International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** I **Month of publication:** January 2018

DOI: http://doi.org/10.22214/ijraset.2018.1032

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 6 Issue I, January 2018- Available at www.ijraset.com

Static and Thermal Analysis of Piston using FEM Analysis

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Abstract: This work describes the static and thermal stress distribution of the combustion engine piston using computer aided design software. Using computer aided design Autodesk Inventor software the solid model of a piston will be created and using SolidWorks the static and thermal analyses are investigated for two variants of a diesel piston, made of different type of materials, Aluminium 6061 Alloy and Gray Cast Iron material.
Keywords: Piston, Static, Thermal Analysis, SolidWorks

I. INTRODUCTION

The piston is the most important part of the engine, which is subjected to the thermal and mechanical stresses. The role of the piston is to guide the movement of the rod while transmitting the gases pressure forces, in order to make the volume variation inside the cylinder (e.g. [1]).
The force of the piston in bolt bearings and thermal expansion deformed the piston casing, in the form of an ellipse. The thermal stress are one of the main causes of the piston failure, in the case of high axis of ellipse is larger than the bore of the cylinder, because there is a danger of the piston blocking in the cylinder.
In specialized literature, the radiation can be simplified by including its contribution through the convection term (e.g. [2], [3]).
The most important heat generation source, in an internal combustion engine, is the gas convection from the combustion. Because the radiation occurs rarely during the combustion of the fuel, the radiation heat contribution is of less importance. The piston surface is exposed to the combustion within the engine cylinder, but the combustion does not occur uniformly across the top. Reference [4] confirm presence of the temperature variations along both the circumferential and radial direction of the piston surface.
A higher temperature than the rest of the piston is registered in the regions where the combustion propagates and therefore, along top surface, the piston will have different heat transfer coefficients (e.g. [5]).
In this study, a solid three-dimensional piston model was analyzed using a finite element analysis module from *SolidWorks.*

II. PISTON DESIGN

The 3D piston model was built, using Autodesk Inventor, according to the specification given in data hand books and machine design. The first step in the modeling of the solid model was the realization of the 2D sketch and imposing the geometric and dimensional constraints. After making the sketch it turns into a solid model. The final model for the piston is as shown in Fig. 1.

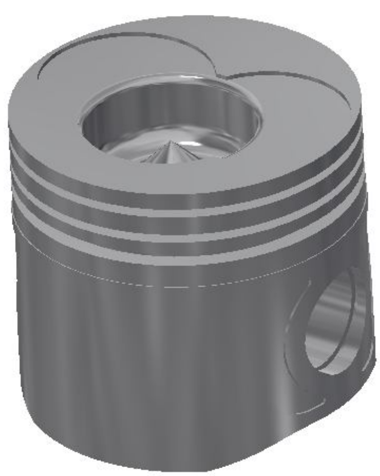

Fig. 1 A geometrical model of the piston

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III.STATIC ANALYSIS

The piston deformation establish the stresses distribution on the piston, therefore the piston crown must have sufficient rigidity to minimize the deformation. A local deformation may occur in the pin bearing, which commonly causes cracks at the top end of the piston head. FEM analysis is used in the scope of determine the maximum local deformation and stress distribution.

FEM analysis is the process of breaking a complex model into smaller parts to obtain a local tension distribution. Using FEM analysis it is possible to predict how the piston will behave in a real engine and allows to see where the stresses and temperatures will be the greatest (e.g. [6]). The current model is subjected to static and thermal analysis. In case of static analysis the maximum pressure load at the top surface of the piston is 6.05 MPa.

The first step is to import the 3D geometric model to FEM, *SolidWorks* software. To simplify the analysis, some parameters such as: the piston taper and the lubrication hole were not taken into account

A. Choosing Material

Knowing that the materials from which the pistons are made have to meet certain stress resistance conditions, an Aluminium Alloy Al 6061 and Cast Iron have been chosen for this study.

The material properties of the Aluminium 6061 Alloy and Gray Cast Iron are presented in Table 1.

