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# Modeling and Analysis of Functionally Graded Material for Disc Plate under Mechanical Loads

R. Vishnu Vardhan Reddy[1], K. Pavan Kumar Reddy[2], B. Yeswanthkumar Reddy[3]
*[1, 2, 3]JNTUA College of Engineering Pulivendula, Pulivendula, Kadapa, Andhra Pradesh, India*

***Abstract: The most crucial components of an automobile are the brakes. The wheel's rotation can be controlled and stopped by using the brakes. Today's cars employ a variety of brakes, with disc brakes being one of the most common. Brake pads are used in disc brakes to exert force against the disc's two sides mechanically, hydraulically, pneumatically, or electromagnetically. The attached wheel and disc come to a stop due to friction. Brakes turn friction into heat; if the temperature rises too high, they tend to stop working because they are unable to remove enough heat from the system. Brake fading is the name of this failure state. During normal braking and under extreme thermal stress during hard braking, disc brakes are exposed to significant thermal strains. Mild steel is typically used for disc brakes, which are attached to the wheel. In this work, functionally graded spinning annular discs exposed to internal pressure and varied temperature distributions underwent an analytical investigation. Considered are two disc brake models: one without holes and one with holes. Different materials for disc brakes will be compared; the materials are mild steel and aluminium alloy 6061 with regard to functional graded materials. The two models with different material compositions are subjected to structural and thermal examination. In CATIA V5 R20, a disc brake model is made, and in ANSYS 14.5, analysis is carried out.***
***Keywords: DISC PLATE, FGM, STRUCTURAL, THERMAL ANALISIS.***

## I. INTRODUCTION

A brake is an obstruction to motion. A clutch is its opposing part. The remainder of this page focuses on several kinds of vehicle brakes. Although different techniques of energy conversion may be used, friction is the most frequent method used by brakes to convert kinetic energy into heat. For instance, a regenerative braking system transforms a significant portion of its energy into electrical energy, which can then be stored for use at a later time. Other processes transform kinetic energy into stored forms of potential energy, like pressured oil or air. Other braking techniques even change the form of the kinetic energy, for instance, by transferring it to a revolving flywheel [1-5]. Automobile friction brakes temporarily store braking heat in the drum or disc brake during braking before gradually transferring it to the air. Some cars have the ability to brake using their engines when going downhill [6-7]. When the brake pedal is depressed, the piston of the calliper forces the brake pad in the direction of the braking disc, slowing the wheel. Similar effects occur on the brake drum because the cylinder forces the brake shoes in the direction of the drum, slowing the wheel in the process [8].

## II. PROBLEM STATEMENT

Brake systems are currently widely employed in automotive applications. The disc brake's ability to operate precisely is its primary benefit. Continuous braking will reduce the brake system's effectiveness. When brakes are utilised, they often become heated, and if the working temperature is too high, the life of the brakes is reduced. Racing automobiles have higher disc brake temperatures than standard cars since they are travelling at higher speeds. When traditional materials are utilised as disc brakes, the life of the brakes is shortened due to the high temperature along the disc brakes. Numerous investigations are being conducted to replace the current brake material with modern composites and ceramics in order to extend the lifespan of the brakes. Ceramics and composites, however, are highly expensive. Functionally graded materials can be used in place of ceramics and composites individually [9].

A new type of advanced composite material called functionally graded material (FGM) modifies the properties in relation to the measurement of structures. A combination of ceramics and metal known as a functionally graded material allows for the simultaneous performance of two different functions. In this method, processing is done layer by layer, with metal as the bottom layer and ceramic as the top layer. From bottom to top, the composition will be more ceramic, and from bottom to top, there will be less metal. Rich metal content is present in the bottom layer, while rich ceramic content is present in the top layer [10-15]. Therefore, functionally graded materials can be considered a new class of sophisticated composite materials. A metal and its alloys, which are renowned for their exceptional strength and toughness, are combined to create FGM.

