iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VIII **Month of publication:** August 2021

DOI: https://doi.org/10.22214/ijraset.2021.37844

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

Failure Analysis and Optimization of the Tie Rod Using FEA

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Abstract**: *A car's steering wheel is used to connect the steering gear which is connect to the wheels via the tie rod ends. The main use of the tie rod end is to ensure the wheels are aligned. Hence the functioning of tie rod is crucial for steering as well as suspension performance of vehicle. Today's world is competitive with respective to efficiency as well as economical in price, every organization striving for cost effective product at a lower price and within minimum period for 'time to market. In this work, an attempt is made on optimization of the tier rod through changing materials and to reducing the weight. FEA analysis is performed on solid section and hollow sections with different thicknesses. The stress results at critical locations for different design iterations are discussed in this work. From the FEA results it is observed that the effected wright for hollow section is reduced by 18.15 % compare to solid section.***
Keywords: Tie rod, ANSYS, CATIA, Stress, optimization

I. INTRODUCTION

Design of suspensions components in an automotive is very critical as they are constantly under varying loads. While designing the component we must ensure the safety. Apart from design perspective it is important to focus on the weight and cost of an individual component. The tie rod is an important part of suspension system. It connects the steering to the suspension in order to transform the motion. A tie rod assembly is attached to each end of the relay rod. The tie rod assembly consists of inner and outer tie rods that are usually connected through an adjusting sleeve.

In Many instances, failure analysis results indicate that the primary cause of failure of the tie rod was likely material deficiency [1]. The failures in the tie rod assembly is observed at the threaded locations, thus, The results of these experiments suggest strong guidelines on the minimum number of turns of thread engagement for preventing the failure of thread teeth of steel tie rods in practical shear and bending applications [2].

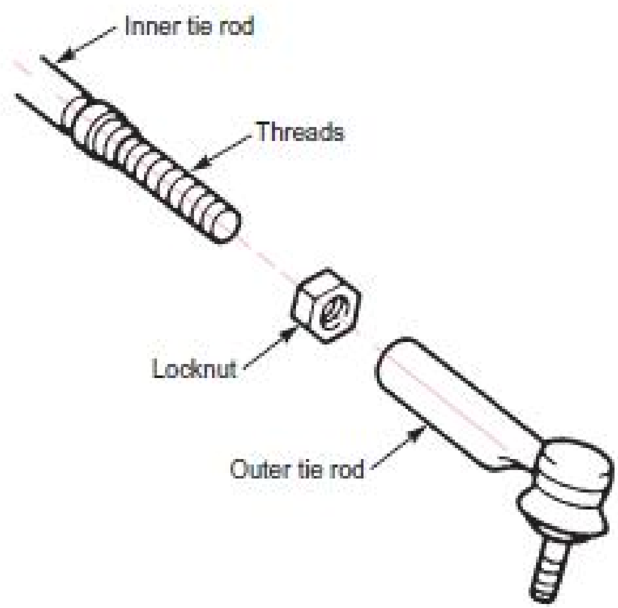


Fig.1 Exploded view of a manual rack-and-pinion steering gear assembly.

Now days, a light weight carbon composite tie bar was developed to replace the conventional steel tie bar. This new composite tie bar can achieve high elastic strain and provides a consistent compaction pressure to the stack over long operation time [3]. For both conventional and composite tie rods, FEA techniques are generally used to determine its strength and durability [4]. Tie rod design is also validated with respective to dynamic analysis to ensure that natural frequencies are away from the system operating frequencies [5]. To optimize the weight of the tie-rod, many lightweight materials including aluminum combinations are used [6].
The above research papers have been very useful for deciding the analysis strategy. There were numerous conference papers, reference manuals, book by Robert cook Concepts and applications of FEA will be helpful for the project. In this work, the results obtained from FEA results are fully validated with experimental results. It is found that there is a good agreement between FEA and numerical results. The objective of this work is to determine; tie-rod stress and deformation analysis, identification of critical factors that affects stress and deformation of tie rod, optimization of tie-rod based on critical factors, and suggestion of best possible combinations of the parameters for better results.