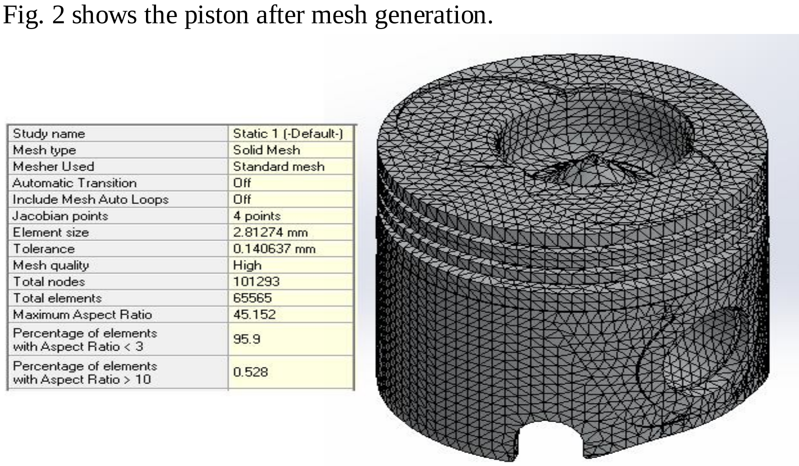
TABLE I

MATERIAL PROPERTIES

Parameters	*Al 6061*	*Gray Cast Iron*
Elastic Modulus	69000 [N/mm^2]	66178.1 [N/mm^2]
Poisson's Ratio	0.33	0.27
Shear Modulus	26000 [N/mm^2]	50000 [N/mm^2]
Mass Density	2700 [kg/m^3]	7200 [kg/m^3]
Tensile Strength	124.084 [N/mm^2]	151.658 [N/mm^2]
Compressive Strength	55.1485 [N/mm^2]	572.165 [N/mm^2]
Thermal Expansion Coefficient	2.4e-005 [/K]	1.2e-005 [/K]
Thermal Conductivity	170 [W/(m·K)]	45 [W/(m·K)]
Specific Heat	1300 [J/(kg·K)]	510 [J/(kg·K)]

B. Generate Meshing

To generate the mesh, the automatic generation mode was used with tetrahedral elements, the solid model being meshed into 65565 elements and 101293 nodes. Fig. 2 shows the piston after mesh generation.



Study name	Static 1 (-Default-)
Mesh type	Solid Mesh
Mesher Used	Standard mesh
Automatic Transition	Off
Include Mesh Auto Loops	Off
Jacobian points	4 points
Element size	2.81274 mm
Tolerance	0.140637 mm
Mesh quality	High
Total nodes	101293
Total elements	65565
Maximum Aspect Ratio	45.152
Percentage of elements with Aspect Ratio < 3	95.9
Percentage of elements with Aspect Ratio > 10	0.528

Fig. 2 Piston meshing with refined setting

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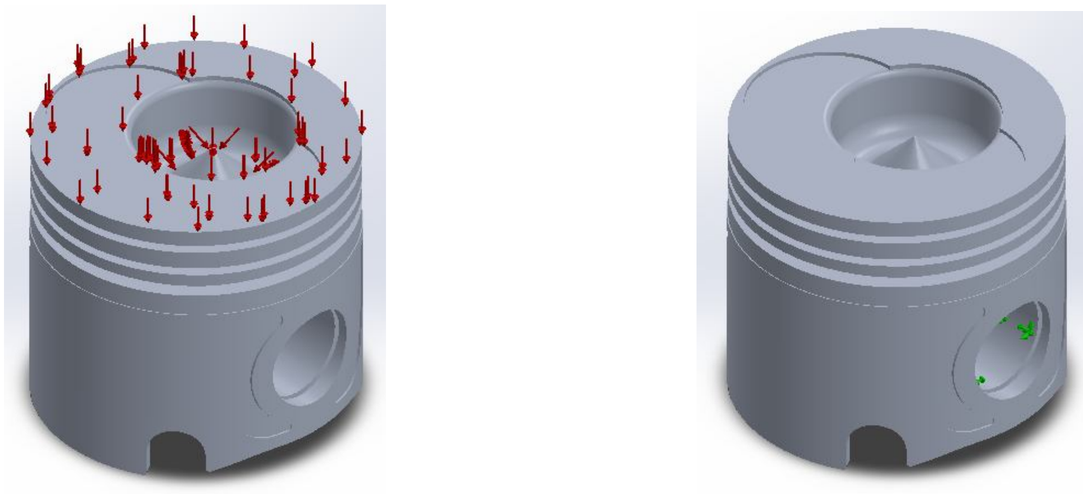
C. The Boundary Condition

