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Analysis of Ventilated Brake Disk using FEM

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Abstract: This paper presents the fatigue and thermal analysis for different types of brake discs using the finite element method. The solid model and thermal analyses of ventilated disc brakes was performed using SolidWorks Computer Assisted Design software and for the fatigue analyses it was used specialized software for finite element analysis Autodesk Simulation Mechanical. Was investigated three materials Cast Iron, which is the common used material, AISI 316 Steel and Aluminium 1060 Alloy.

Keywords: Disc brakes, Thermal analysis, Fatigue, SolidWorks

I. INTRODUCTION

In the automotive industry, many components are subjected to thermal and mechanical stress simultaneously. Disc brakes were invented in 1902 in England, but were used as the current Citroen in 1954 on the DS. Factory machines have several kinds of brake discs. The most common model is wheel ventilated disc brake, which is actually a double disc with a small space between two discs, where the air can circulate. The heat is taken up by the air and are cooled more easily ventilated brake.

Thermo mechanical stresses can cause deformations and damage, for example, a brake friction disc generates heat, which may cause deformation and vibration. Hwang P. and Wu X. [1] investigated in the temperature and thermal stress ventilated brake disc during braking unique technique based on the study of multi-thermo-mechanical coupling body and the 3D model. Lakkam S. et al. [2] studied the heat dissipation characteristics of the different types of brake discs during their operation.

Wang G. and Fu R. [3] using ABAQUS software, determined the relationship between a brake pad and the temperatures and thermal stresses on the surface of the brake disc. Sowjanya K. and Suresh S. [4] treated a static structural analysis of the brake disc using ANSYS, where several composite materials were selected to compare the results obtained, such as deformation, normal stresses and Von-Mises stresses. Thilak V. M. M. [5], in a test, investigated the transient thermo-elastic behavior of disc brakes on repeated braking, in which the different results were compared, while the materials used for the rotor were composed of cast iron, aluminium-based matrix composite and composites of high-strength fiberglass.

Tehrani P. H. and Talebi M. [6] performed an analysis of the thermal stress on two models of ventilated disc brake, one of which is made of composite material and the other of steel alloy. A 3D finite element model and ABAQUS software were used in this study.

Nathi G. M. et al. [7] developed a transient thermal analysis using ANSYS software to investigate disk temperature variation, with static analysis coupled with thermal analysis to predict the effect of stiffness and stress fields and deformations in brake disc rotor design. Youfu H. et al. [8], used a nonlinear method of analysis to study the variation of disc brake temperature under speed conditions during the braking process. Abdullah M. et al. [9], used the finite element method to study the contact pressure and stress field during the period of full clutch coupling using different contact algorithms. In addition, they analyzed the contact pressure to show the importance of the rigidity of the contact between the surfaces.

Gnanesh P. et al. [10] investigated the thermal-structural analysis of the normal disc brake rotor and ventilated using ANSYS software 13.0 in the case of the holes and no holes in the rotor. Das D. et al. [11] using ANSYS software have studied the distribution of stresses and thermal properties of the hard disk during short braking and emergency four different materials. The temperature distribution depends on various factors, such as friction, surface roughness and outer speed. The angular velocity and contact pressure induced temperature rise of the rotor. The temperature, the force of frictional contact, the movement of the nodal and deflection for different pressure conditions have been taken into account in their study, using the analysis software with four materials: cast iron, cast steel, aluminium and carbon fiber. The analysis of thermo mechanical led to the evaluation of the temperature and the deformations of the total of the braking disc, the structural behavior and contact of the disc and pad during the braking phase, with or without the influence of thermal effects, the results of the analyses are useful in the design of the brakes automotive. The most common brake disc model is the ventilated disc, which is actually a double disc with a small space between the two discs where the air can circulate. The heat is taken up by the air and the ventilated brakes cool down more easily. Currently almost all cars have ventilated brake discs on the front axle. Ventilated brake discs may be simple, perforated, ribbed, or combinations of these variants. The ventilated and perforated ones ensure good cooling of the entire braking system. With the perforated discs appeared, a better gas outlet between the plate and the full disk was made.