Ceramic, however, has strong anti-corrosion and thermal properties. These two materials are combined to increase their resistance qualities, which have engineering uses. Each layer's characteristics, which are mixtures of inner and exterior structures, can be incorporated. In the sphere of automobiles, the development of FGM in testing facilities has advanced to new levels. Combinations for essential components are simple in the current structures. In order to calculate precise values for materials as well as gradients and their geometric components, many process methodologies have been developed [16]. Shown in figure 1 represents the component of FGM.

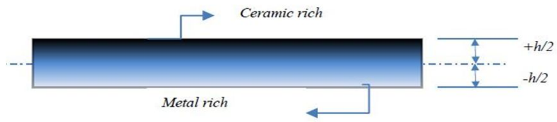


Figure 1: Component of FGM

## III. TECHNIQUES FOR PROCESSING MATERIALS GRADED IN FUNCTIONALITY

The majority of the time, functionally graded materials takes the form of surface coatings. Various surface deposition techniques are available based on the needs of the service.

### A. *Method of Vapour Deposition*

There is several different deposition processes employed, including sputtering, chemical, and physical depositions. On the thin surfaces of this kind of treatment, good microstructural findings are seen. The several types of coating used in FGM include electrophoretic, electron position, and plasma coating. Due of the sluggish and time-consuming methods used in mass manufacturing, the aforementioned process cannot prepare FGM [17–18].

### B. *Metallurgy in Powder*

This is the method that can be used for manufacturing in large quantities. The powder method of trying it is based on the component's sequential design. To perform, these three steps have been taken. The procedure calls for combining the powders of various components. Finally ramming the combined one. Centrifugal Process

This technique is comparable to centrifugal casing, where gravity is a factor. In this instance, the FGM is prepared in a continuous manner, and the final result is based on a cylindrical one. This method of creating gradients has some restrictions. Solid free form is employed to address this issue. [19]

### C. *Method of Solid Freeform (SFF) Fabrication*

This technique makes use of CAD software. The procedure consists of five fundamental steps. Those are making a software model the transformation into an STL file modelling in two dimensions The layer-by-layer method removal and completion shown in figure 3.3. By employing this technique, time can be saved, bulk manufacturing can be improved, less material will be required, and complex pieces can be modeled, among other benefits. The approach is accurately formulated by the laser-based technology. Using this technique, both flexible and rigid pieces can be created. The techniques indicated above are among the finest for preparing for FGM, while there are many others [20–21].

## IV. METHODOLOGY

The modeling and analysis process for a disc plate under mechanical and thermal loads is shown in Figure 3.

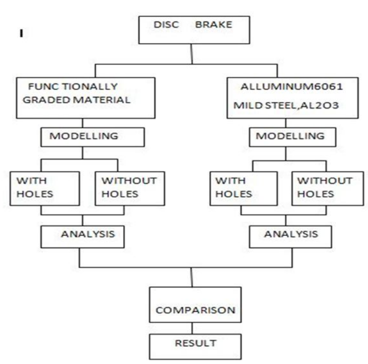


Figure 3. Methodology Flow Chart

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## V. CALCULATIONS

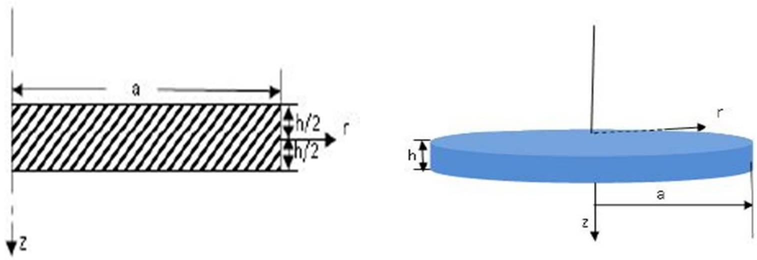


Figure 4: FGM Circular Disc with Height and Radius

### A. *Power Law*

The power-law distribution of a panel considered from the mid-plane reference plane can be written as in equation 1

$$V_{F=} \quad \left[\frac{z}{h} + \frac{1}{2}\right]^{n} \quad \text{-----} \text{ Equation 1}$$

.