The maximum explosion pressure is 6.05 MPa, and it operates uniformly on the piston head, Fig. 3.a. The degrees of freedom of the bolt are suppressed to leave the piston in a static state. Restrictions are imposed on the lower part of the piston to eliminate the rotation of the piston around the bolt, as shown in Fig. 3.b.

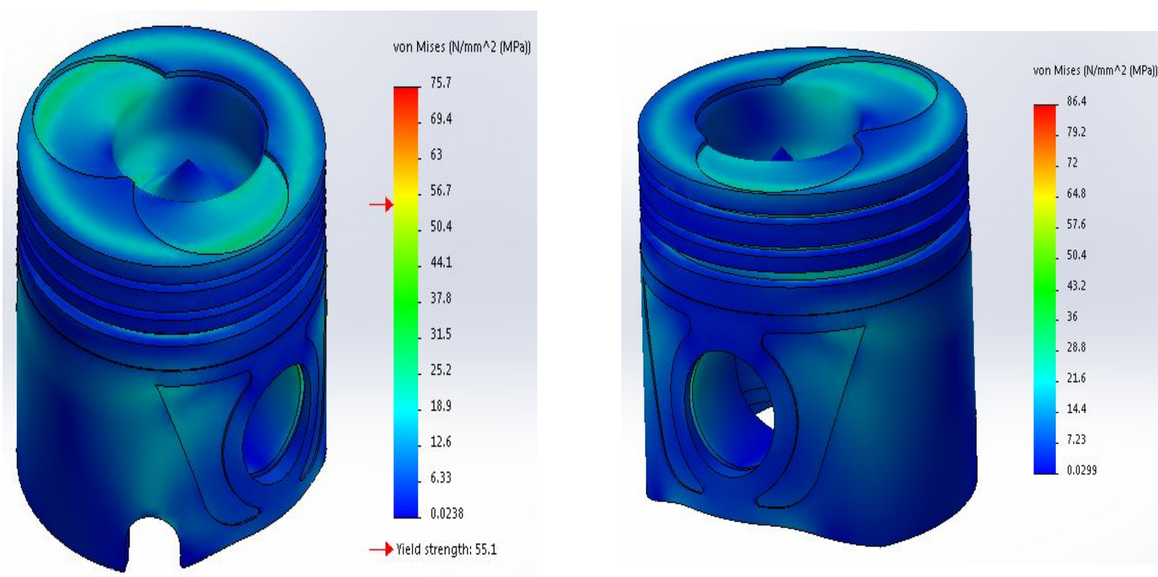


a) b)

Fig. 3 Piston initial condition

D. Static Results

After selecting the material, the imposition of boundary conditions and the meshing of the model proceed to the running of the simulation. The results of the finite element analysis are shown in a report. Fig. 4 presents the results obtained for Von Mises stress,) Aluminium 6061 Alloy and b) Gray Cast Iron. The maximum deformation for engine piston as shown in Fig. 5, a) Aluminium 6061 Alloy and b) Gray Cast Iron.



