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Design of Roll Cage Model for All Terrain Vehicles

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Abstract: The paper focuses on software design methods and analysis of the roll cage for an All-Terrain Vehicle (ATV). The roll cage is crucial for the safety of the driver and the vehicle's occupants, and the study outlines a step-by-step design methodology using Solid Works and Creo. The design process includes material selection, shape, and welding, followed by Finite Element Analysis for safety and reliability. Static and dynamic stress analyses are performed, and the roll cage is designed to offer double strength in case of rolling while considering aesthetics.
Keywords: Solid works, Finite Element Analysis, static stress analysis, dynamic analysis, aesthetic.

I. INTRODUCTION

The primary goal of this study is to design a roll cage that will provide maximum protection to the occupants of a vehicle in case of an accident. The roll cage is a specially engineered and constructed framework that is built in the passenger compartment of a vehicle to protect its occupants in case of a rollover or other accidents. The study begins by designing a model for the roll cage using Solid works and Creo software, taking into consideration the intended use and size of the vehicle. The design is modified based on requirements such as the type of roads the vehicle will be driven on.

To ensure the roll cage's efficacy, Finite Element Analysis (FEA) is conducted using Ansys/Lisa software to analyze the roll cage's strength in various scenarios such as front and rear collisions, rolling, front and rear bumps. Material selection, the shape of the roll cage, and welding material are also crucial design criteria. The load is calculated using energy theorems, and no assumptions are taken while calculating the force on the roll cage in different conditions.

Based on the results of the analysis, the design is modified accordingly to provide maximum protection to the vehicle occupants. Overall, this study emphasizes the importance of designing a roll cage that meets specific requirements and is structurally sound, as it is the foundation of a vehicle's safety system.

II. LITRETURE SURVEY

Several studies have been conducted on the design of roll cages for all-terrain vehicles (ATVs). These studies have explored various aspects of roll cage design, including material selection, shape optimization, and the use of simulation techniques.

One study focused on the use of composite materials in roll cage design for ATVs. The study found that composite materials can provide a high strength-to-weight ratio, making them an ideal choice for roll cage construction. Another study investigated the use of topology optimization to design roll cages for ATVs. The study found that topology optimization can be used to reduce the weight of the roll cage while maintaining its strength and stiffness.

In addition to these studies, simulation techniques such as finite element analysis (FEA) have been used to analyze the performance of roll cages under various loading conditions. One study used FEA to investigate the performance of roll cages in ATV rollover accidents. The study found that the shape of the roll cage can significantly affect its ability to protect occupants in rollover accidents.Overall, these studies highlight the importance of careful design and analysis in the development of effective roll cages for all-terrain vehicles.

III. METHODOLOGY

It sounds like you have described a methodology for designing a roll cage. The flow chart suggests that you started with gathering detailed information from a previous design and then used this information to create a new design.The previous design had a high number of welding nodes, which may not have been sufficient to ensure the driver's safety. Therefore, you selected a new design and material with maximum fatigue and tensile strength to avoid reducing the strength and changing the original properties of the pipes.

To verify the effectiveness of the new design, you conducted front, rear, and side impact test analyses using Ansys software, which is commonly used for simulation and analysis of engineering problems.

Overall, it appears that you have followed a structured and iterative approach to design a roll cage that ensures the driver's safety by selecting appropriate materials and verifying the effectiveness of the design through simulation analysis.

IV. DESIGN

A. Material

After thorough comparison of many opted materials, final selection of material for roll-cage of ATV was finalized based on the following criteria:

1) High Purpose of utility.
2) High Strength of Material
3) Light weight
4) Low cost
5) Feasible size
6) Availability of the material.

TABLE NO 1. PROPERTIES OF MATERIALS

Materials/ properties	AISI 4130 Carbon steel	AISI 1020 Carbon steel	AISI 1080 Carbon steel
Tensile Ultimate	560 mpa	420 mpa	870 mpa
Tensile Yield Strength	460 mpa	350 mpa	380 mpa
Hardness	220	121	260
Poisson ratio	0.29	0.29	0.29
Density	7.8 g/cm^3	7.9 g/cm^3	7.7 g/cm^3
Modulus of Elasticity	190 gpa	205 gpa	190-200 gpa
Shear strength	340 gpa	280 gpa	520 gpa
Fatigue strength	320 mpa	180 mpa	190 mpa
Cost (25.4 mm OD and1.5mm Thickness)	400 rs/ meter	300 rs/meter	450 rs/meter

