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Design and Analysis of Exhaust Valve of an IC Engine by using Finite Element Analysis

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Abstract: ***Engine is the heart of automobiles and valve mechanism is the heart of engine. There are two types of the valves are used in internal combustion engines which are intake valve and exhaust valve. Intake and exhaust valves are used to control the flow of intake fresh charge and Exhaust flue gases alternatively in Engine. They are used to seal the working space inside cylinder against the manifold and they open and close by means of what is known as the Valve gear mechanism. Exhaust valve work well in engines because the pressure inside the combustion chamber pushes valve against the seat, sealing the chamber and preventing leaks during this cycle exhaust valves are exposed to high temperature and pressure which will affect the life and performance of the engine. The aim of the project is to design an exhaust valve with a suitable material along with the three different fillet radii for a four-stroke diesel engine by using Finite Element Analysis. In exhaust valve we have considered Aluminium 7068 alloy, Silicon carbide reinforced Zirconium di-boride and Carbon fiber composite material. In this we observe the results of existing exhaust valve's stress, strain and total deformation values are compared to the modified exhaust valve design are shows tremendous change in stress, strain and total deformation of the composite material.***
Keywords: Exhaust Valve design, Composite Materials, Fatigue.

I. INTRODUCTION

An exhaust valve is termed as an essential component of an Internal Combustion engine as it provides a path to expel out the exhaust gases generated after the combustion of the fuel in the combustion chamber. Exhaust valve used to seal the working space inside the cylinder against the manifolds and is opened and closed employing what is known as the valve train mechanism. Usually, the exhaust valve is made of steel valve material (steel alloy) to make it less weight and thermal conductivity. But the steel alloy valves have less strength and a high coefficient of thermal expansion, thus making it not suitable for the high-temperature experience. Aluminium 7068 alloy, Silicon carbide reinforced Zirconium diboride and Carbon fiber composite materials are used as an alternative for steel alloy valves to overcome the problems faced. Composite materials, when compared to conventional steel alloys, have good strength, thermal conductivity, and less weight density. Catia v5 software is decided to use for 3d drafting and Ansys 15.0 is decided to use for analysis.

II. ENGINE CONSIDERATION

Engine consideration -- TVS VICTOR 4 stroke petrol engine

Bore x Stroke (D X L)	=	53.5 x 48.8 (mm)
Engine displacement (CC)	=	109.7 cc
Valve seat angle	=	45^{O}
Gas Velocity, vg	=	2100m/min
Overall Length of valve	=	68.55 cm,
Engine speed, Ns	=	7500 rpm,
Max. Gas Pressure, P max	=	6.0 N/mm2
Mean Piston Speed, N	=	275 m/min,
Exhaust valve Temp, T	=	750^{O} C
Allowable stress σ	=	57.5 Mpa
K1	=	0.42
Exhaust Valve diameter d_1	=	18.2 mm

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III. FORCE CALCULATIONS

Force due to gas pressure (F_G) When valve opens

$$F_G = \frac{\pi}{4} d_c^2 p_c$$

$$= \frac{\pi}{4}(25)^2 \; x \; 0.45$$

$$F_G = 220.89 \; N$$

Inertia force when valve moves up (F_A)

$$F_A = m \,.\, \alpha^2$$

Sub, valve acceleration

$$\alpha^2 = \pi^2 . \omega^2 . h \; / \; 2\theta L^2$$

Angle of lift

Sub, $\theta_L = \frac{1}{2}\theta_{Cam}$

$$F_A = 2. m. \omega^2 . h / \theta_{Cam}$$

$$F_A = 2 \; x \; 0.213 \; x \; \pi^2 x \; 60.21^2 \; x \; (6.93x10^{-3})/2.53$$

$$F_A = 15.31 \; N$$

Where, θ_L = Crankshaft speed

Cam shaft speed, ω = 60.21 rad/sec (for four stroke)

Cam angle during valve lifting θ_{Cam} = 145°or 2.53 rad.