Where, n is the power-law index, the variations of volume fraction of the ceramic and metal phase through the non-dimensional thickness. The different values of power-law indices are (n = 2, 3, 4, 5). The functionally graded material with two constituents and their properties such as, Young's modulus E and the mass density ℓ thermal conductivity k and specific heat C have been obtained using the following steps shown in equations 1,2,3, and 4.

$$E= \ (E_c - E_m) + \left[\frac{z}{h} + \frac{1}{2}\right]^{n} + E_m \quad \text{---} \quad \text{Equation 2}$$

$$\ell= \ (\ell_c - \ell_m) + \left[\frac{z}{h} + \frac{1}{2}\right]^{n} + \ell_m \quad \text{--} \quad \text{Equation 3}$$

$$K= \ (K_c - K_m) + \left[\frac{z}{h} + \frac{1}{2}\right]^{n} + K_m \quad \text{---} \quad \text{Equation 4}$$

$$C= \ (C_c - C_m) + \left[\frac{z}{h} + \frac{1}{2}\right]^{n} + C_m \quad \text{--} \quad \text{Equation 5}$$

Power indices (n) = 2

Table 1: FEM Analysis of Disc plate for FGM

| Layers | Youngs Moduls (E) (Mpa) | Density (ℓ) (kg/mm3) | Thermal Conductivity(K) ($W/mm^0k$) | Specific Heat (Cp) ($KJ/g^0c$) |
|---|---|---|---|---|
| Z=1 | 167959.187 | 3.11*10^-6 | 0.12718 | 906.53 |
| Z=2 | 193979.598 | 3.22*10^-6 | 0.11501 | 908.26 |
| Z=3 | 223061.245 | 3.34*10^-6 | 0.10141 | 910.20 |
| Z=4 | 255204.016 | 3.47*10^-6 | 0.08638 | 912.34 |
| Z=5 | 290408.133 | 3.67*10^-6 | 0.06992 | 914.69 |
| Z=6 | 328673.494 | 3.74*10^-6 | 0.05202 | 917.24 |
| Z=7 | 3700000 | 3.96*10^-6 | 0.03230 | 920 |
| Z=-1 | 125102.048 | 2.94*10^-6 | 0.14723 | 903.67 |
| Z=-2 | 108265.361 | 2.87*10^-6 | 0.15510 | 902.55 |
| Z=-3 | 94489.795 | 2.88*10^-6 | 0.16154 | 901.63 |
| Z=-4 | 83775.5102 | 2.75*10^-6 | 0.16655 | 900.91 |
| Z=-5 | 76122.4489 | 2.77*10^-6 | 0.17013 | 900.40 |
| Z=-6 | 71530.6122 | 2.70*10^-6 | 0.17228 | 900.10 |
| Z=-7 | 70000 | 2.7*10^-6 | 0.17300 | 900 |

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## VI. DESIGN OF DISC BRAKE

### A. *Specifications for without Hole*

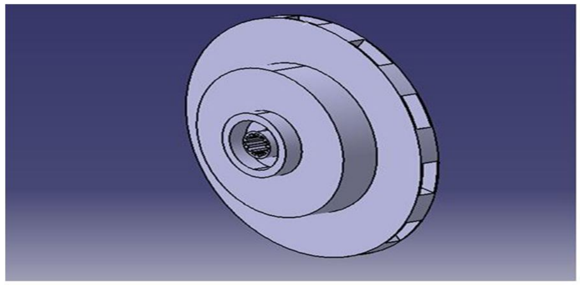


Figure 5: design of the disc brake without hole

### B. *Specifications for with Hole*

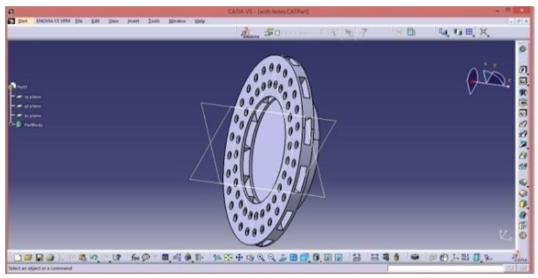
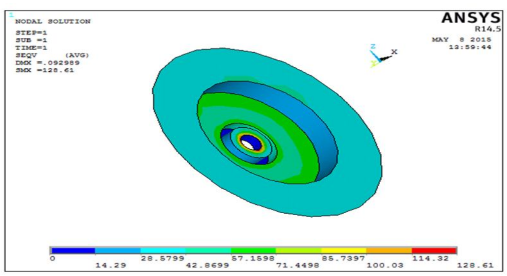


