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# Static Finite Element Analysis of Roll Cage of Patrolling ATV Developed by CSMT, BSF Academy Tekanpur

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***Abstract: An All-Terrain Vehicle (ATV) roll cage is a structural arrangement that gives three-dimensional protection for the driver in the event of a rollover or abrupt impact accident, while also supporting the subsystems. In order to ensure that an ATV is structurally well-balanced and can protect the driver from impacts from the terrain, it should meet regulations with a proven design, few structural elements, light weight, great strength, and should be tested for unexpected impact loading. The objective of present work is to formulate a conceptual design followed by analysis of roll cage of robust 3-seater ATV need to be fabricated by CSMT, Tekanpur for the BSF frontiers at creeks of Gujarat. Ansys student 2024 R1 is used for analysis under defined constraints like front, side and rear impact on the roll cage. Three types of materials AISI 4130, AISI 1020 (DOM), and AISI 1018 are used for comparative analysis of crash test. This work provides the well-studied and optimal design approach on ATV roll cage to improve its impact bearing capability with better weight reduction and enriched strength ratio for a long duration. The research aims to give an introduction to the material selection procedure that need to be done before finalizing the design, using FEA software. In present work, various factors such as impact force calculations, loading points, generated Von-Misses Stress, deformation and Factor of Safety (FOS) are studied. The result of Finite Element Analysis (FEA) simulation showed least stress and deformation with highest factor of safety to suggests AISI 4130 as best suitable material for fabrication of roll cage.***
***Keywords: ATV Roll cage, Finite element analysis, Deformation Von-Misses Stress, and Factor of Safety.***

## I. INTRODUCTION

The American National Standard Institute defined all-terrain vehicles as vehicles with three or four low-pressure tyres with a driver straddling the seat and guiding the vehicle. As the name implies, the variety of terrains can be handled by the ATV and it can be driven on the gravel roads better than most other vehicles[1].An All-Terrain vehicle (ATV) roll-cage often known as the vehicle chassis is a skeletal structure that protects the driver as well as the powertrain, suspension, and steering systems. The roll cage, serve as the primary structural support for the vehicle other subsystems. The chassis main function is to handle various static and dynamic conditions without creating member deflections[2].The performance of ATV roll cage was studied against crashes that can be encounter in the real-life scenario and its consequences on the individual components, which must be designed to ensure the safety of the driver while not compromising the ergonomics[3].

Finite element analysis (FEA) was used in an attempt to optimise the rollcage, and the effects of stress and deformation were investigated for a linear static frontal impact study on the roll cage structure. The impact of additional auxiliary structures, such as the engine mount, gearbox, and other vehicle components, attached to the frame was investigated further. When the Von-Mises stresses were less than the material's yield strength and the structural components' deflections were sufficiently favorable to ensure the driver's safety, the structure's design was considered safe[4].

Particle swarm optimization algorithm along with the artificial immune algorithm is combined to address the multi-objective optimization problem of improving rollover crashworthiness while reducing mass, and the Pareto solution set exhibits superior uniformity and diversity[5].To ensure that the occupants remain secure in the event of an impact, a finite element model of the car is produced and computationally tested. In order to innovate the design of the Body in White (BIW) component of the car. A body-in-white (BIW) portion of the vehicle is taken, and the roll cage which is constructed with the material properties of carbon fibre (ePA-CF) and ASTM A36 steel (comparison) is taken for the dynamic analysis using ANSYS Workbench and LS DYNA [6].