The initial spring force ((F_I) to hold the valve in its seat against the suction or negative pressure inside the cylinder

$$F_I = \frac{\pi}{4} . d_2^2 . P_s$$

Where, Maximum suction pressure $P_s = 0.025 \; mpa$

$$F_I = \frac{\pi}{4} . 25^{2.0} . (0.025)$$

$$F_I = 12.217 \; N$$

Total force acting on valve face (F_I)is calculated as

$$F_T = F_G + F_A + F_I$$

$$= 220.59 \; N + 15.31 + 12.27$$

$$F_T = 248.17 N$$

Tensile force generated due to inertia

$$F_A = 15.31 \; N$$

Compressive force due to gas pressure and Initial spring force ($F_G + F_I$)

$$= 220.89 + 12.22$$

$$= 233.11 \; N$$

IV. DIMENSIONS AND DESIGN OF EXHAUST VALVE

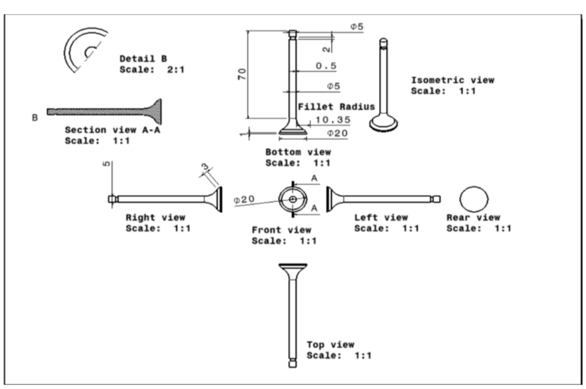

Fig.1. Existing exhaust valve design of 10.35 mm fillet radius

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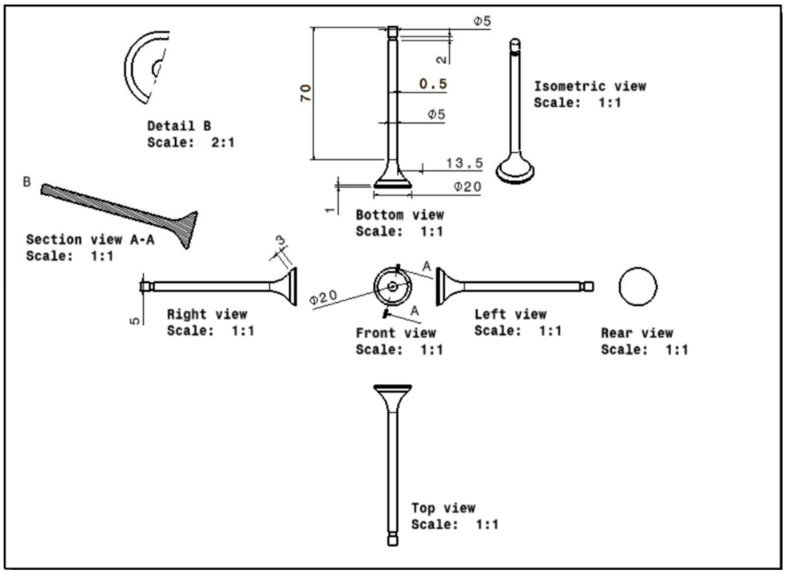

Fig.2. Optimized exhaust valve design of 13.5 mm fillet radius

V. MATERIAL SELECTION

For structural design it is important to consider all materials appropriate to the application. For the design of this multipurpose machine, the material should be cost effective and capable of providing the required properties of each application.

For the frame, the material selection was completed using stress analysis, strain analysis and displacement analysis based on the required stresses that will be applied by lift and drag forces.

Table.1. Material properties

Material	Density (kg/m)	Youngs Modulus (gpa)	Poisson ratio	Tensile strength (mpa)
21-4N	7750	193	0.25	700
Aluminium 7068 Alloy	2850	73.1	0.23	710
SiC ZrB_2	2060	486	0.33	1070
Carbon Reinforced Carbon fibre	2000	228	0.33	36006

VI. STRESS RESULTS FOR EXHAUST VALVE DESIGN OF FILLET RADIUS 10.35 mm

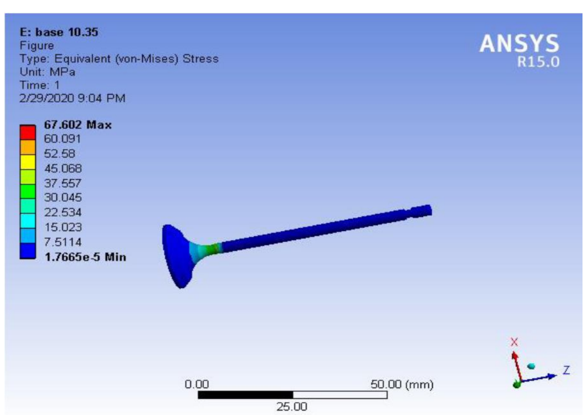

Fig.3. Von-mises stress

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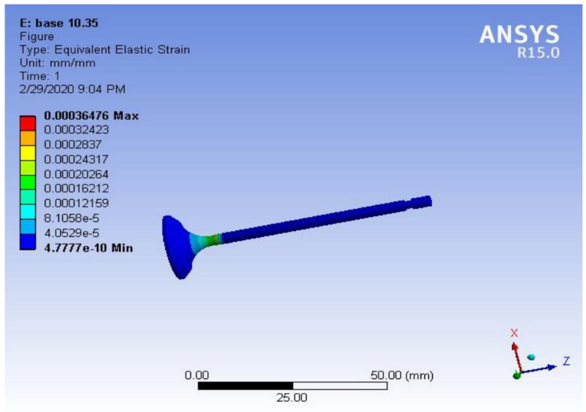

