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STUDY AND ANALYSIS OF SINGLE POINT CUTTING TOOL UNDER VARIABLE RAKE ANGLE

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Abstract: *The finite element method is used to study the effect of different rake angles on the force exerted on the tool during cutting. This method is attracting the researchers for better understanding the chip formation mechanisms, heat generation in cutting zones, tool-chip interfacial frictional characteristics and integrity on the machined surfaces. In present study the three different rake angles are studied to find out the variation in values of Vonmisses stress for the specified applied forces. As we increase the rake angle then the value of Vonmisses stress goes on decreasing. The value of Vonmisses stress decrease for increase of rake angles of 7°, 9° and 11° respectively. From results it seems that reduction of resultant forces might cause increase in tool life but it cause decrease in tool life. In present study mesh is created in ANSYS and the boundary conditions are applied and the analysis is carried out for the applied constraints. The results calculated on software can be verified with experiments carried out with tool dynamometers for lathe tool. For future study the applied model can be used for multipoint cutting tools such as milling cutters, broaching tools etc.*

Keywords: *Single Point Cutting Tool, Back Rack Angle, Vonmisses stress, Finite Element Method.*

1. Introduction

Finite Element Method (FEM) based modeling and simulation of machining processes is continuously attracting researchers for better understanding the chip formation mechanisms, heat generation in cutting zones, tool-chip interfacial frictional characteristics and integrity on the machined surfaces. Predicting the physical process parameters such as temperature and stress distributions accurately play a pivotal role for predictive process engineering of machining processes. The cutting forces vary with the tool angles, feed and cutting speed. Knowledge about the forces acting on the cutting tool may help the manufacturer of machining tool to estimate the power requirement.

Tool edge geometry is very important, because its influence on obtaining most desirable tool life and surface integrity is extremely high. Therefore, development of accurate and sound continuum-based FEM models are required in order to study the influence of the tool edge geometry, tool wear mechanisms and cutting conditions on the surface integrity especially on the machining induced stresses.

On the other hand, the friction in metal cutting plays an important role in thermo-mechanical chip flow and integrity of the machined work surface. The most common approach in modeling the friction at the chip-tool interface is to use an average coefficient of friction. Late models consist of a sticking region for which the friction force is constant, and a sliding region for which the friction force varies linearly according to Coulomb's law.

The round edge of the cutting tool and the highly deformed region underneath has dominant influence on the residual stresses of the machined surface. The use of a separation criterion undermines the effect of the cutting edge on the residual stress formation on the machined surface. In this project, the work material is allowed to flow around the round edge of the cutting

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tool and therefore, the physical process is simulated more realistically.

2. Literature review

There are different approaches that have been applied in the recent past for formulating numerous static field problems. As the number of these problems is varied, there can be many types of approaches that have been found to give reasonable results since their time of occurrence. Below gives a glimpse of the finite number of techniques for dealing with these problems.

2. 1 Finite difference method

It is one of the older and yet decreasingly used numerical methods. In essence, it consists in superimposing a grid on the space-time domain of the problem and assigning discrete values of the unknown field quantities at the nodes of the grid. Then, the governing equation of the system is replaced by a set of finite difference equations relating the value of the field variable at a node to the value at the neighboring nodes.

Limitation: -

1. Lack of geometrical flexibility in fitting irregular boundary shapes.

2. Large points are needed in regions where the field quantities change very rapidly.

3. The treatment of singular points and boundary interfaces do not coincide with constant coordinate surfaces.

2.2 Boundary element method

To formulate the eddy-current problem as a boundary element technique, an integral needs to be taken at the boundary points. To avoid the singularity which occurs in the integrand when the field point corresponds to the source point, the volume is enlarged by a very small hemisphere whose radius tends to zero, with the boundary point being the center of the sphere. The usage of the boundary element method reduces the dimensionality of the problem from three to two or from two to one. It is found to be useful in open boundary problems where it strongly challenges the finite element method.

Limitation: - Instead of sparse (and usually symmetric and positive definite) matrices of the FDM and FEM, the resultant matrices in this method are full (and usually non-symmetric).