From above table it is clear that the best suitable material for the Model of Roll-Cage is ASI 4130,
Best Material: AISI 4130

a) Less weight
b) Less deformation
c) Better factor of safety
d) Good Strength
e) But high cost 400 rupees/meter

TABLE NO 2. CHEMICAL COMPOSITION OF THE MATERIALS

Material	**AISI 4130**	**AISI 1020**	**AISI 1040**
Carbon (C)	0.28 - 0.33%	0.18 - 0.23%	0.37 - 0.44%
Manganese (Mn)	0.40 - 0.60%	0.30 - 0.60%	0.60 - 0.90%
Phosphorus (P)	0.025% max	0.040% max	0.040% max
Sulfur (S)	0.040% max	0.050% max	0.050% max
Silicon (Si)	0.15 - 0.35%	0.15 - 0.35%	0.15 - 0.35%
Chromium (Cr)	0.80 - 1.10%	-	-

Please note that these are approximate ranges for the chemical compositions, and the actual values may vary depending on specific manufacturing processes and standards.
Overall, the chemical composition of AISI 4130 steel offers superior performance characteristics compared to AISI 1020 and AISI 1040 steel, particularly in terms of strength, hardness, and corrosion resistance.

TABLE NO 3. ALLOWABLE VS DESIGNED VALUE

Parameters	Allowable Value	Designed Value
Material used	AISI 1018	AISI 4130
Max. Vehicle width (inch)	64	32
Max. Vehicle length (inch)	108	65
Vertical distance of S.I.M. From seat (inch)	8-14	14
Vertical distance between seat and R.H.O. (inch)	Greater than 41	42

B. *Number of Nodes*

At nodes pressure points are created which results in failure of the design model. The design to be optimum should consist of minimum number of nodes. The Nodes should be minimum to avoid the pressure points.

C. *Welding Techniques and Material*

There are different types of welding techniques available for the material being used, including Gas tungsten arc welding, Gas Metal arc welding, and Resistance/spot welding. Resistance/spot welding is cheaper and more effective for retaining the strength. The optimal welding material should be reasonably priced and suitable for the application, with Tungsten rod being the most suitable choice.

D. *Design Software*

SolidWorks 2019 was used for designing the roll cage, which offers a user-friendly interface and easy material customization. The design approach followed in this study was based on a case study that analyzed earlier designs in detail, identifying weak points and making changes accordingly.

We have remodeled the previous design for better performance.

The basic properties of all the designs are:

1) Diameter: 30 mm
2) Material: AISI 4130
3) Modulus of elasticity: 210 Gpa
4) Fatigue strength: 320 mpa
5) Outer diameter: 30 mm
6) Thickness: 2 & 3 mm
7) Inner diameter: 27 & 28 mm

V. ANALYSIS

It's important to analyze whether the modified design is better than the previous one and to verify which material with the modified design gives better results. Ansys 19.2 has been used for analysis due to its high problem-solving ability and user-friendly interface. It provides better results and is easily accessible.

A. *Calculations for Structural analysis*

Weight of roll cage = 44 kg

Weight of ATV with driver = 235 kg

1) Calculations for front impact test

Initial velocity = 45 kg/hr = 12.5 m/s

Final velocity = 0 m/s

Impact time = 0.2 sec (approx.)