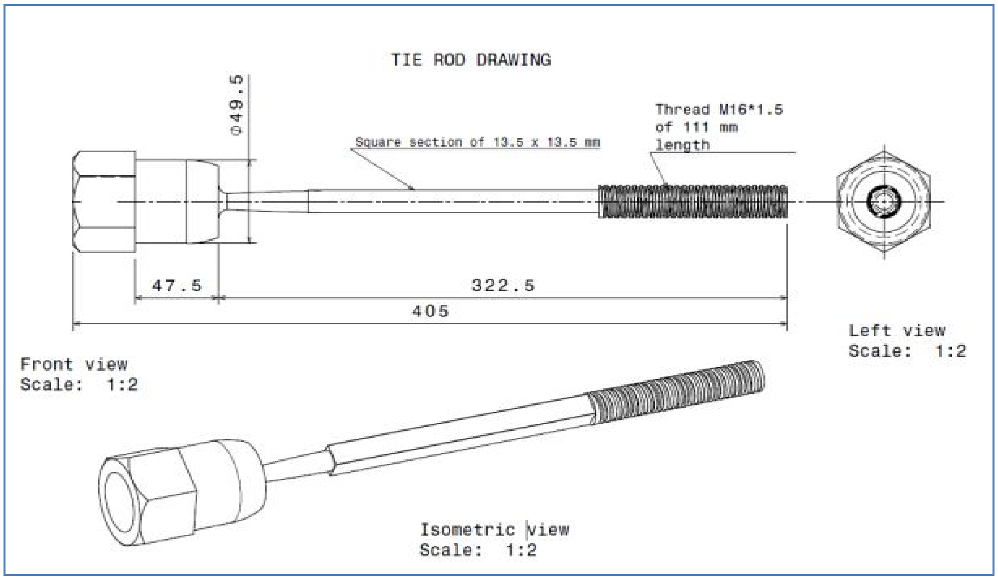


Fig. 2 Tie Rod Drawing

Table I Tie Rod Parameters

Parameter	Initial Design	Unit
E	211	GPa
L	405	mm
D	50	mm
W * H	15*15	mm
D	21	mm
Density	7.830^{-9}	Tons/mm^3
Thickness	Solid	mm

II. FINITE ELEMENT ANALYSIS APPROACH

Finite element analysis is performed to optimize the tie rod in two ways as follows;

1) Changing Material
2) Optimizing the design parameters

A. Optimization Analysis For Tie Rod At Different Materials

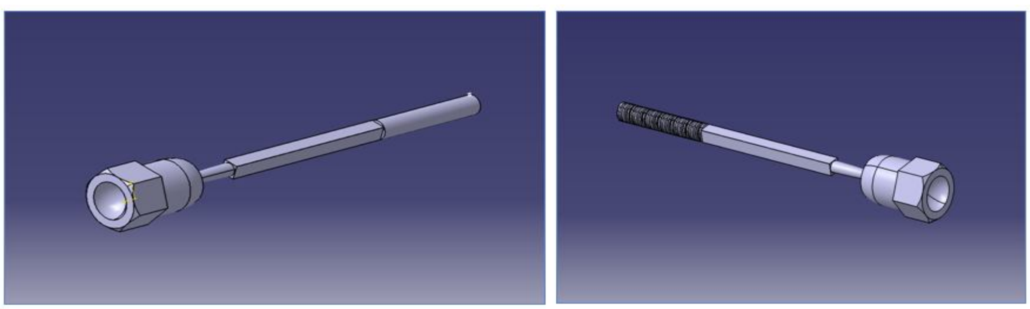
Materials are selected based on the usage in the industry. Four materials are selected which are widely used for tie rod. The mechanical properties of different materials are listed as shown in Table II.