Fig.4. Elastic strain

From the obtained solution of basic 10.35 mm fillet radius valve the maximum stress is concentrated at valve face and stem junction. The maximum stress is 67.602 Mpa at the fillet section which could be optimized by selecting various fillet radii, the fillet radius below the existing radii shows huge stress and hence the fillet radius above the existing radius is selected. Then maximum fillet radius is constrained to 14.5 mm, because due to valve seat and size restriction. More over the stresses above the 14.5 mm fillet radius are large and are neglected. So, the fillet radius between 10.35 mm and 14.5 mm are selected.

Table.2. Results based on various fillet radii.

Fillet radius (mm)	Max stress (Mpa)	Max strain	Max deformation (mm)
10.35 (Current)	67.02	0.00036476	0.1135
12.5 (Optimized)	58.356	0.00032028	0.1104
13.5 (Optimized)	50.003	0.00028086	0.11092

From the above data we could observe that the stress value is least for the fillet radius 13.5 mm. Hereby we conclude that the fillet radius 13.5 mm is suitable for exhaust valve design, for longer life of the valve. The fillet radius 13.5 mm is chosen to carry out further design and analysis of the exhaust valve using different composite materials to choose the best composite material**.**

VII. STRESS RESULTS

A. For Aluminium 7068 Alloy with 13.5 mm Fillet Radius

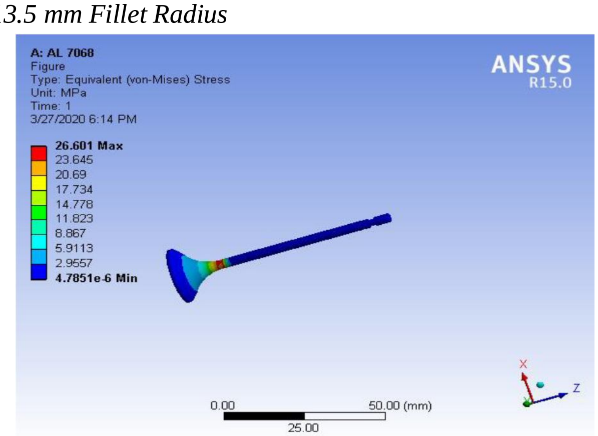

Fig.5. Von-mises stress

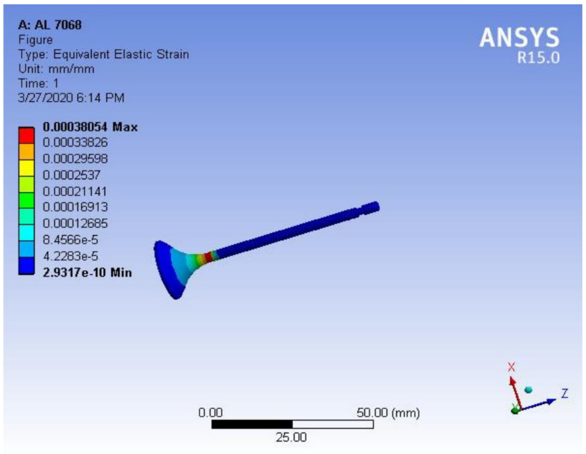

Fig.6. Elastic strain

B. For Silicon Carbide Reinforced Zirconium di-boride with 13.5 mm fillet Radius

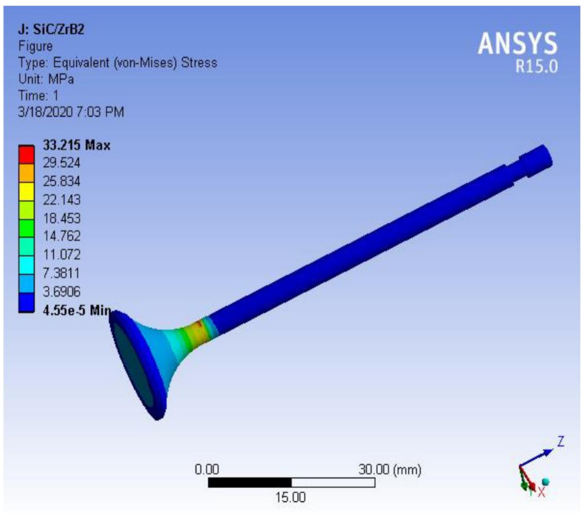

Fig.7. Von-mises stress

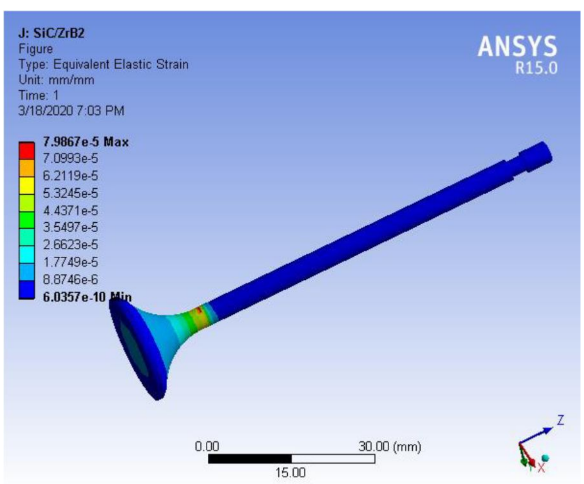

Fig.8. Elastic strain

C. For Carbon Reinfoced Carbon fibre with 13.5 mm Fillet Radius

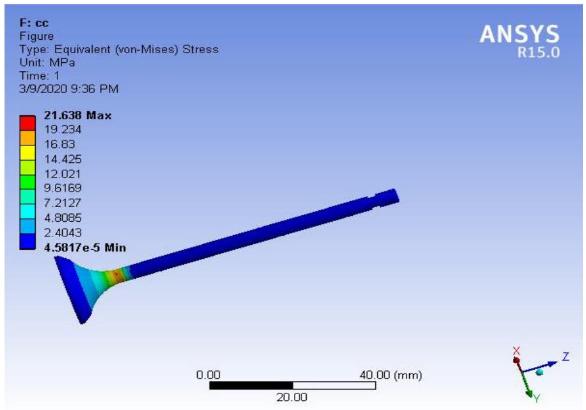

Fig.9. Von-mises stress