Work done = $\frac{1}{2}mv^2$

$= \frac{1}{2} * 235 * 12.5^2$

$= 117.5 * 12.5^2$

= 17968.5 Nm

To find force

Force = $\frac{Workdone}{distance}$

Distance = 12.5 * 0.2 = 2.5 m

Force = $\frac{17968.5}{2.5}$ = 7187 Nm

FOS = $\frac{YT}{Max\,stress}$

= $\frac{460}{384}$ = 1.19

Impact force for front impact is 7187 Nm

Yield strength of 4130 steel is 460 Mpa

2) Calculations for side impact test

Work done = 17968.5 Nm

Time = 0.25 sec

Distance = 12.5 * 0.25

= 3.125 m

Force = $\frac{17968.5}{3.125}$ = 5750 N

FOS = $\frac{YT}{Max\,stress}$

= $\frac{460}{255}$ = 1.8

3) Calculations for rear impact test

Time = 0.15 sec

Work done = $\frac{17968.5}{1.875}$ = 9982 N

FOS = $\frac{YT}{Max\,stress}$

= $\frac{460}{389}$ = 1.18

4) Calculations for roll impact test

Impact time = 0.17 sec

Height of fall = 10 ft = 3.048 m

Initial velocity = 12.5 m/s = 45 km/hr

Potential energy = Kinetic energy

PE = KE

$$mgh = \frac{1}{2}mv^2$$

$$2gh = v^2$$

$$2 * 9.81 * 3.048 = v^2$$

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$v = 7.73$ m/s

$$workdone = \frac{1}{2} m\, v^2$$

$$w = \frac{1}{2} * 235 * 7.73^2$$

= 7020.96 N

Time = .017 sec

Displacement = 0.17 * 7.73

D = 1.3141

$$\text{Force} = \frac{workdone}{displacement}$$

$$= \frac{7020.96}{1.3141}$$

F = 5342 N/m

$$\text{FOS} = \frac{YT}{Max\,stress}$$

$$= \frac{460}{160} = 2.8$$

B. Optimize Model Analysis

The which has been shortlisted from the design stage have to be tested I Ansys 19.2 for finalizing the material.

Analysis for Material ISI 4130 Steel

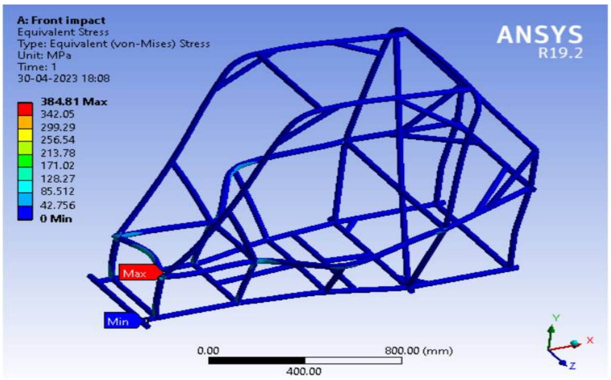

Fig No 1 Equivalent Stress For Roll-Over Test

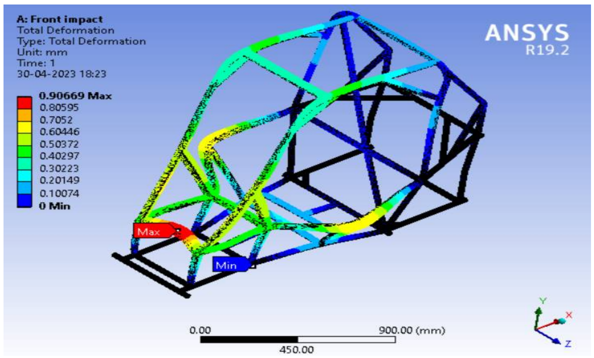

Fig No 2 Total Deformation For Front Impact Test

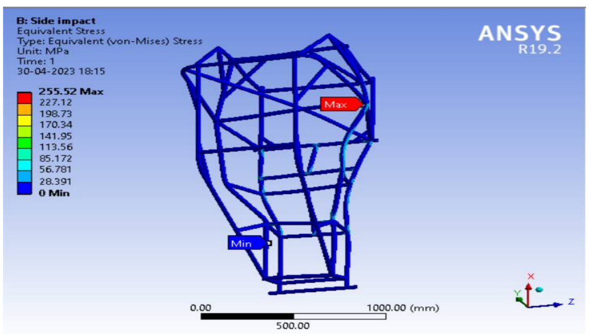

Fig No 3 Equivalent Stress For Side Impact Test

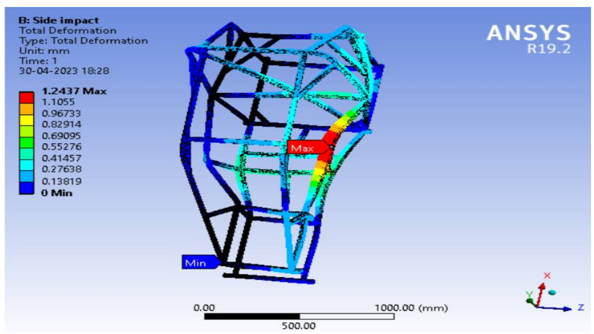

Fig No 4 Total Deformation For Side Impact Test

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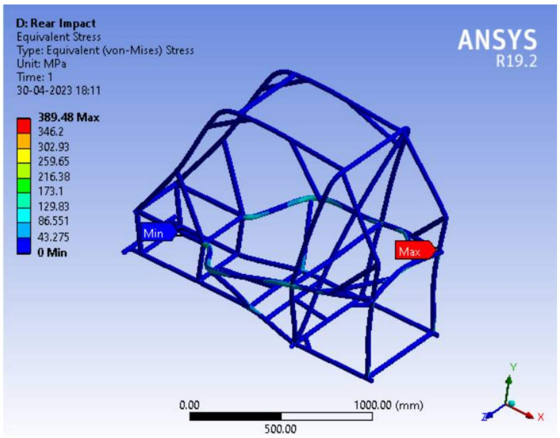