Table II Material Properties

Material	Young's Modulus 'E' (Mpa)	Poisson's ratio	Density (Kg/m3)	Tensile strength, yield (Mpa)
Steel- SM45C	210×10^3	0.3	7860	343
Aluminum Alloy 6082	72×10^3	0.33	2710	310
Cast Iron – FG 350	110×10^3	0.29	7200	350
Titanium alloy (Ti-6Al-4V)	113.80×10^3	0.342	4430	880

3D model is created in 3D modeling software that is CATIA, and meshing is done in ANSYS (Fig. 3).

Higher order elements are used for meshing the model as shown in Fig. 4.



(a) (b)

Fig. 3 (a) CAD model of tie rod, (b) Threaded portion

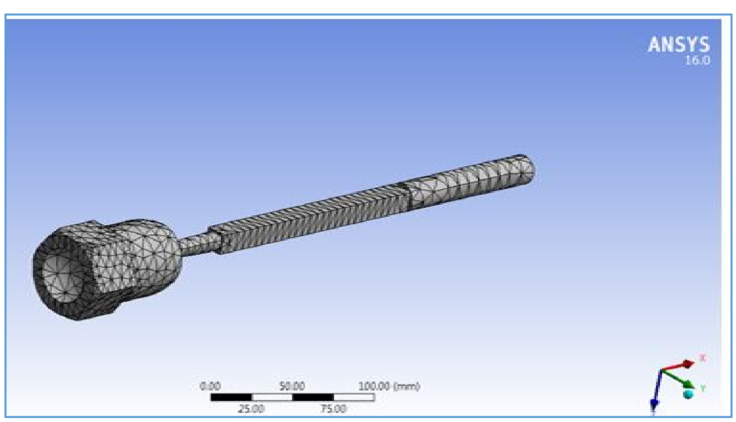


Fig. 4 Mesh Model

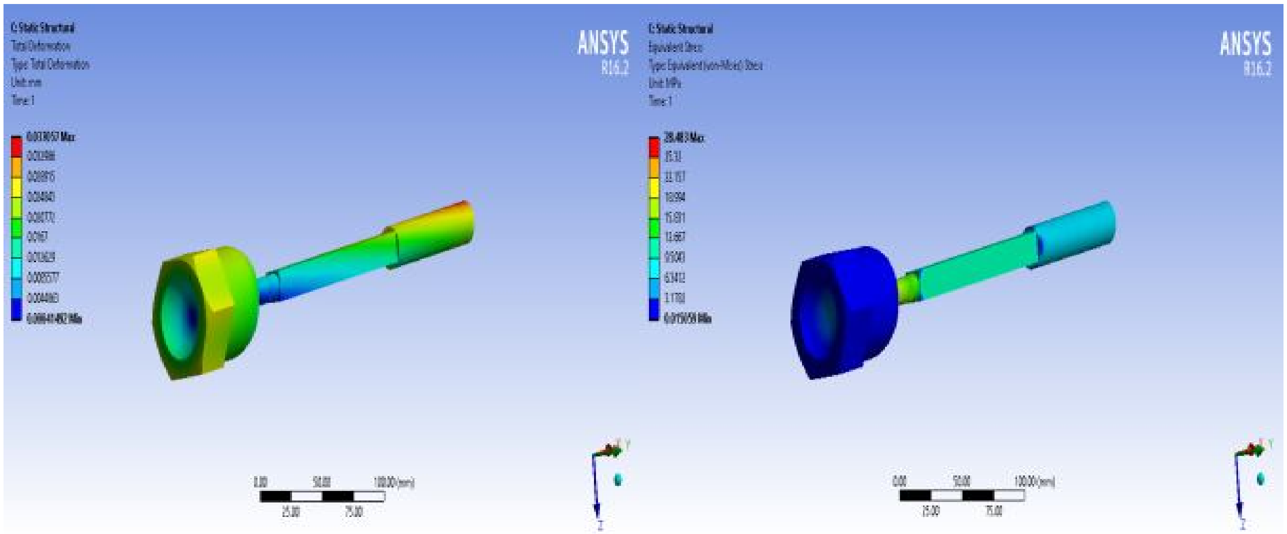


Fig. 5 Results: Deformation and Stress

The stress at the critical sections of the tie rod for different materials is shown in Table II. From the FEA results shown in Table II indicates that there is no significant change stress.