Figure 6: design of the disc brake with hole

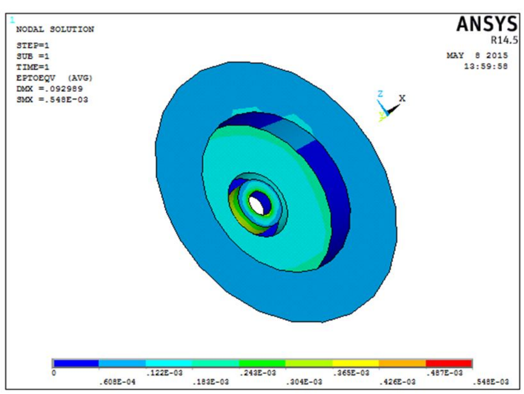
The models are designed using CATIA V5 R20 Software and are shown in figure 5 & 6. Basically the disc brake without hole is considered for stress, strain, displacements values. In order to get better results for disc brake with holes is taken.

### C. *Power indices(n)=2 for without hole*

1) *Stress*




2) *Strain*



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*3) Displacement*

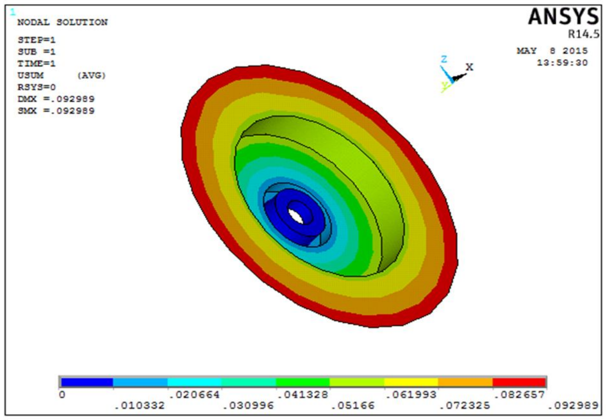
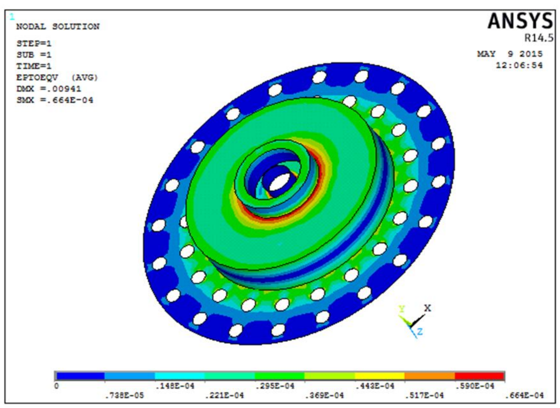



Table 2: Comparison of Disc Plate Analysis (Without Holes)

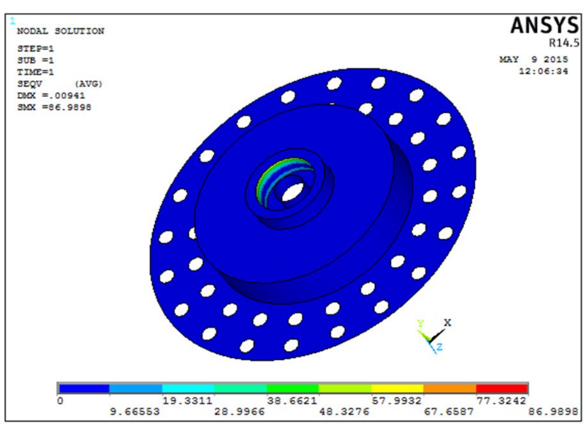
| Material | Stress | Strain | Displacement |
|---|---|---|---|
| MILD STEEL | 175.562 | 0.937E-03 | 0.266683 |
| AL6061 | 140.88 | 0.6021E-03 | 0.258091 |
| FGM | 128.61 | 0.548E-03 | 0.092989 |