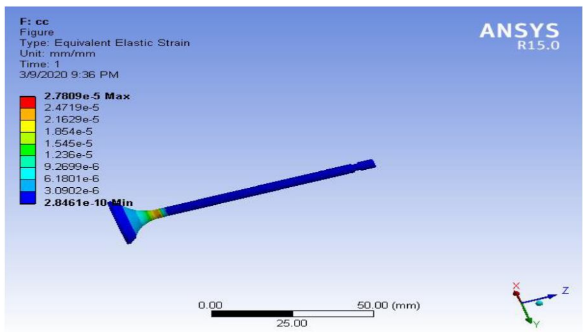

Fig.10. Elastic strain

VIII. COMPARISON OF STRESS

Table.3. Stress results

Material	Max stress (mpa)	Max strain	Max deformatio n (mm)
21-4N	50.003	0.00028086	0.11092
Aluminium 7068 Alloy	26.601	0.00038054	0.11266
SiC ZrB_2	33.215	0.00007986	0.10108
Carbon Reinforced Carbon fibre	21.837	0.00003293	0.11071

IX. RESULT & DISCUSSION

Table.4. Percentage of reduction in stress

MATERIAL	PERCENTAGE OF REDUCTION IN STRESS (%)
Aluminium 7068 alloy	46.8
SiC ZrB_2	33.5
Carbon Reinforced Carbon fibre	56.3

From the above table values we can observe that the least stress value is in Carbon reinforced carbon fiber, so conclude that carbon reinforced will be the best composite material for exhaust valve.

X. CONCLUSION

The Automobile industries are requiring less weight and high tensile materials in these days, so we have gone with alternative materials for automobile parts. We had chosen an exhaust valve of an internal combustion engine for further alteration which is light in weight and improve performance of the engine. We had considered the exhaust valve design with 12.5-mm & 13.5-mm fillet radius along with three composite materials. Exhaust valve which is having 13.5 mm fillet radius gives a good result when applying the load. By analyzing the 13.5 mm fillet radius design with different composite materials (Aluminium 7068 alloy, Silicon carbide reinforced Zirconium diboride & Carbon fiber composite), Carbon reinforced carbon gives the result as well. The stress developed in the carbon fiber exhaust valve is least when compared with 21-4N exhaust valve material. The overall reduction in stress is 56.328 % for Carbon-Carbon fiber. Hereby we conclude that Carbon fiber composite will be the best alternative for exhaust valve of an internal combustion engine.