Table III Results

Sr No	Material	Weight, kg	Deformation, mm	Stress, MPa
1	Steel	1.7517	0.037057	28.483
2	Aluminum alloy	0.6181	0.10107	28.72
3	Gray Cast Iron	1.6066	0.06064	28.641
4	Titanium alloy	1.0309	0.075799	28.166

B. Optimization Analysis: Design Optimization

1) *Design Optimization: Rectangular Cross Section:* Hollow rectangular bar with different thickness are analyzed in order to optimize the design.Eight different design iteration are considered in this work as shown in Table II Till design iteration-7, the stress from FEA is observed below the yield strength (Table V). Design Iteration-8 shows that the stress from the FEA is above the allowable strength of the material. The deformation and stress plots for the design iteration-7 is shown in Fig 5.

Table IV Design Iterations

Trial No	Hole ID, mm	Hole ID, mm	Thickness, mm
1	19.00	5.00	7.00
2	19.00	6.00	6.50
3	19.00	7.00	6.00
4	19.00	8.00	5.50
5	19.00	9.00	5.00
6	19.00	10.00	4.50
7	19.00	11.00	4.00
8	19.00	12.00	3.50

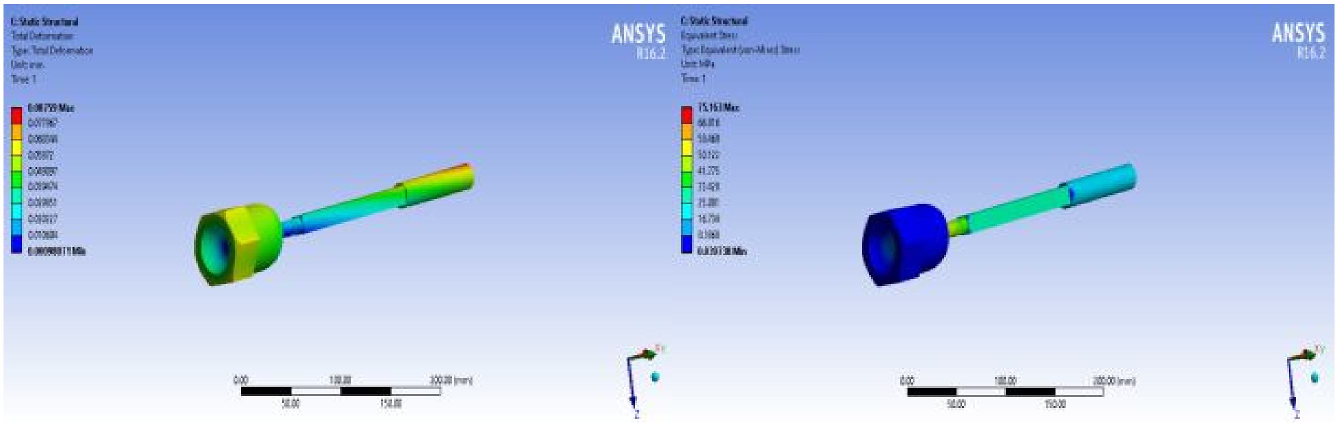


Fig. 6 Results: Deformation and Stress

Table V Design Iterations

Trial No	Hole ID, mm	Thickness, mm	Weight, kg	Stress, MPa	Deformation, mm
1	5.00	7.00	1.69	30.461	0.05
2	6.00	6.50	1.67	32.439	0.06
3	7.00	6.00	1.65	39.56	0.07
4	8.00	5.50	1.62	43.516	0.07
5	9.00	5.00	1.60	49.054	0.07
6	10.00	4.50	1.56	58.548	0.08
7	11.00	4.00	1.53	75.163	0.08
8	12.00	3.50	1.49	197.8	0.14