a) Aluminum 6061 Alloy piston b) Gray Cast Iron piston

Fig. 4 Von Mises stress

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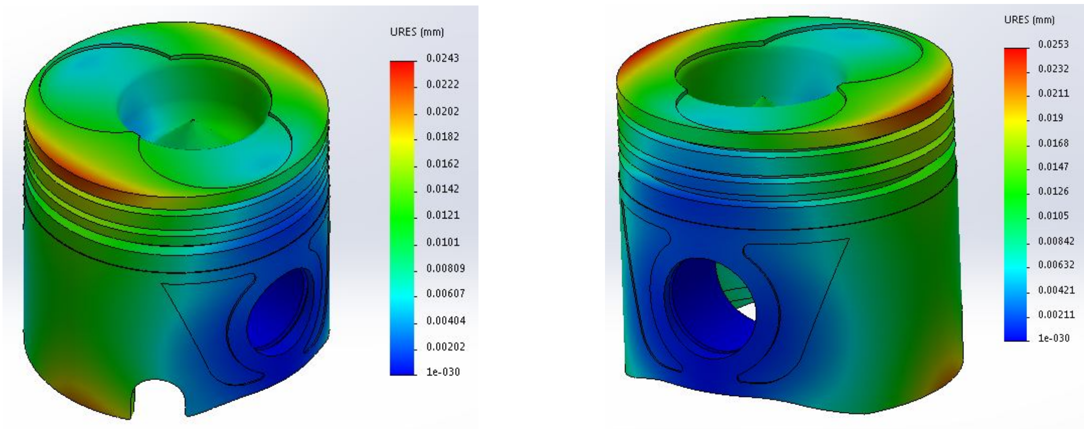
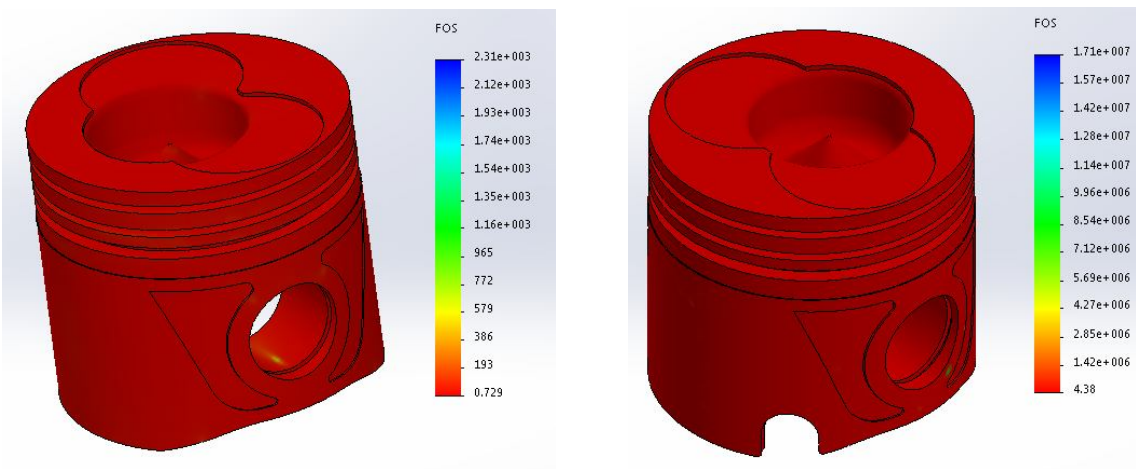


a) *Aluminum 6061 Alloy* piston b) *Gray Cast Iron* piston

Fig. 5 Total deformation



a) *Aluminum 6061 Alloy* piston b) *Gray Cast Iron* piston

Fig. 6 Safety factor

Result of the static analysis of the piston shows that, the maximum Von Mises stress of the piston, which occurs at the piston bearing, is 86.4 MPa for Gray Cast Iron and 75.7 MPa in the case of Aluminium 6061 Alloy model. The maximum deformation for engine piston as shown at the piston top, is 0.0243 mm for Aluminium 6061 Alloy and 0.0253 mm in the case of Gray Cast Iron model. Maximum value for the Safety factor was recorded for Gray Cast Iron model.

IV. THERMAL ANALYSIS

A. Convection and Heat Flux Loads

In order to control the deformations and thermal stresses at acceptable values it is important to determine the piston temperature distribution. Thermal boundary conditions, the convection and the heat fluxes, were identified based on data from (e.g. [4]). The heat transfer within the engine piston follow the Fourier Law, so the thermal analysis to the piston is a stable thermal analysis without internal heat source.