XI. FUTURE SCOPE

A. Valve shape optimization with new shapes of valve than existing can be studied.
B. To increase the work life of the exhaust valve further modification can be done.
C. Performing tensile test on Universal Testing Machine and results interpreting can be done.
D. Instead of dynamic analysis can be done.
E. Modal analysis can be added to study natural frequencies and their behavior of various frequencies.
F. Performance test of the optimized valves and composite material valve can be done.
G. Research on composite materials to enhance their mechanical, chemical and thermal properties.

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A. Conflict of Interest

There is no conflict of interest to be described.

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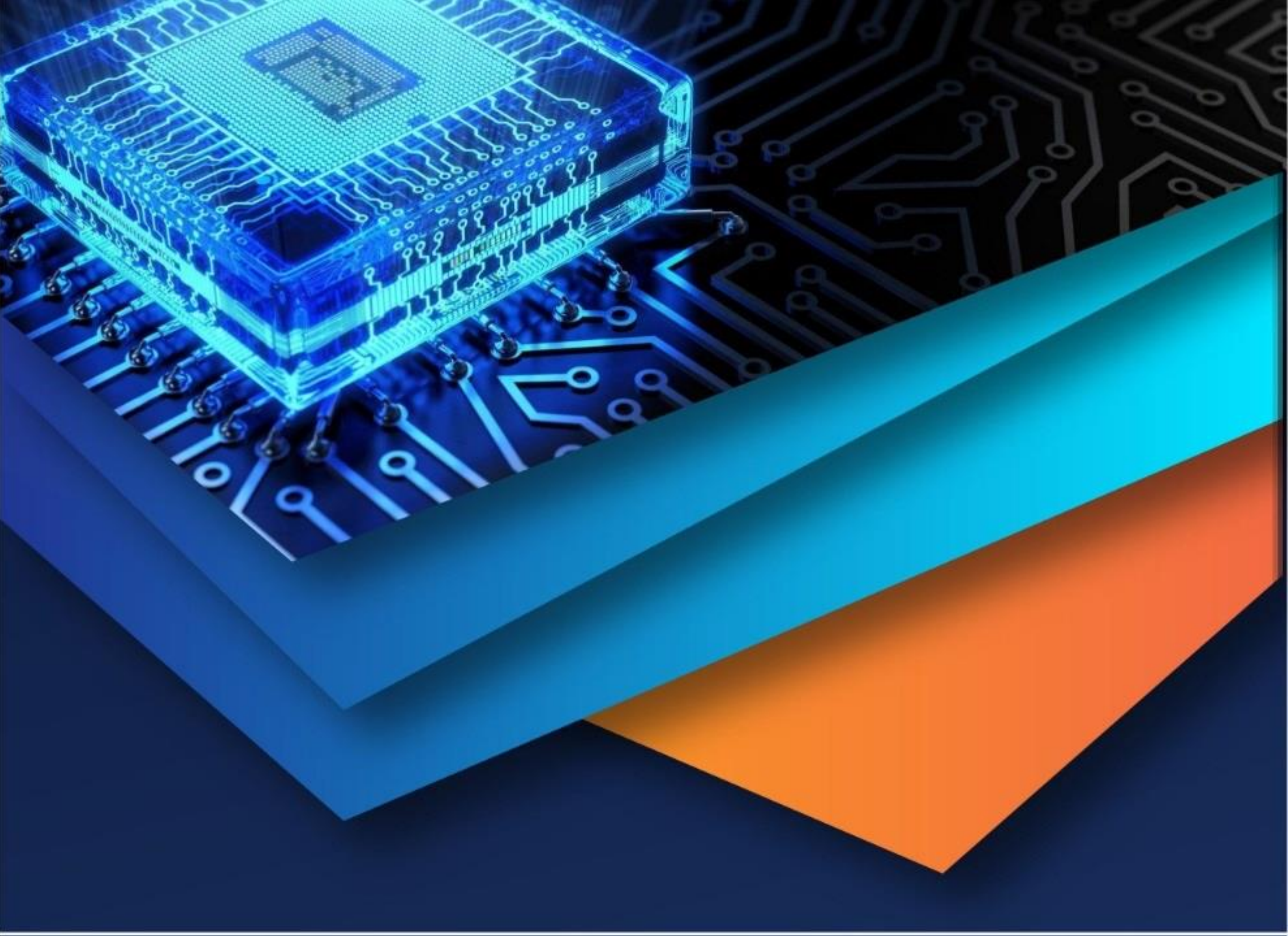

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