2) Design Optimization: Circular Cross Section

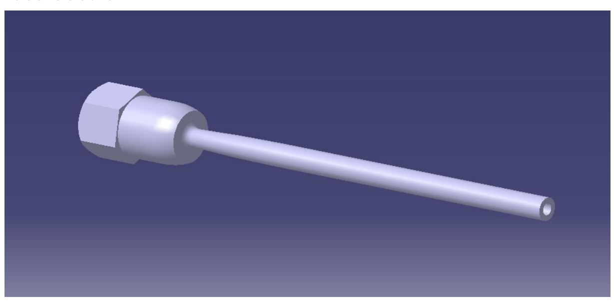


Fig. 7 Results: Deformation and Stress

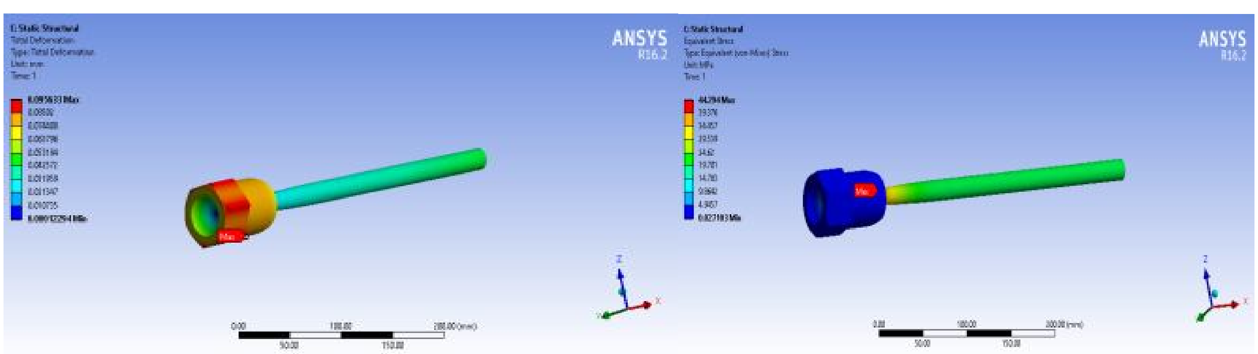


Fig. 8 Results: Deformation and Stress

III.TEST RESULTS

Based on results of rectangular cross section of tie rod (section 2), at design iteration 7, it is observed that the stress is below the allowable limit of the material. The FEA analysis is repeated with circular hollow section of the tie rod with the same dimensions of design iteration-7 (Hollow rectangular cross section and observed that the peak stresses are lower than the allowable limit of the material. Testing is done for hollow circular cross section and the measured displacement is 0.0954 mm (Table VI). From the FEA, the displacement of the hollow circular cross section is 0.0946 mm. It is observed that there is good agreement between FEA and test results.

Table VI Test Results

Condition	ID, mm	Material	Deformation, mm			
			Trial 1	Trial 2	Trial 3	Avg.
New Design	11	Steel- SM45C(Circular with hole)	0.0955	0.0952	0.0955	0.0954

Table VII Results Comparison

Parameters	Existing Rod	Suggested Rod
Material	Steel- SM45C (Rectangular + circular and Solid)	Steel- SM45C (Circular + Hollow- ID 11 mm)
Weight	1.7517 kg	1.4338 kg
% Change in Weight	Hollow Tie rod is 18.15 % lighter than solid	
Stress (Static)	28.544 MPa	45.674 MPa
% Change in Stress	Hollow tie rod has 37.50 % more Stress than solid but its within allowable limit	
Deflection (Static)	0.035969 mm	0.094642 mm
% Change in Deflection	Hollow tie rod has 62.0 % More deflection than Solid but it's within allowable limit	

IV.TEST RESULTS

A. Tie rod material and rod diameter play important role in rod failure and should be carefully selected.

B. Tie rod with hollow ID- 11 mm shows safe results and is selected for further work.

C. Circular section and Hollow tie rod at 11 mm ID show less weight (18.15 %) compare to Rectangular + Circular and solid and hence finally suggested for weight reduction case.

D. Hollow tie rod at 11 mm ID shows high Stress (37.50 %) and deflection (62.0 %) values compare to existing but those are within limit.

E. Fabrication of Tie rod with square and circular section is complex than only circular shape. Hence this new selection will also save time.