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The disc brakes striated have grooved channels on their surface for gas evacuation and for collecting the residues resulting from friction between pads and discs that effectively reduce braking, because they act as small ball bearings between the pads and the disc. Regarding the disadvantages of these brake discs, we can mention much faster wear of the plates, precisely because there is a greater friction with the disc.

The paper presents an analysis of different types of ventilated brake discs made of AISI 316 Steel, Cast Iron and Aluminium 1060. With the help of the finite element analysis, a prediction of the behavior of the brake discs can be made and will determine the location of the highest stresses and temperatures.

II. BRAKE DISCS DESIGN

Ventilated brake discs can have different types of vanes: straight, curved, tangential and pillars [12, 13]. In this paper three types of ventilated discs were taken into consideration: ventilated discs with curved vanes (long and short), ventilated discs with straight vanes (long and short), and drilled ventilated brake discs. Solid modeling of ventilated brake discs was done using SolidWorks software with the literature data. For comparison, the same dimensions of the disc were chosen:

A. Outer disc radius r_e = 119 [mm];
B. Inner disc radius r_i = 82.5 [mm].

The solid models of the discs are shown in Fig. 1.

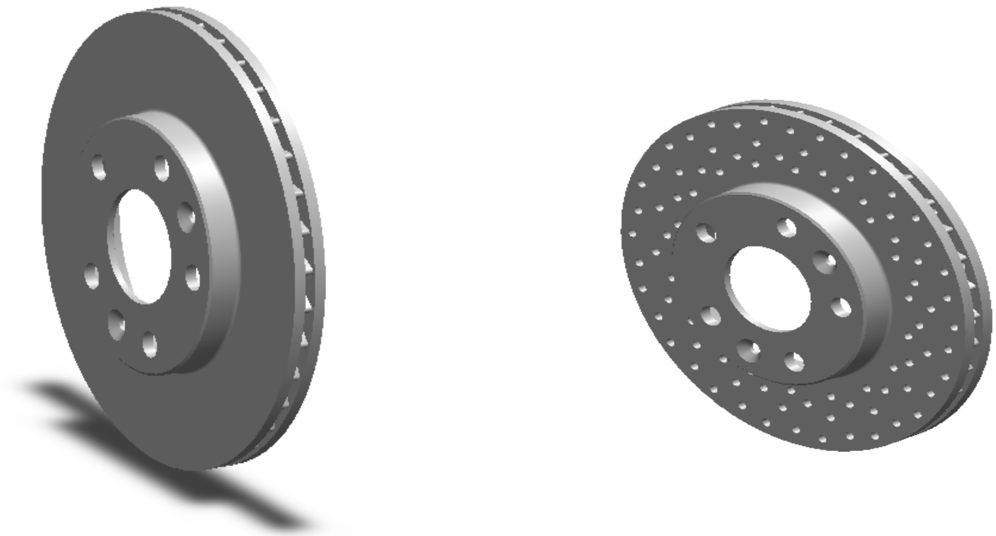

Fig. 1 A Geometrical model of the ventilated brake discs

III. THERMAL ANALYSIS

In order to determine the thermal stresses, it is important to determine the temperature distribution in the brake discs, the thermal conditions imposed, the convection and the heat flows have been identified based on specialty literature.

When braking is stopped, it is assumed that all the heat produced is taken over by the brake disk. If a constant braking deceleration is considered, the density of the heat flow has decreased linearly with the speed. By neglecting the air resistance and rolling resistance, it is possible to calculate the density of the heat flow with the relationship:

$$q_d = \frac{V_a}{1537} \cdot \frac{1}{A_g} \cdot \left(R_p - R_r - R_a\right) \tag{1}$$

where:
R_r, R_p, R_a – car resistances (running, slope, air);
A_g – the area of friction seals;
v_a – speed of travel.

A. Choosing Material

Knowing that the materials from which the brake discs are made have to meet certain stress resistance conditions AISI 316 Steel, Cast Iron and Aluminium 1060 Alloy have been chosen for this study. The material properties are presented in Table I.