The most powerful numerical method appears to be the FEM, which (from the mathematical point of view) can be considered as an extension of the Rayleigh-Ritz / Galerkin technique of constructing coordinate functions whose linear combination approximates the unknown solutions. In this method, the field region is subdivided into elements i.e. into sub-regions where the unknown quantities , such as , for instance, a scalar or vector potential , are represented by suitable interpolation functions that contain, as unknowns, the values of the potential at the respective nodes of each element. The potential values at the nodes can be determined by direct or iterative methods.

The normal procedure in a field computation by the FEM involves, basically, the following steps:-

1] Discretization of the field region into a number of node points and finite elements.

2] Derivation of the element equation: - The unknown field quantity is represented within each element as a linear combination of the shape functions of the element and in the entire domain as a linear combination of the basis functions. A relationship involving the unknown field quantity at the nodal points is then obtained from the problem formulation for a typical element. The accuracy of the approximation can be improved either by subdividing the region in a finer way or by using higher order elements

3] Assembly of element equations to obtain the equations of the overall system. The imposition of the boundary conditions leads to the final system of equations, which is then solved by iterative or elimination methods.

4] Post-processing of the Results: - To compute other desired quantities and to represent the results in tabular form or graphical form, etc.

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2.3 Formulation Of The Finite Element Method

The FEM is concerned with the solution of mathematical or physical problems which are generally defined in a continuous

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domain either by local differential equations or by equivalent global statements. To render the problem amenable to numerical treatment, the infinite degrees of freedom of the system are discretized or replaced by a finite number of unknown parameters, as indeed is the practice in other processes of approximation. The concept of 'finite elements' replaces the continuum by a number of sub-domains (or elements) whose behavior is modeled adequately by a limited number of degrees of freedom and which are assembled by processes well known in the analysis of discrete systems. Hence this method can be defined as any approximation process in which:-

(a) The behavior of the whole system is approximated by a finite number n of parameters a_j , i = 1 to n . These parameters are described by "n" number of equations.

(b) The "n" equations governing the behavior of the whole system

$$F_j\,(a_i) = 0 \qquad j = 1 \text{ to } n$$

can be assembled by the simple process of addition of terms contributed from all sub-domains (or elements). These elements divide the system into physically identifiable entities (without overlap or exclusion). Then

$$F_j = \Sigma\, F^e_j$$

Where F^e_j is the element contribution to the quantity under consideration. This method combines the best of the features found in the earlier used methods like the variational method, Rayleigh Ritz method, and so forth. The implementation of this method involves steps in the following chronological order:-

2.3.1 Discretization of the continuum

The electromagnetic field is described as a continuum of numerous points. The field variable is projected as having been endowed with infinite degrees of freedom, as it can be expressed as a function of different coordinates of each point in the solution domain. The finite element method aims to approximate this field to finite degrees of freedom. By thus transforming this problem into finiteness, the finite element method thus divides the solution region into known number of non-overlapping sub-regions or elements. Thereafter, nodes are assigned to different elements.

2.3.2 Selecting approximating or interpolation function

Within each element, an approximation for the variation of potential is sought which is described by an interpolation function. This function inter-relates the potential distribution in various elements such that the potential is continuous across inter-element boundaries. Now, the field variable may take any one of the form from vector, scalar or a tensor. Depending on its form, the corresponding variation of the potential is approximated and hence the choices of a particular interpolation function. More often, polynomial functions are used as interpolation function for the ease of their differentiability as well as integrability. The potential, in general, is non-zero within an element and zero outside its periphery. The element shape functions are denoted by α_i and have the following properties:-

$$\alpha_i\,(x_i, y_i) = 1, \quad i = j$$

$$\alpha_i\,(x_i, y_i) = 0, \quad i \neq j$$

2.3.3 Element governing equations

On the completion of the above two steps, equations describing the properties of elements are derived for different elements. These equations are then combined to form the element coefficient matrices. For each element, a typical element coefficient matrix is obtained. This computed value of this matrix when, viewed as a determinant, gives the numerical value of the area of that particular element. The value of the matrix is found to be positive if the nodes are numbered counterclockwise (starting from any node).

2.3.4 Assembling all elements

Having derived matrix for individual elements, the next step is to assemble all such elements in the solution region. The basic idea behind this is to obtain the overall or global coefficient matrix, which is the amalgam of individual coefficient matrices.