Fig No 5 Equivalent Stress For Rear Impact Test

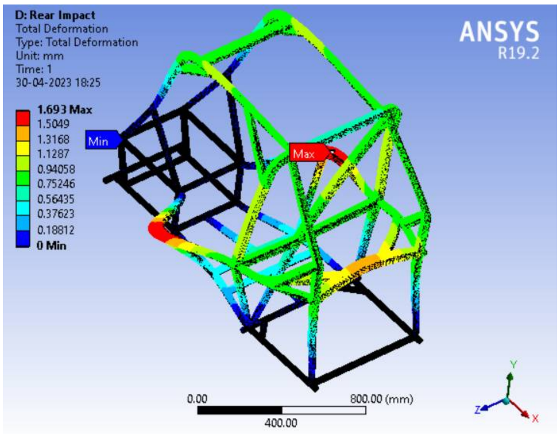

Fig No 6 Total Deformation For Rear Impact Test

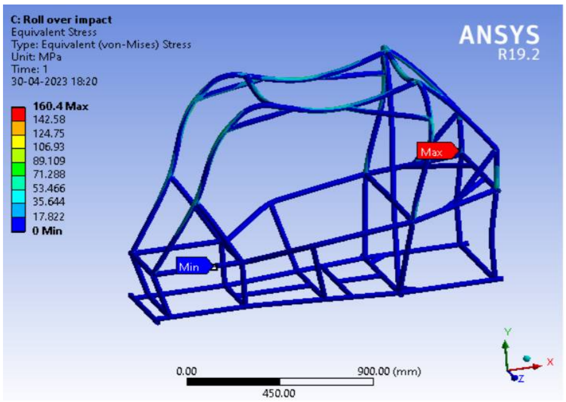

Fig No 7 Equivalent Stress For Roll Over Impact Test

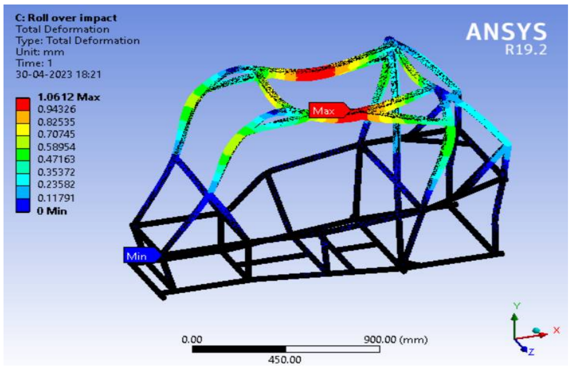

Fig No 8 Total Deformation For Roll Over Impact Test

TABLE NO 4. STRESS AND DEFORMATION

Parameter	Front Impact Test	Side Impact Test	Rear Impact Test	Roll-Over Test
Impact Force N	7187	5750	9982	5342
Factor Of Safety for 4130 steel	1.19	1.8	1.18	2.8
Material 4130 Stress (Mpa)	384.81	255.52	389.48	160.4
Material 4130 Deformation (mm)	0.9	1.24	1.69	1.06

Material 4130 Stel is suitable for the modified design of Roll-Cage. As it does not exceed the yield strength of material which is 460 Mpa.

VI. RESULTS

A. Optimum Material For Roll Cage

The suitable material for the Model of Roll-Cage is AISI 4130
As it has following properties,

TABLE NO 5. MATERIALS PROPERTIES

Tensile Ultimate	560 mpa
Tensile Yield Strength	460 mpa
Hardness	220
Poisson ratio	0.29
Density	7.8 g/cm^3
Modulus of Elasticity	190 gpa
Shear strength	340 gpa
Fatigue strength	320 mpa
Cost (25.4 mm OD and 1.5mm Thickness)	400 rs/ meter

Best Material: AISI 4130
1) Less weight
2) Less deformation
3) Better factor of safety
4) Good Strength
5) But high cost 400 rupees/meter