*D. Power indices(n)=2 for with holes*

*1) Stress*




*2) Strain*



*3) Displacement*

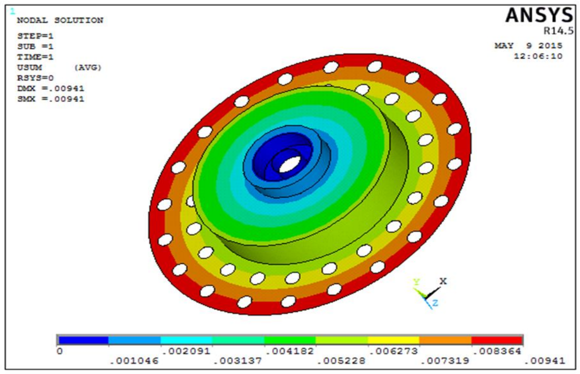
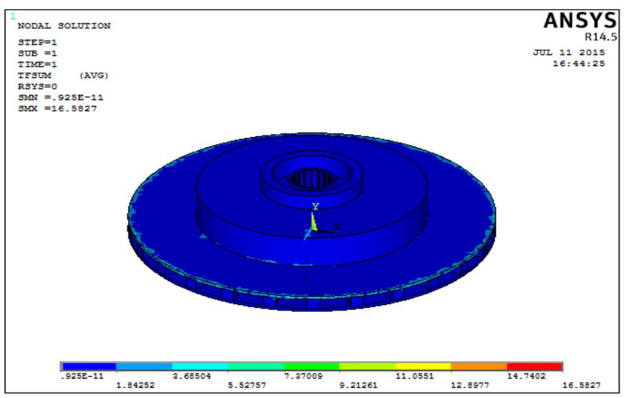



Table 3: Comparison of Disc Plate Analysis (With Holes)

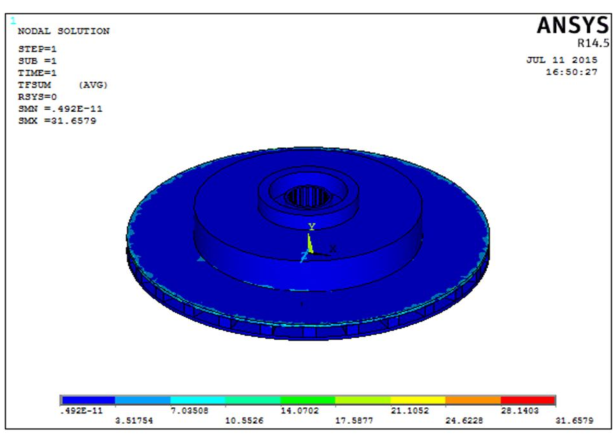
| Material | Stress | Strain | Displacement |
|---|---|---|---|
| MILD STEEL | 167.782 | 0.802E-03 | 0.139919 |
| AL6061 | 110.55 | 0.606E-03 | 0.0701 |
| FGM | 86.9898 | 0.664E-04 | 0.00941 |