2.3.5 Imposition of boundary constraints

Before going for the solution of the global coefficient matrix, it is mandatory to impose certain boundary constraints. Keeping this in view, these matrices are modified accordingly. For obtaining a unique solution of the problem, two possibilities can be examined:-

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(1) In some cases, a value of potential is assigned across a line. If the specified potential is same everywhere, equi-potential conditions are said to be specified. When the potential is set to zero, this condition is termed as dirichlet homogeneous condition.

(2) In others, a value of the normal derivative of the potential is specified. When this value is set to be zero, this is known as Neumann homogeneous condition.

The matrix equations so obtained after accounting for the boundary constraints, are then solved, using a suitable procedure. The task behind obtaining the solution of the equations is to compute the value of field variable at the nodes. That is to find the variation of the field variable within each node.

2.3.6 Error Analysis

The results obtained above are compared with standard results in order to obtain extent of conformity with the desired ones. The desired or standard results are acquired from the empirical formulas. Thereafter, the error analysis is carried out. In case, the error is found to be exceeding the required tolerance limits, the results obtained from the equations are again channeled through the iterative procedure. At this juncture, the power of this numerical approach can be realized. Iterative techniques tend to refine the results, every time a process does not conform to the desired level of accuracy.

3. **New proposed scheme (STRESS MODELING OF CUTTING TOOL)**

3.1 CUTTING FORCES ACTING IN TURNING

The cutting forces vary with the tool angles, feed and cutting speed. Knowledge about the forces acting on the cutting tool may help in the manufacturing of machine tool to estimate the power requirement.

The forces components in the lathe turning can be measured in three directions, as shown in Fig 3.1. The component of the force acting on the rake face of the tool, normal to cutting edge, in the direction OY is called the cutting force Fc. This is usually the largest force component, and acts in the direction of cutting velocity. The force component acting on the tool in the direction OX, parallel with the direction of feed, is referred to as the feed force, F_f . The third component, acting in OZ direction, pushes the cutting tool away from the work in the radial direction. This is the smallest of the force components.

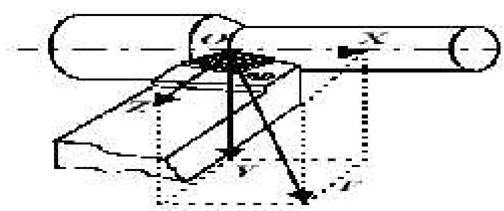

Fig. 3.1 Forces acting on tool

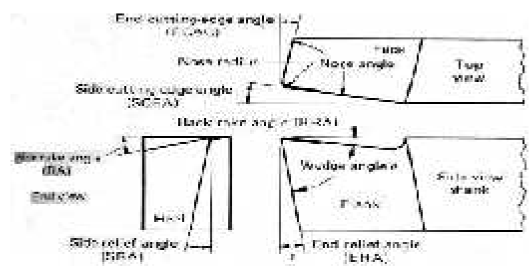

Fig. 3.2 (Tool geometry)

3.2 VARIOUS ANGLES IN TOOL GEOMETRY

Back Rake Angle

It is the angle between the face of the tool and a line parallel to the base of the tool and measured in a plane (perpendicular) through the side cutting edge. This angle is positive, if the side cutting slops downward from a point towards the shank and is negative if the slope of side cutting edge is reverse. So this angle gives the slops of the face of the tool from the nose towards the shank.

Side Rake Angle

It is the angle between the side cutting edge and a line parallel to the top surface of the tool when viewed from side.

End Relief Angle

It is the angle between the flank and the line perpendicular to the shank when viewed from the front.

Side Relief Angle

It is the angle between the line perpendicular to the shank and the surface formed by side cutting edge and end cutting edge if viewed from side.

3.3 APPROACH OF THE ANALYSIS:

Cutting Forces are the three dimensional in nature: The present works investigate the effect of different forces on varying tool geometries. It considers the three cases of forces on the tool which are the experimental. It measured by Dynamometer for cutting Aluminium with High Speed Steel. As given in table 3.1

Experimental Cutting Force Data- Table 3.1

Force Conditions	Forces (F_x) in N	Forces (F_y) in N	Forces (F_z) in N
1	20	300	80
2	35	450	105
3	50	500	130

Geometry condition:

Back rake angles of the tool for different cases, are taken as below for cutting Aluminum with High Speed Steel i.e.