From Fourier's Law (e.g. [7]), result maximum Heat flux of the piston crown:

$$q = -k \cdot \frac{dT}{dx}$$

where:

- q is heat flux;
- k is the heat conduction coefficient of the material;
- dT is temperature gradient;

- *dx* is thickness of the top land of the piston.

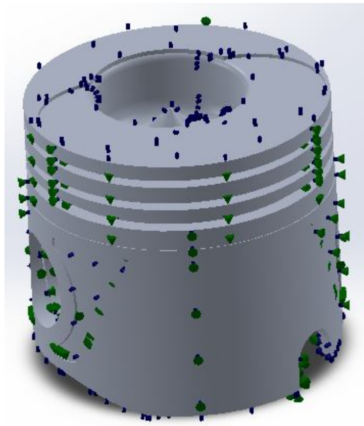


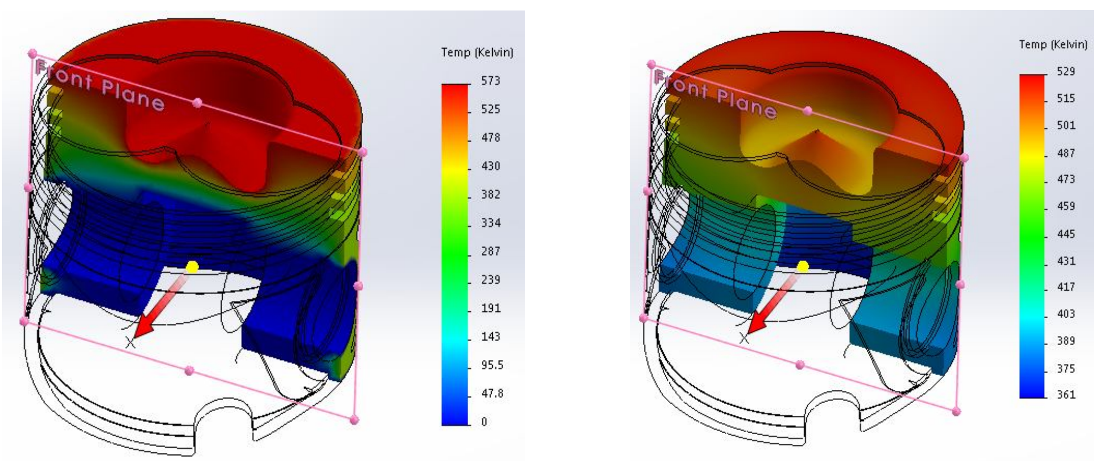
Fig. 7 Piston thermal condition

B. Thermal Analysis Results

Through the FEM analysis, it is confirmed that the main factor influencing the piston performance is the temperature, thus offering basis for the optimization the engine piston model.

After the analysis of temperature distribution the result confirm, as expected, as the minimum temperature is on the piston base and the maximum temperature is on the piston head. The temperature distribution of the *Gray Cast Iron* piston is from 529 K to 361 K, maximum value and Heat Flux is 0.05 W/mm^2 on the piston head.

The FEM analysis results show that steel piston is showing maximum surface temperature than *Aluminium 6061 Alloy* piston for imposed boundary conditions. It is due to lower thermal conductivity of *Gray Cast Iron* material than *Aluminium 6061 Alloy*.



a) *Aluminum 6061 Alloy* piston b) *Gray Cast Iron* piston

Fig. 8 Temperature evolution

V. CONCLUSION

Based on the fundamental of mechanical and thermal analysis, this paper utilizes the FEM software to analyze the stress and deformation condition of the engine piston under the effect of the mechanical load and thermal load and compares two different materials that are used automotive construction.

From the above mechanical and thermal analysis we concluded that maximum temperature on the Aluminium 6061 Alloy piston is 573 K and minimum Von Mises stress is 75.7 MPa. Also the minimum value of deformation is registered in the case of Aluminium 6061 Alloy piston, 0.0243 mm.

