composite Design (CCD).The mathematical model of flank wear, cutting force and surface roughness had been developed using second order regression analysis. It was concluded that at constant cutting speed and feed rate, when depth of cut increased, the flank wear and cutting force decreased and then significantly increased.

VI. CONCLUSION

A. Tool life is a function of process parameters and the lubrication method. Wet lubrication and MQL improves the tool life significantly.
B. Inserts have significantly longer tool life compared to brazed tip tool. Type of coating on inserts does not affect tool life significantly.
C. Surface roughness in turning process depends upon various parameters like cutting speed, feed rate, depth of cut, tool type and cutting fluid application method.
D. As the feed rate is low the surface finish obtained is good as compared to higher feed rate. Feed rate causes the chatter marks on surface produced.
E. Analysis shows that turning with MQL is a good alternative for conventional lubrication.
F. The inserts were found to be more productive because less tool change time as the tool life is increased in MQL**.**
G. With MQL practice disposal problem of the coolant after its intended life can be addressed.

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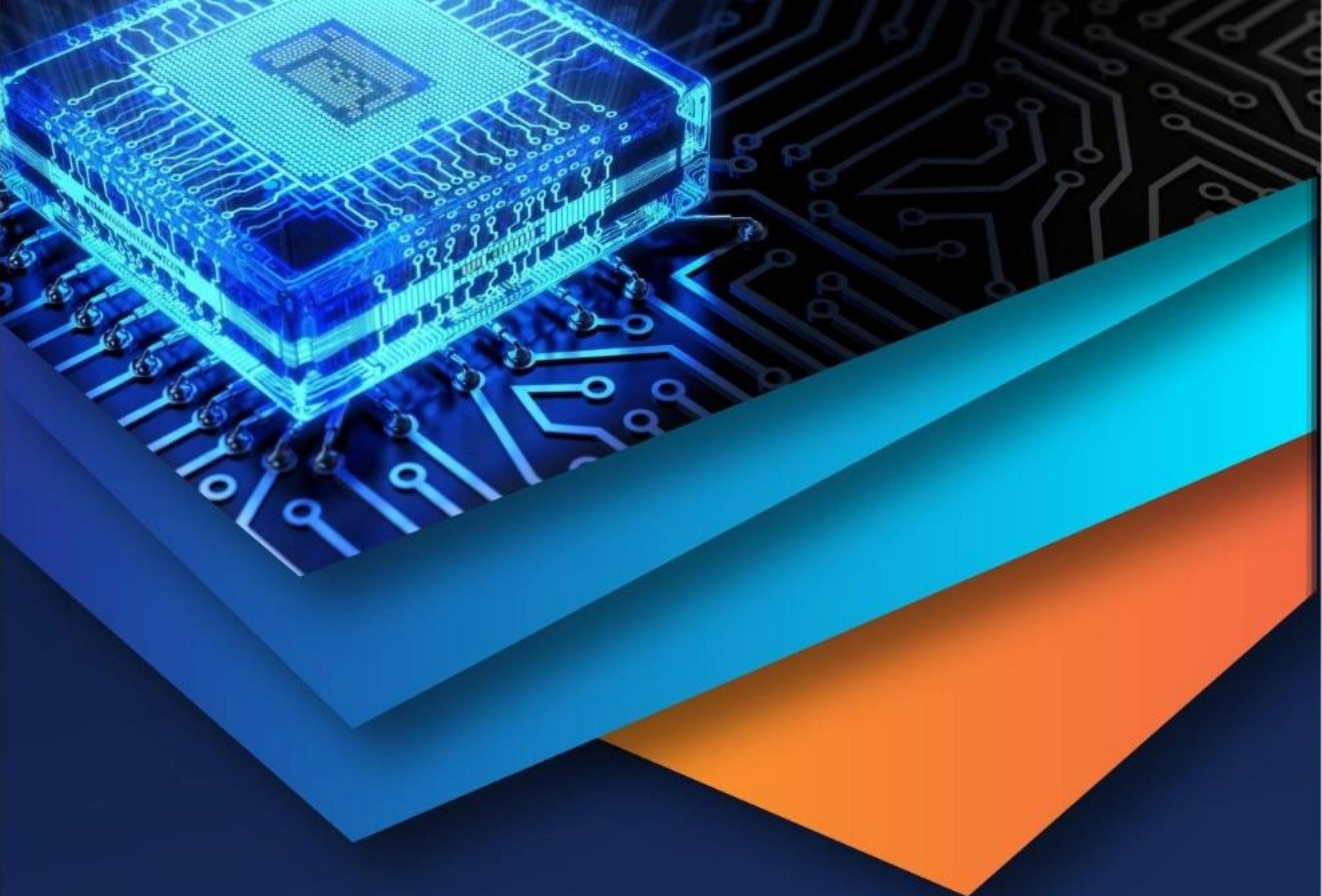

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