Case A: When the Back Rake angle = 7°

Case B: When the Back Rake angle = 9°

Case C: When the Back Rake angle = 11°

Geometrical detail of the single point cutting tool:

Side Rake Angle = 14°

Side Relef Angle = 5°

End Relef Angle = 5°

End Cutting Edge Angle = 20°

Side Cutting Edge Angle = 15°

Corner nose Radius = 1/8 R

Overall length of the tool =120 mm.

Height of the tool = 30 mm.

Width of the tool = 25 mm.

The single point cutting tool geometry is made in CATIA V4R14 as shown in Fig. 4.3(a). It is then imported into *ANSYS* using a GUI command.

3.4 MATERIAL PROPERTIES

Material Properties of single point cutting tool is defined as given in below :-

Single point cutting tool is made up of H.S.S.

Modulus of Elasticity = 250 Gpa

Poisson's Ratio = 0.26

Yield Strength of HSS = 280 Mpa.

3.5 ELEMENT TYPE

The selection of element type in FEM is very important. If the element type is not proper then the results may deviate from the actual values. For rectangular section SOLID 92 becomes the most suitable candidate of element type.

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SOLID92 has a quadratic displacement behavior and is well suited to model irregular meshes & satisfies the patch test condition. (A method of testing finite elements to determine if they perform acceptably under less than ideal conditions) So in present work SOLID92 element type is selected for analysis.

S.No.	Force Conditions	Geometric Conditions	Vonmisses Stress
1.	1	A	0.566 + E6
2.	1	B	0.534 + E6
3.	1	C	0.451 + E6
4.	2	A	0.855 + E6
5.	2	B	0.802 + E6
5.	2	C	0.502 + E6
6.	3	A	0.115 + E8
8.	3	B	0.106 + E8
9.	3	C	0.801 + E6

Table- 3.2 Vonmisses stress for different force and geometric conditions

3.6 STRESS ANALYSIS ON TOOL RAKE FACE RESULTS

The Results of the study are categorized in different force and geometric conditions as given below:

i. Force in X-Direction (F_x) is 20 N, Force in Y–Direction (F_Y) is 300 N and Force in Z-Direction (F_z) is 80 N along with Geometric parameters of back rake angle 7°.

ii. Force in X-Direction (F_x) is 20 N, Force in Y–Direction (F_Y) is 300 N and Force in Z-Direction (F_z) is 80 N along with Geometric parameters of back rake angle 9°.

iii. Force in X-Direction (F_x) is 20 N, Force in Y–Direction (F_Y) is 300 N and Force in Z-Direction (F_z) is 80 N along with Geometric parameters of back rake angle 11°.

iv. Force in X-Direction (F_x) is 35 N, Force in Y–Direction (F_Y) is 450 N and Force in Z-Direction (F_z) is 105 N along with Geometric parameters of back rake angle 7°.

v. Force in X-Direction (F_x) is 35 N, Force in Y–Direction (F_Y) is 450 N and Force in Z-Direction (F_z) is 105 N along with Geometric parameters of back rake angle 9°.

vi. Force in X-Direction (F_x) is 35 N, Force in Y–Direction (F_Y) is 450 N and Force in Z-Direction (F_z) is 105 N along with Geometric parameters of back rake angle 11°

vii. Force in X-Direction (F_x) is 50 N, Force in Y–Direction (F_Y) is 500 N and Force in Z-Direction (F_z) is 130 N along with Geometric parameters of back rake angle 7°

viii. Force in X-Direction (F_x) is 50 N, Force in Y–Direction (F_Y) is 500 N and Force in Z-Direction (F_z) is 130 N along with Geometric parameters of back rake angle 9°

ix. Force in X-Direction (F_x) is 50 N, Force in Y–Direction (F_Y) is 500 N and Force in Z-Direction (F_z) is 130 N along with Geometric parameters of back rake angle 11°