TABLE NO 6.. CHEMICAL COMPOSITION OF OPTIMUM MATERIAL

Material	AISI 4130
Carbon (C)	0.28 - 0.33%
Manganese (Mn)	0.40 - 0.60%
Phosphorus (P)	0.025% max
Sulfur (S)	0.040% max
Silicon (Si)	0.15 - 0.35%
Chromium (Cr)	0.80 - 1.10%

AISI 4130 steel is an excellent choice for constructing roll cages in all-terrain vehicles (ATVs) due to its superior mechanical and chemical properties. It offers high tensile strength, good toughness, and excellent fatigue resistance, making it capable of withstanding extreme off-road conditions. The material's carbon content provides adequate hardness and strength, while manganese enhances its toughness and wear resistance. Additionally, the inclusion of chromium and molybdenum in AISI 4130 steel improves its corrosion resistance and high-temperature strength. These properties ensure that the roll cage can effectively protect occupants during impacts, while the material's durability and resistance to environmental factors make it well-suited for off-road applications.

B. Comparison Of Original Vs Remodel Model

Based on the information you provided, it seems that the modified model has been shown to be safer and undergoes less stress than the original model. In this case, it may be a good idea to proceed with the modified model, provided that other factors such as cost, feasibility, and potential trade-offs have been carefully considered.

Table no 7. Comparison of original vs modified

Parameters	Original Model	Modified Model
Weight	82 kg	44.6 kg
Thickness of pipe used	4 mm	2 & 3 mm
Equivalent stress for Front Impact test	243.98 Mpa	384.81 Mpa
Total Deformation for Front Impact test	0.7395 mm	0.90669 mm
Equivalent stress for Side Impact	231.05 Mpa	255.52 Mpa

test		
Total Deformation for Side Impact test	2.2236 mm	1.2437 mm
Equivalent stress for Rear Impact test	898.25 Mpa	389.48 Mpa
Total Deformation for Rear Impact test	2.8444 mm	1.693 mm
Equivalent stress for Roll over Impact test	574.58 Mpa	160.4 Mpa
Total Deformation for Roll over Impact test	1.2126 mm	1.0612 mm
Number of Nodes	14,74,510	11,60,413

C. Cost And Weight Analysis Of Previous And New Model

The new roll-cage model, which weighs 44.6 kg, achieved significant weight reduction by using thinner pipes. While this can lead to cost savings, it may also compromise the model's structural integrity. However, using 2- & 3-mm pipes reduce material costs and transportation costs. In addition to the cost savings, the modified model is safer and has better stress and deformation analysis compared to the previous model, making it a superior solution for the project.

Table no 8. Cost analysis previous vs new model

Parameters	Previous Model	New Model
Weight	82 kg	44.6 kg
Material used	4130 steel	4130 steel
Total length of pipes required	30 to 35 meters	30 to 34 meters
Thickness of pipes	4 mm	2 & 3 mm
Length each pipes required	32 meters	2 mm = 22 meters 3 mm = 10 meters
Cost of pipe per meter	400 rupees per meter	350 rupees per meter
Final cost	12,800 rupees	11,200 rupees

Based on the information mention above, it appears that the new model is a more cost-effective and efficient solution for the project. By reducing the weight of the model from 82 kg to 44.6 kg and using thinner pipes, you were able to significantly reduce the cost of materials by 12.5 %. This is a substantial cost saving that will positively impact the project's budget.

VII. FUTURE SCOPE

Roll cages are an essential safety feature for ATV riders, and there are several potential future developments in this field. Here are some possible areas for future research and development:

1) *Smart roll cages:* Another area for future development is the integration of sensors and communication systems into roll cages. These smart roll cages could monitor the ATV's speed, tilt, and other parameters and alert the rider if they are at risk of a roll-over. Additionally, they could automatically send an alert to emergency services if an accident occurs.
2) *Improved mounting systems:* The mounting system of a roll cage is critical to its effectiveness. Future research could focus on developing new mounting systems that are stronger, more secure, and easier to install.
3) *Integration with other safety features:* Roll cages could be integrated with other safety features such as airbags, seat belts, and helmets to provide additional protection to riders.

VIII. CONCLUSION

For designing a roll cage involved a systematic approach that included gathering detailed information from a previous design and using it to create a new design. The previous design had a high number of welding nodes, which raised concerns about the driver's safety due to high stress at the welding joints that could reduce the strength and alter the properties of the pipes.