The roll-cage's design is an essential component that determines the ATV's success; if it malfunctions, the driver and passengers will be in grave danger. As a result, the roll-cage of an all-terrain vehicle is designed with the driver's safety, ease of manufacture, durability, compactness, light weight, and ergonomics in mind. The roll cage is composed of thin, seamless pipes that are welded together to form a sturdy framework that can endure hard circumstances at the site of operation and vehicle flips that end upside down [7]. The roll cage is designed to meet the specifications of designed ATV mentioned in Table-1

Table-1: Specifications of ATV

| Parameter | Specification |
|---|---|
| Gross Vehicle Weight | 800 Kg |
| Ground Clearance | 600mm/2 Feet |
| Vehicle Length | 2986 mm/ 3 Mtr |
| Vehicle width | 2100 mm/ 2.5 Mtr |
| Vehicle Height | 2000 mm/2 Mtr |
| Wheel base | 2200 mm/ 2.2 Mtr |
| Wheel Track | 2500 mm/ 2.5 Mtr |
| Tyre Size | AT 32x10-14 (BKT) |

Based on the literature review, numerous researchers have explored into the design and optimization of roll cages. However, minimal attention has been paid to fortifying the roll cage materials. In this study, CSMT (Central School of Motor Transport), BSF Academy, Tekanpur focus on designing and analyzing a roll cage model that adheres to the usage of vehicle by Border Security Force frontiers at Creeks of Gujarat as shown in Fig-1 and also complying with the vehicle specifications as mentioned in **Table-1** .After developing a roll cage, it is subjected to non-destructive analysis, namely finite element analysis (FEA) simulation. Input data, derived from testing values of the selected materials, is fed into engineering material section for analysis. Boundary condition calculation is done for collision from 3 different directions. Prior to finalizing the material for fabrication of roll cage research offered simulations of impact tests of roll cages to determine best suitable strength characteristics of material. The actual figure of developed 03-seater ATV (02 front and 01 rear) under operation at frontiers is shown in Fig-2.


Fig-1 BSF Frontiers at Creeks of Gujarat

Fig-2 Actual view of ATV developed by CSMT, Tekanpur and operating at Gujrat Frontiers

## II. MODELING AND MATERIAL SELECTION OF ROLL CAGE

The modeling of the Roll Cage has been done using AUTODESK Inventor student version. While designing the roll cage, a maximum height 5 ft 8 inch was placed inside the roll cage in the driving position to check the roll cage clearances with respect to the driver. The size of the designed Roll Cage is 2900 × 1225 × 940 mm in length, width and height, respectively. Circular section is preferred comparatively for torsional rigidity for its higher polar moment of inertia compared than any other section[8] .Tubes of two different cross-sections namely primary, and secondary of dimensions 29.2 × 1.65 mm and 25.4 × 1.00 mm respectively have been used to design the roll cage structure to achieve the optimal strength to weight ratio. The roll cage has been designed to achieve better stress flow due to dynamic forces during vehicle operation, hence minimizing stress concentration at the joints. The final roll cage design has been achieved after performing a few design iterations and simulating them to check the stress flow and stress concentration in that design. The different members of the roll cage are shown in the **Fig-3**.

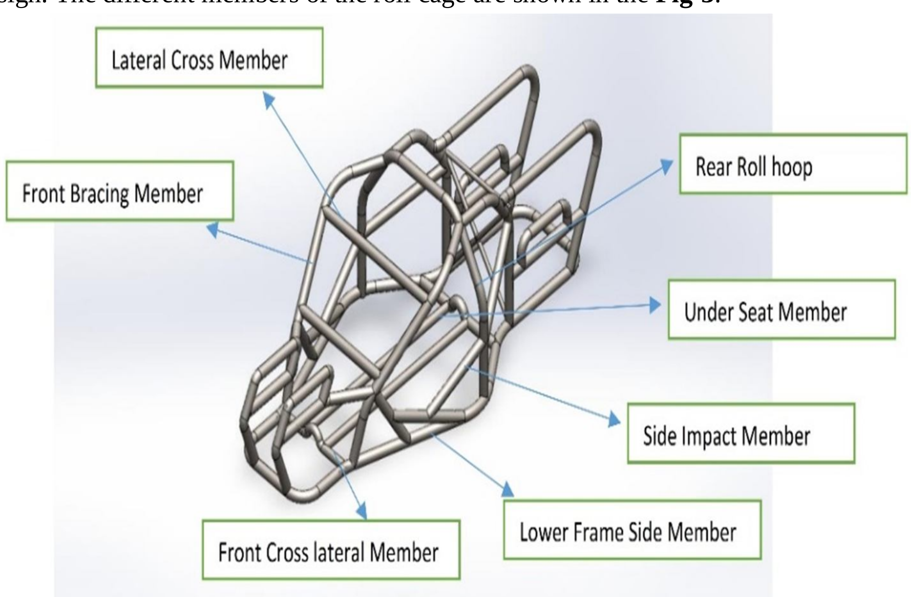


Fig-3 Isometric view of the Roll-cage.