Table I
Material Properties

Parameters	*Cast Iron*	*AISI 316 Steel*	*Aluminium 1060 Alloy*
Elastic Modulus	66178.1 [N/mm^2]	192999.9 [N/mm^2]	69000 [N/mm^2]
Poisson's Ratio	0.27	0.27	0.33
Shear Modulus	50000 [N/mm^2]		27000 [N/mm^2]
Mass Density	7200 [kg/m^3]	8000 [kg/m^3]	2700 [kg/m^3]
Tensile Strength	151.658 [N/mm^2]	580 [N/mm^2]	68.9356 [N/mm^2]
Compressive Strength	572.165 [N/mm^2]		
Thermal Expansion Coefficient	1.2e-005 [/K]	1.6e-005 [/K]	2.4e-005 [/K]
Thermal Conductivity	45 [W/(m·K)]	16.3 [W/(m·K)]	200 [W/(m·K)]
Specific Heat	510 [J/(kg·K)]	500 [J/(kg·K)]	900 [J/(kg·K)]

B. Generate Meshing

To generate the mesh, the automatic generation mode was used with tetrahedral elements, the solid model of the brake disc being meshed into 13862 elements and 26101 nodes. Fig. 2 shows the brake disc made of Gray Cast Iron after mesh generation.

Fig. 2 The brake disc meshing

C. The Boundary Condition

The first step in imposing thermal stresses, is to establish a thermal transfer. The Convection command is accessed from the Thermal Loads menu. After opening the dialog box, the value of the convection coefficient, chosen from the specified literature, is specified, Fig.3. The coefficient of thermal conductivity for the studied materials is shown in Table II.

TABLE III
Coefficient of Thermal Conductivity

Parameters	Convection Coefficient [W / m·K]	Bulk Ambient Temperature [K]
Gray Cast Iron	49	373
AISI 316 Steel	45	291
Aluminium 1060 Alloy	207	373

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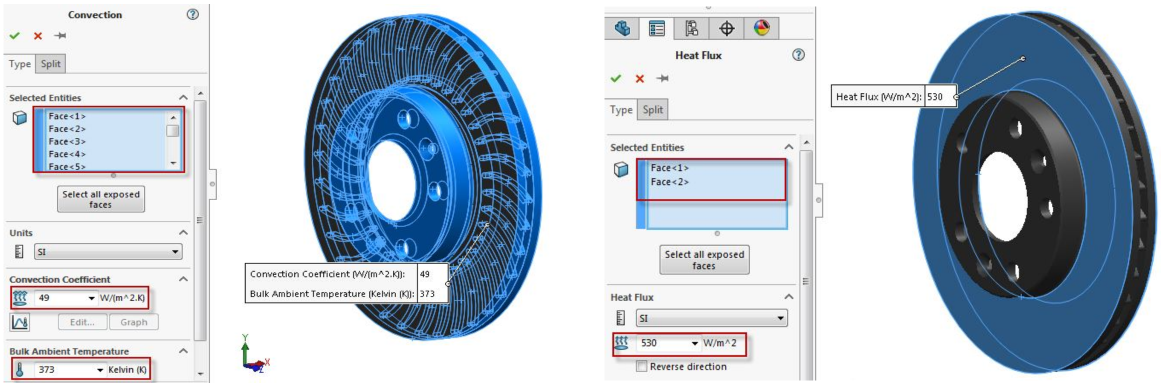


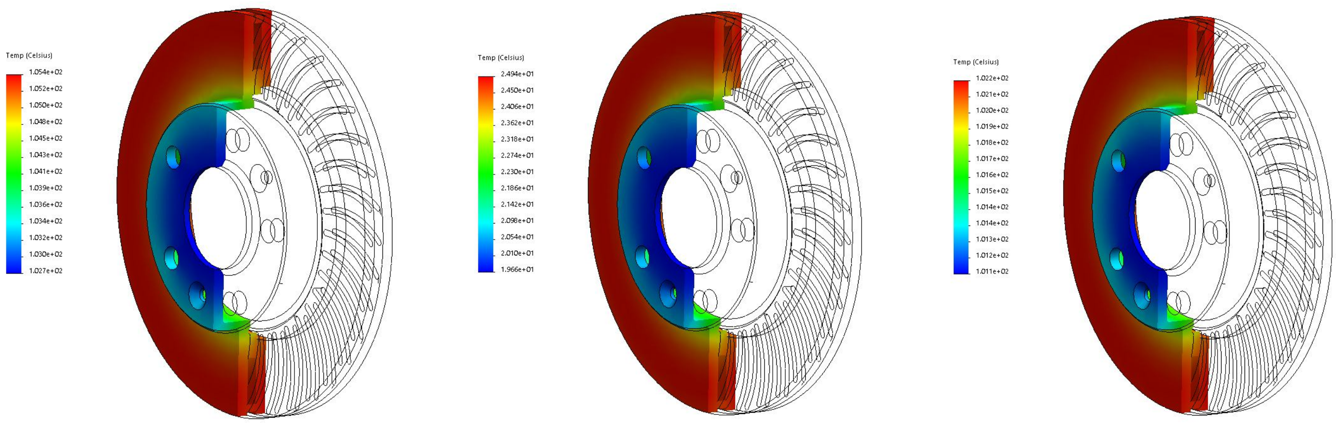
a) b)