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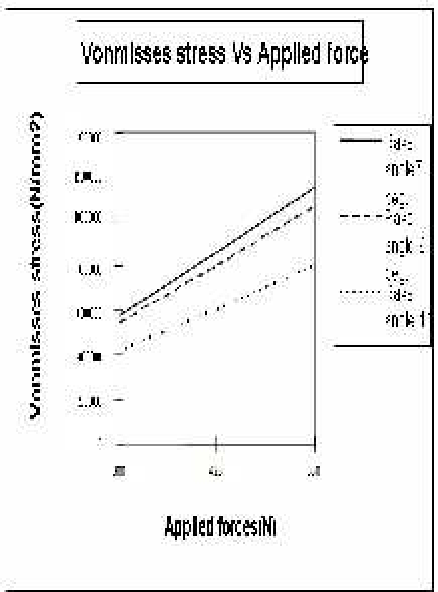

Fig. 3.3 Variations in Vonmisses Stress against resultant force at different rake angles

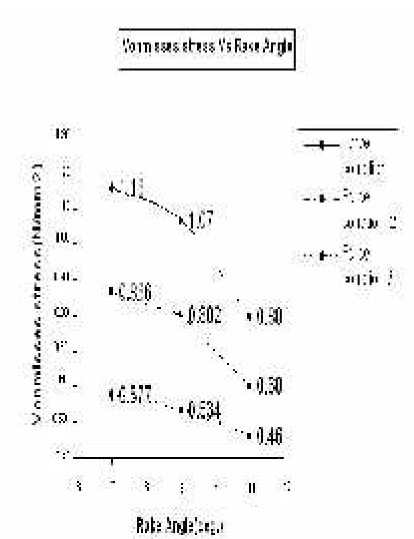

Fig- 3.4 superimposing three charts with Variations of Vonmisses stresses

with 7^0, 9^0 & 11^0 rake angles

4. Conclusion and future scope

The results are generated from various classifications of Force and geometric conditions imposed on the tool and following conclusion are made.

Rake angle specifies the ease with which materials is cut. In practice it is observed that as the rake angle is increased, the tool forces decrease and tool life increases. On further increase it is reported that although tool forces goes on decreasing, tool-life decreases. It is said that on increasing the rake angle, cutting force reduces and so less heat is generated. It is the reason of consequent improvement in tool life. Shear plane region inside the work material stands approximately at an angle of 90^0 to the face of the tool. The length of shear plane is determined by the rake angle. Larger the rake angle lesser will be the length of the shear plane so lesser power is required to shear the materials. However, very large positive rake angled tool have less mechanical strength which reduces tool life.

In this study, we have utilized the explicit dynamic Arbitrary Lagrangian Eulerian method with adaptive meshing capability to develope a FEM simulation model for orthogonal cutting of Aluminium using round edge HSS cutting tool without employing a re-meshing scheme and without using a chip separation criterion. The development of temperature distributions during the cutting process is also captured. Very high and localized temperatures are predicted at tool-chip interface due to a friction model. Predictions of the Vonmisses stress distributions in the chip, in the tool and on the machined surface are effectively carried out. Process induced stress profiles depict that there exist only a tensile stress region beneath the surface. These predictions combined with the temperature field predictions are highly essential to further predict surface integrity and thermo-mechanical deformation related property alteration on the microstructure of the machined surfaces. It is believed that the ALE simulation approach presented in this work, without remeshing and using a chip separation criterion, may result in better predictions for machining induced stresses.

THE FUTURE SCOPE

In the present work although care was taken to predict stress distribution behavior accurately, but there are some scope for improvement in the present work due to the limitations of time and resources available at the researcher's end which can be addressed in future.

4.1.1. For solid model

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The future scope of this analysis can be extended for calculating the force acting on a tool in general metal cutting environment. This analysis can be explored for multi point cutting tools like milling cutters, broach tool etc. It can helps in estimation of tool life & wear of cutting tools. We can calculate heat generation and temperature by calculating the material flow. The generalization of constrained can further help to handle actual problem of industry like the case when tool material is non-homogeneous, non-linear, as well as when the problem state are dynamic & transient.