The material selection process is a critical first step in the design and manufacture of a roll cage. The review of previous research specifies that the chassis material must include at least 0.18 percent carbon. As a result, the market offers a diverse range of materials that are permissible for usage, and have a variety of grades within each type of material from which to choose the best for the application. Three types of materials AISI 4130, 1020 DOM, and AISI 1018 are selected for roll cage fabrication. The side-by-side comparison of properties of these materials are mentioned in **Table-2**[9].

Table -2 Comparison of Material Properties

| Property | Material | 1018 Steel | 1020 DOM | 4130 Steel |
|---|---|---|---|---|
| Physical Properties | Density ($kg/m^3$) | 7870 | 7865 | 7850 |
| | Yield Strength (MPa) | 370 | 480 | 460 |
| | Tensile Strength (MPa) | 440 | 550 | 731 |
| Chemical Properties | Carbon, C | 0.14-0.20 | 0.05-0.26 | 0.28-0.33 |
| | Iron, Fe | 98.81-99.26 | 99.08-99.53 | 97.3-98.2 |
| | Manganese, Mn | 0.60-0.90 | 0.3-0.6 | 0.4-0.6 |
| | Sulphur, S | ≤0.50 | ≤0.05 | ≤0.04 |
| | Phosphorus, P | ≤0.40 | ≤0.04 | ≤0.035 |
| | Chromium, Cr | - | - | 0.80-0.95 |

## III. FINITE ELEMENT ANALYSIS

### *A. Element Type*

The finite element model's meshing has always been crucial, and any object's precise solution depends on it being correctly meshed with the appropriate element size and shape. Tetra mesh is typically recommended for solid bodies, that is why it is being used[10].

### *B. Assumptions*

1) The chassis material is considered to be isotropic and homogenous.
2) Chassis tube joints are considered to be perfect joints.
3) The Crumple zone phenomenon is not considered.

### *C. Mesh Size*

Meshing of roll-cage was carried out in Ansys student 2024 R1. In finite element analysis, the degrees of freedom are reduced from infinite to finite with the help of discretization or meshing (nodes and elements). Each small volume is called an element. Each element has a set of points called nodal points or nodes[10]. Nodes are usually located at the endpoints of elements. The stress values and mesh sizes for front, side and rear impact test are tabulated in Table-3.

Table-3 Parameters of Discretization and Von-Misses Stress

| Parameter | Front | Side | Rear |
|---|---|---|---|
| Size of Mesh (mm) | 16.736 | 16.736 | 16.736 |
| No. of nodes | 253451 | 254064 | 254064 |
| No. of Elements | 133384 | 133775 | 133775 |
| Max value of Von-Misses Stress (MPa) | 11.201 | 22.231 | 20.47 |

### *D. Boundary Conditions*

The designed IGES file is imported into the FEA solver. In static structural analysis, the boundary conditions were assigned for performing the front, side, and rear impact analysis corresponding to the constraints and application of load in each case. The front impact test was conducted by fixing the rear members and loads were applied at the front nose point of the roll cage. The side impact test was carried out by giving the constraints on one side of Side Impact Member (SIM), Rear Roll Hoop (RRH), rear middle Fore/Aft Bracing (FAB) member and respective side impact force was applied on another side the SIM, Rear RRH, rear middle FAB member. Similarly, the rear impact test was performed by fixing the front nose points and load was applied at the rear FAB members of the roll cage.

Impact Force Calculations***[11]:***

Weight of the vehicle including driver (m) = 800 kg

Initial velocity ($V_{initial}$) = 3.33 m/s (12 Km/hr.)