*4) Thermal Flux*

*a) At 150$^0$c*




*b) At 2500c*



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*c) At 3500c*

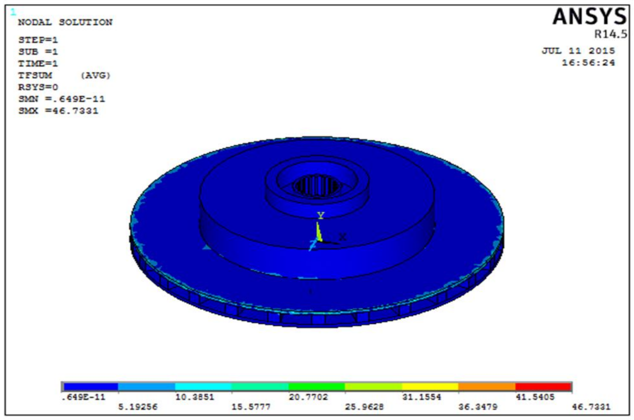
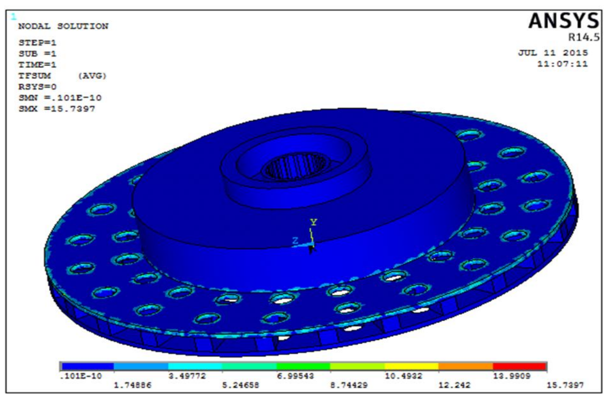
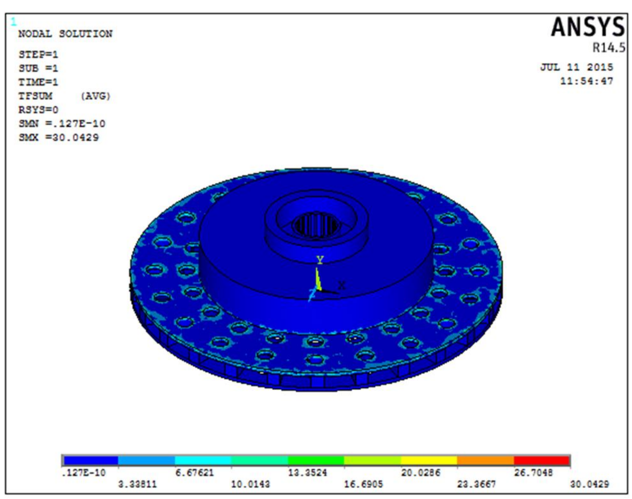



Table 4: Comparison of Disc Plate thermal Analysis (Without Holes)

| Temperature($^0$c) | Mild Steel | Al6061 | FGM |
|---|---|---|---|
| 150$^0$c | 20.394 | 40.308 | 16.582 |
| 250$^0$c | 38.934 | 82.785 | 31.657 |
| 350$^0$c | 57.475 | 113.597 | 46.733 |




*d) At 2500c*



*e) At 3500c*

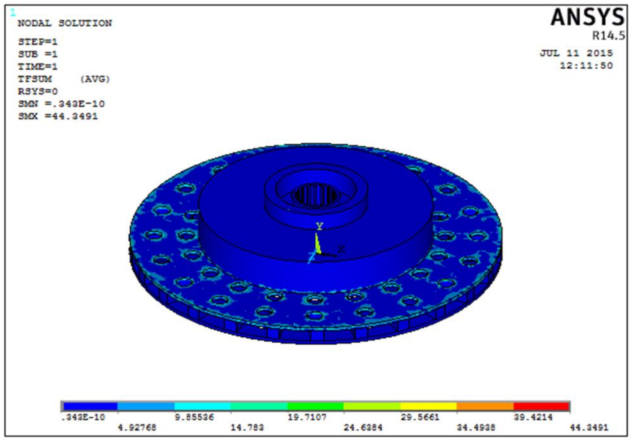



Table 5: Comparison of Disc Plate thermal Analysis (With Holes)

| Temperature($^0$c) | Mild Steel | Al6061 | FGM |
|---|---|---|---|
| 150$^0$c | 18.431 | 39.658 | 15.739 |
| 250$^0$c | 35.188 | 75.7114 | 30.042 |
| 350$^0$c | 51.502 | 111.764 | 44.349 |

## VII. CONCLUSION

1) The stress, strain, and displacement values for several materials (mild steel, Al6061, and FGM) are compared in structural analysis. Comparing disc plates with and without holes to M.S, Al6061, and FGM exhibit higher stress and strain displacements.
2) Thermal analysis compares the thermal flux for various materials at various temperatures. Comparing MS, Al6061, and FGM, the heat flux of FGM is minimal.
3) Disc plates made of FGM can have good structural and thermal qualities, but the material is highly expensive when compared to MS, and Al6061.
4) Consequently, FGM, a blend of ceramic and metal alloys with superior structural and thermal qualities. FGM can withstand high temperatures, which helps prevent the disc plate from ceasing to function.
5) FGM can be used in place of $Al_2O_3$ as the material for the disc plate. FGM can lower the cost of disc plates, and the lifespan of disc plates is roughly equivalent to that of $Al_2O_3$.