Fig. 3 The brake disc initial condition

The second step in imposing thermal stresses is to determine the heat transfer rate by defining the heat flow value q_d, rel. 1. The Heat Flux command from the Thermal Loads menu is accessed. After opening the dialog, the heat flow values for each surface will be imposed, Fig.3. Is proceeded analogously with other models.

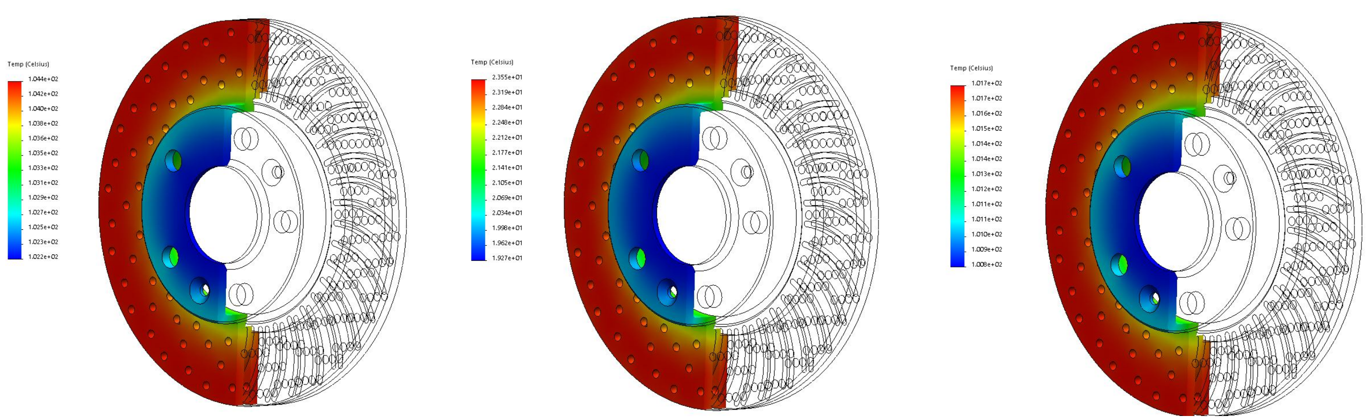
D. Thermal Analysis Results

Figure 4, 5 presents the results of the thermal analysis for the studied variants. The FEM analysis confirms that the main factor influencing the performance of the brake disc is temperature, thus providing a basis for future optimization.



a) Gray Cast Iron LC b) AISI 316 Steel LC c) Aluminium 1060 LC

Fig. 4 Temperature evolution of ventilated brake discs with long curved vanes



a) Gray Cast Iron DLC b) AISI 316 Steel DLC c) Aluminium 1060 DLC

Fig. 5 Temperature evolution of drilled ventilated brake discs

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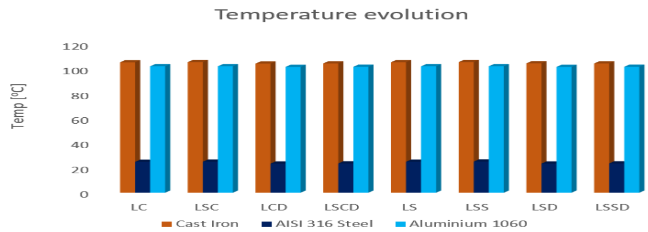