F. Future scope of this work includes; dynamic analysis can be done, composite materials can be tested for less weight applications, and effect of Vibrations can be considered

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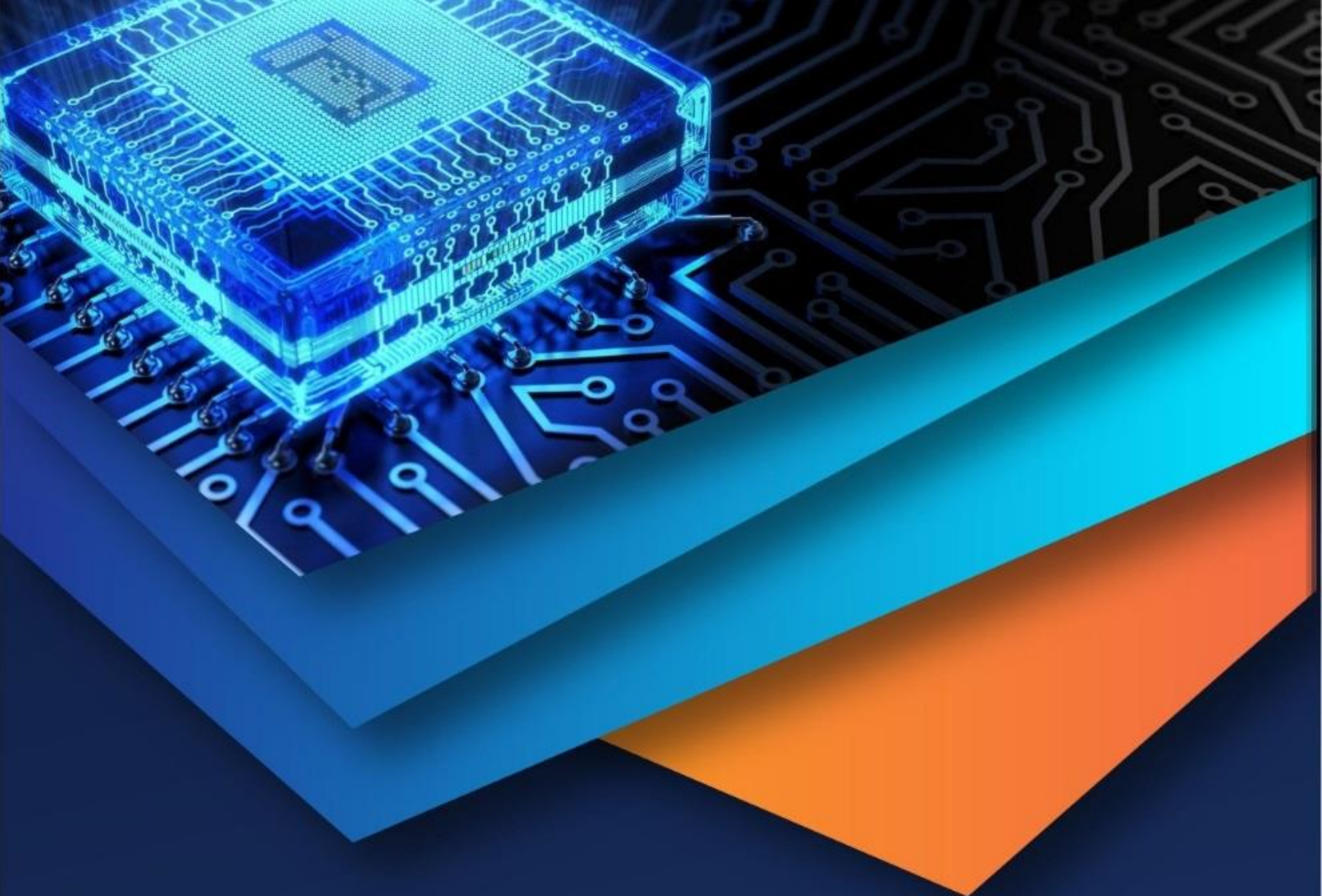

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