Final Velocity ($V_{final}$) = 0 m/s

Impact/impulse time (t) = 0.30 seconds [12]

From work energy principle,

Work done = Change in K.E,

$|W| = |\frac{1}{2} \times m \times (V_{final})^2 - \frac{1}{2} \times m \times (V_{initial})^2|$

$|W| = |\frac{1}{2} \times m \times (V_{initial})^2| = 4435.56$ Nm

Displacement (s) = Velocity(V) x Time (t)

$s = V_{final} \times t = 3.33 \times 0.3 = 0.999m$

W=Force(F) x Displacement (s)

F = W/s = 4435.56/0.999 = 4440.0 N

## IV. RESULTS OF STATIC STRUCTURAL ANALYSIS OF ROLL CAGE MODEL

The designed CAD model is imported into the Ansys student 2024R1. Then, the boundary conditions and constraints were applied as mentioned above to begin the simulation process. The output values of stress, deformation, and factor of safety for AISI 4130 material are shown for front, side, and rear impact in Table-4.

1) *Front impact analysis:* The roll cage model is analyzed for its front impact, the load of about 4440 N is applied in the front member of the roll cage, which is parallel to the longitudinal axis of the roll cage and in the opposite direction. The output values such as total deformation of 0.497mm, Von-Mises stress of 11.201Mpa, and factor of safety of 2.75 are obtained.
2) *Side impact analysis:* The roll cage model is analyzed for its side impact the same load of about 4440 N is applied in the side member such as SIM, RRH, rear middle FAB member of the roll cage, which was parallel to the lateral axis of the roll cage and giving constraints to another side of SIM, RRH, rear middle FAB members. The output values such as total deformation of 0.541mm, Von-Mises stress of 22.231 MPa , and factor of safety of 1.498 are obtained.
3) *Rear impact analysis:* The roll cage model is analyzed for its rear impact, again the same impulse/impact load of about 4440N is applied in the rear member such as rear FAB member and Rear Lateral Cross member (RLC) of the roll cage, which is perpendicular to the lateral axis of the roll cage and giving constraints to the front nose point. The output values such as total deformation of 0.485mm, Von-Mises stress of 20.47Mpa, and factor of safety of 2.5 are obtained.

Similar analysis are carried out for front, rear and side impact with other two materials viz. 1018 steel and 1020 (DOM).

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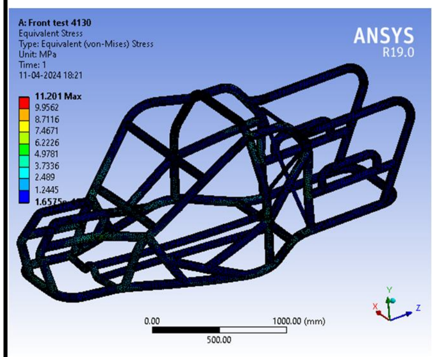
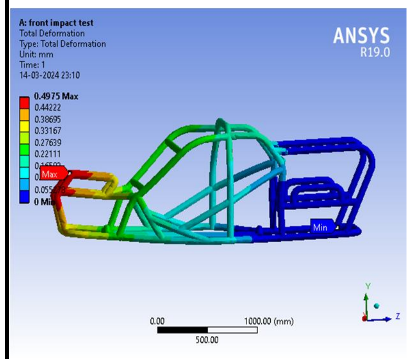
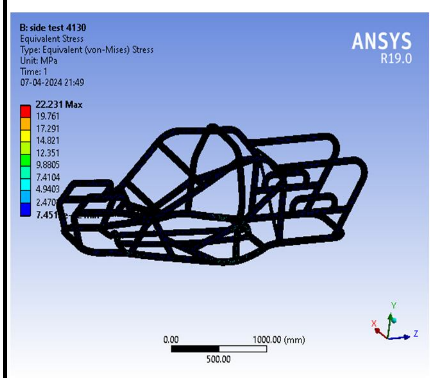
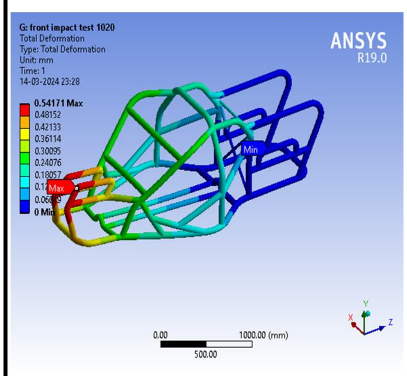
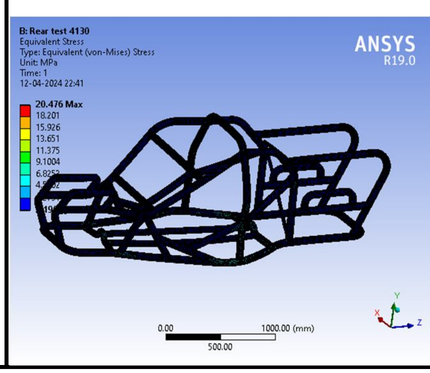
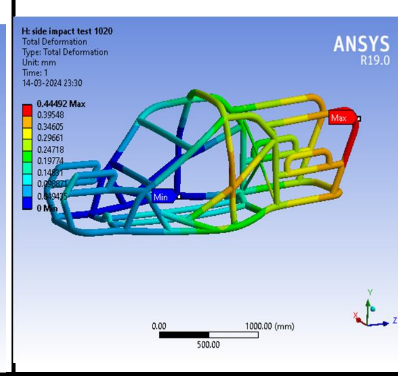
Table-4 Result of Front, Side and Rear Impact Analysis of AISI 4130 Roll-Cage