To address these issues, a new design was created, taking into account the lessons learned from the previous design. The new design included a reduced number of welding nodes and the selection of a material with maximum fatigue and tensile strength which is steel AISI 4130 The design was modelled using design software, and the final stage of the process involved conducting front, rear, and side impact test analyses using Ansys software to verify the safety and effectiveness of the design. Overall, the design methodology involved a rigorous and iterative approach that focused on minimizing welding nodes, selecting appropriate materials, and ensuring safety through simulation and testing analysis.

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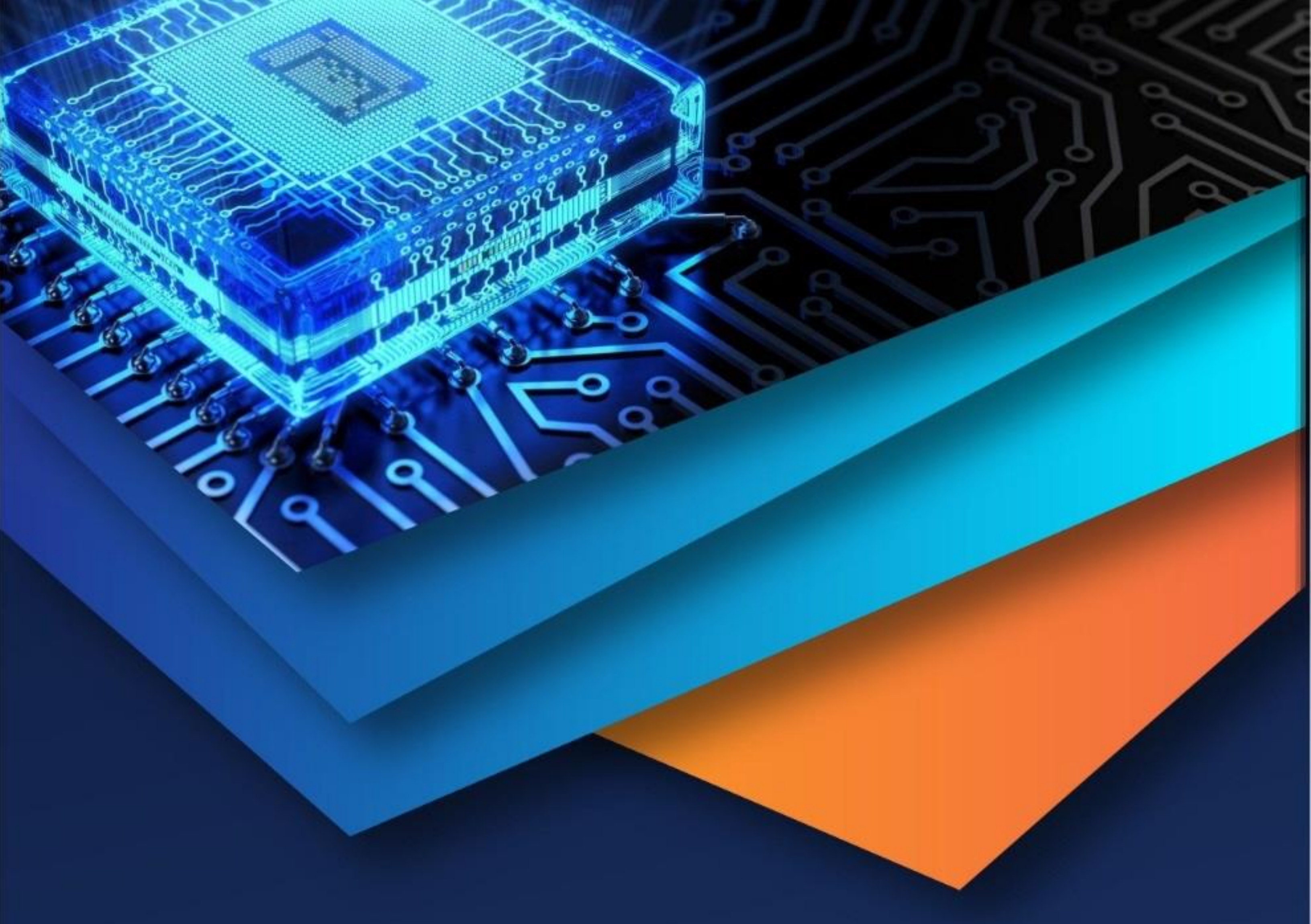

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