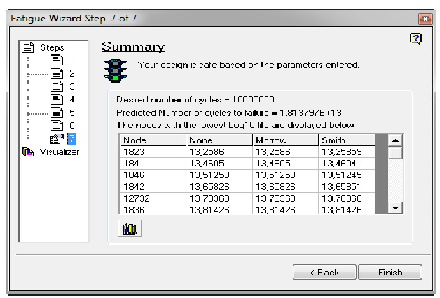
Fig. 6 Temperature evolution of all ventilated brake discs

The thermal analysis results for all the studied models are presented in figure 6. Notations have the following meaning: LC – ventilated disc with long curved vanes; LSC - ventilated disc with long and short curved vanes; LCD - ventilated disc with long curved vanes and drilled; LSCD - ventilated disc with long and short curved vanes and drilled; LS - ventilated disc with long straight vanes; LSS - ventilated disc with long and short straight vanes; LSD - ventilated disc with long straight vanes and drilled; LSSD - ventilated disc with long and short straight vanes and drilled. It can be seen that the most important factor in thermal analysis is the material, the geometry of the ribs having a secondary role.

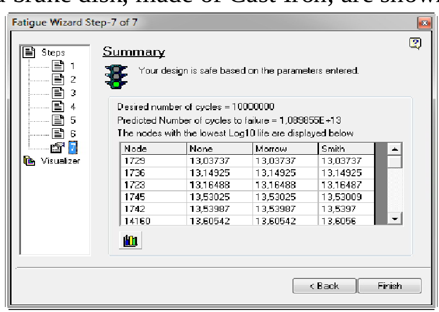
IV. FATIGUE ANALYSIS

The fatigue is a process that involves several stages of deterioration. At each stage, there are various mechanisms of damage accumulation, following more or less known laws. Researches on fatigue degradation [14, 15] have shown links between the different mechanical properties of the material, such as: flow limit, tensile strength, toughness and the fatigue life. Current methods of fatigue design for components and structures have evolved based on the application of new calculation methods correlated with the experimental determinations results. Before running the simulation loads have been defined so that they match as much as possible with real conditions. In this case the simulation was performed using the same border conditions as the thermal analysis, imposing the maximum number of cycles, (10000000 cycles), required by the software. Because fatigue simulation analysis requires the choice of a coefficient based on the degree of part surface machining, was chosen machined for surface processing.

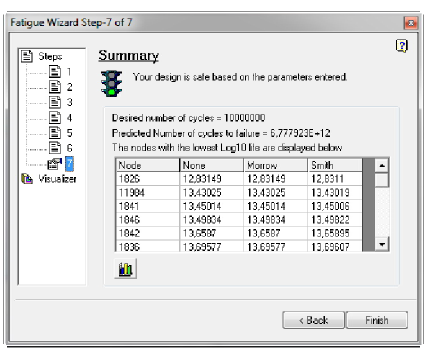
The fatigue simulation results for the four variants of the ventilated brake disk, made of Cast Iron, are shown in Figure 7.



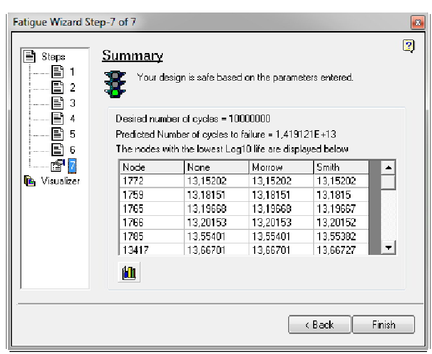
a) Cast Iron LS



b) Cast Iron LSS



c) *Cast Iron LC*



d) *Cast Iron LSC*

Fig. 7 Fatigue analysis results of ventilated brake discs

From the comparative analysis of the results obtained for all variants it can be noticed that the highest resistance to fatigue was obtained for ventilated disc with long straight vanes, and the smallest fatigue resistance for ventilated disc with long curved vanes.

V. CONCLUSION

Based on the basics of thermal analysis, this paper uses SolidWorks software for finite element analysis of three types of brake discs made of gray cast iron, AISI 316 Steel and Aluminium 1060 Alloy.