4.1.2. For single point cutting tool and chip contact

The future scope of single point cutting tool and chip contact analysis can be further extended to 3D analysis of cutting tool and chip contact and also for 3D analysis of multi point cutting tool and chip contact (e.g. milling, Broaching, etc.). The use of re-meshing technique and adaptive meshing technique can increase the accuracy of results. It can be further extend to very complex processes like metal forming, crack propagation in work materials, tool life & simulate tool wear

4.2 VALIDATIONS OF RESULTS

For solid model all those results that had been worked by me in this thesis with the help of ANSYS platform can be practically verified by using dynamometer for measurement of cutting forces. More over the same can be measured through power measurement and calorimetry. The measurement assist in estimating the efficiency of the machine tool, in determining the size of the cutting tool required to resist those encountering forces and for verifying the result

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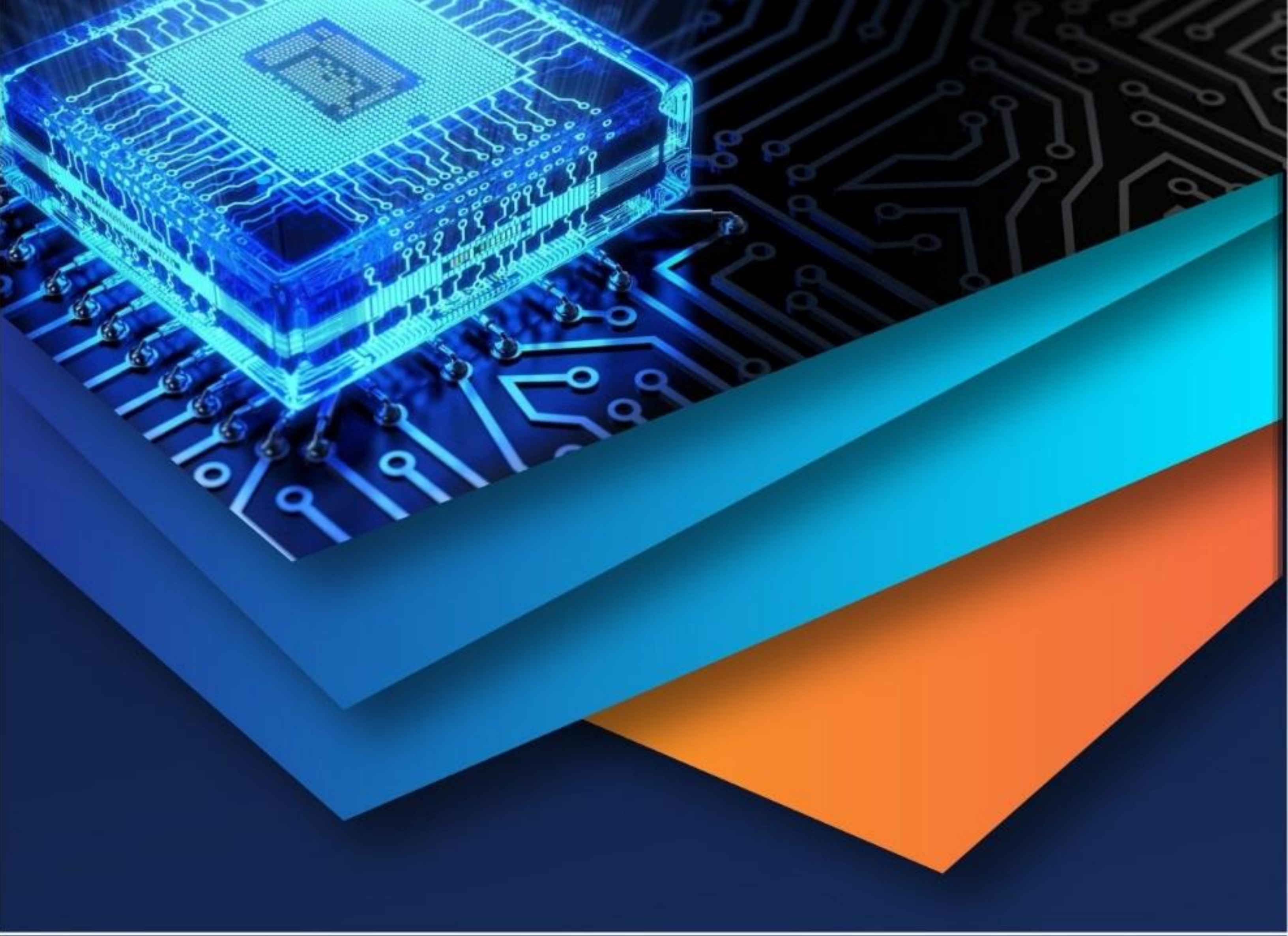

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