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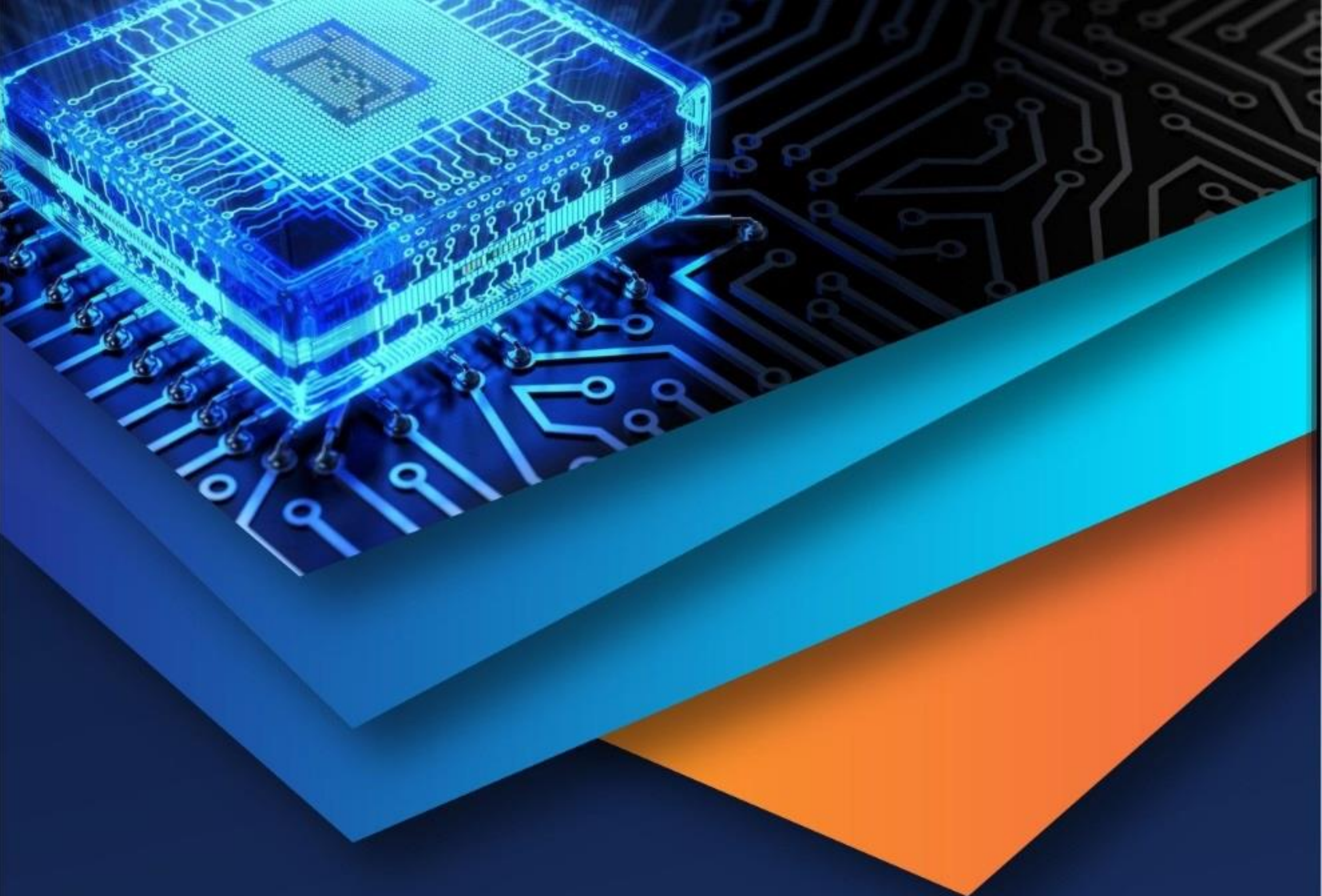

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