After the thermal analysis it was concluded that the maximum temperature recorded is for the ventilated discs with straight or circular ribs, the minimum temperature, as expected for the ventilated disc that has perforations.

For all three variants studied, the maximum temperature was below the maximum allowed 300 °C for the brake discs.

The study finds that the temperature difference is small for the studied cases and does not justify additional costs for the perforated discs and the premature wear of the brake pads.

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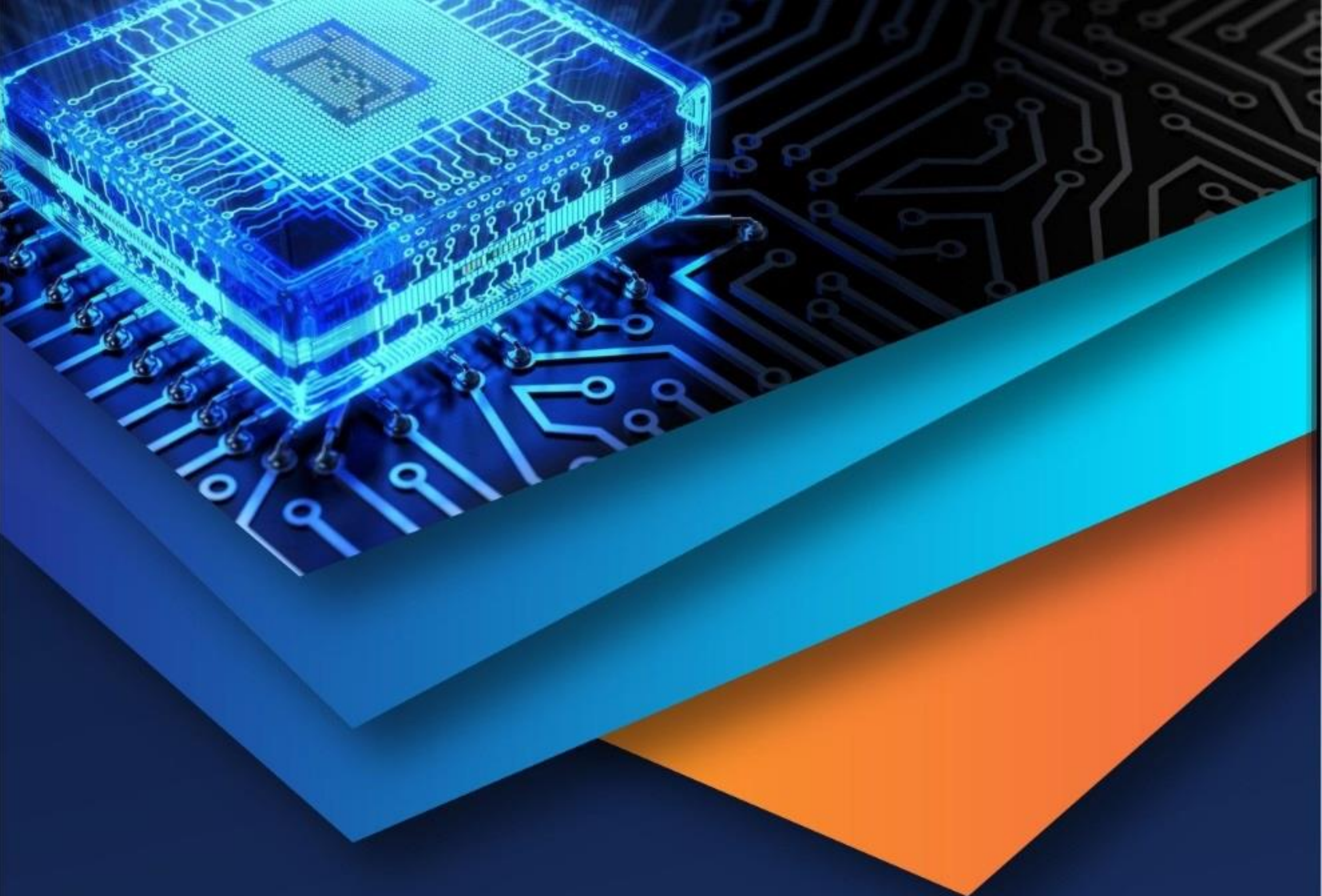

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