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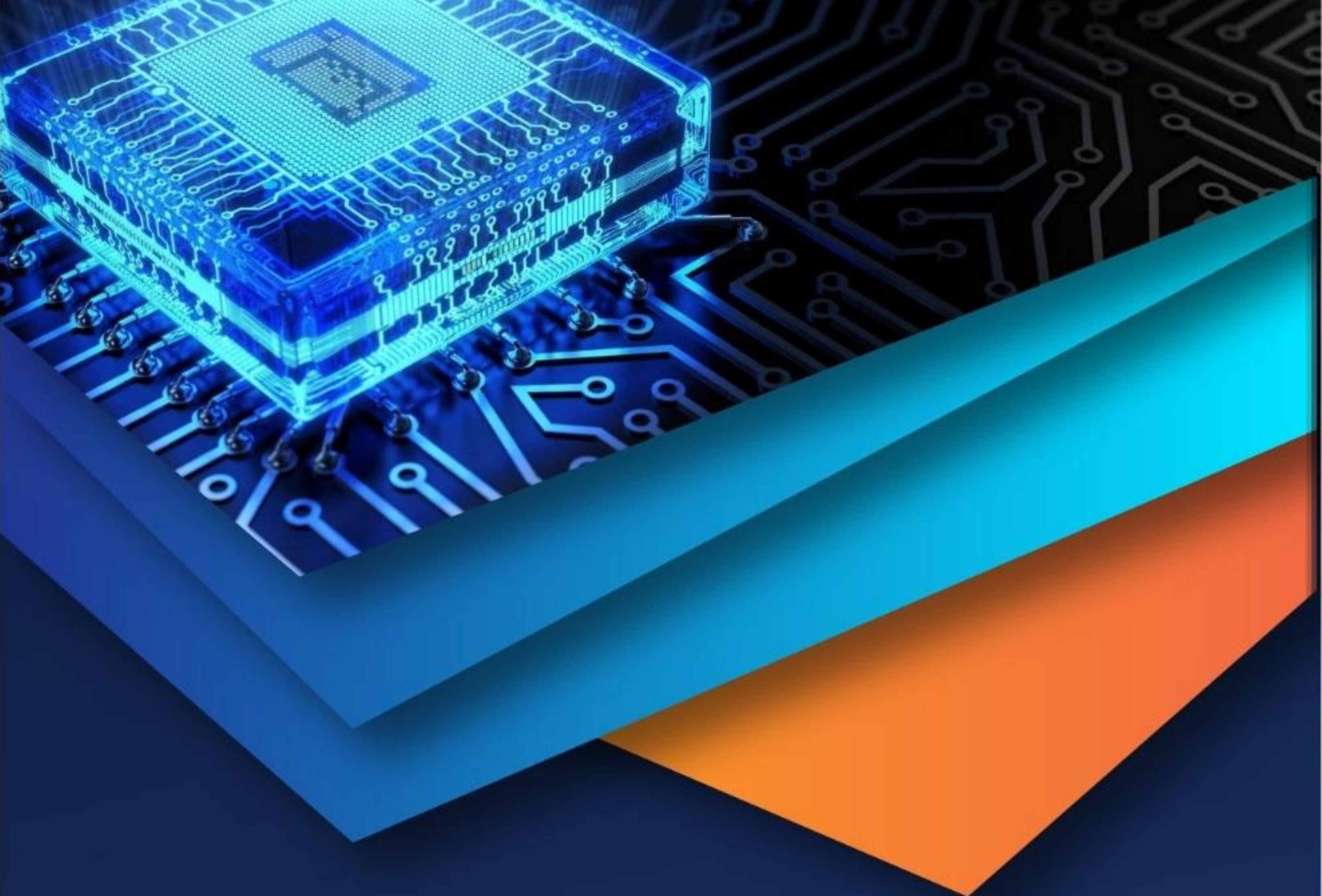

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