| | Parameter | Values | Stress Analysis | Deformation |
|---|---|---|---|---|
| Front | Load Applied<br>Max.Stress<br>Max,Deformation<br>FOS | 4440 N<br>11.201 MPa<br>0.497 mm<br>2.75 |  |  |
| Side | Load Applied<br>Max.Stress<br>Max,Deformation<br>FOS | 4440 N<br>22.231 MPa<br>0.541 mm<br>1.498 |  |  |
| Rear | Load Applied<br>Max.Stress<br>Max,Deformation<br>FOS | 4440 N<br>20.47 MPa<br>0.485 mm<br>2.5 |  |  |

- *Results of Solution Phase of FEA:*

The comparative analysis of deformation for the three materials and under three cases of impact loading is shown in **Fig-4.** The result showed highest deformation for side impact followed by rear and front impact, ensuring highest driver's safety under front collision. The deformation developed for AISI 4130 material is 3.7% and 12.7% lower than AISI 1020 and AISI 1018 material under front impact loading.

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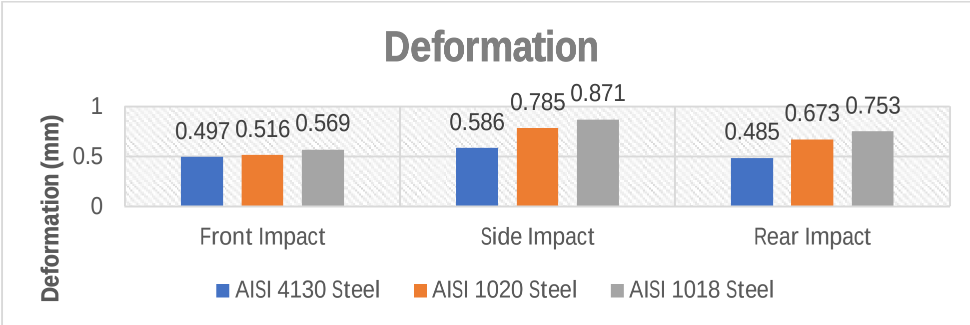


Fig-4 Comparison of Deformation

- *Results of Post-Processing Phase of FEA:*

The comparative analysis of equivalent Von-Mises stress for the three materials under consideration is shown in **Fig-5.** The result showed highest stress for side impact as compared to front and rear impact. The stress developed for AISI 4130 material is 25% and 46% lower than AISI 1020 and AISI 1018 material under front impact loading. Similar is the case with other two directional impact test.

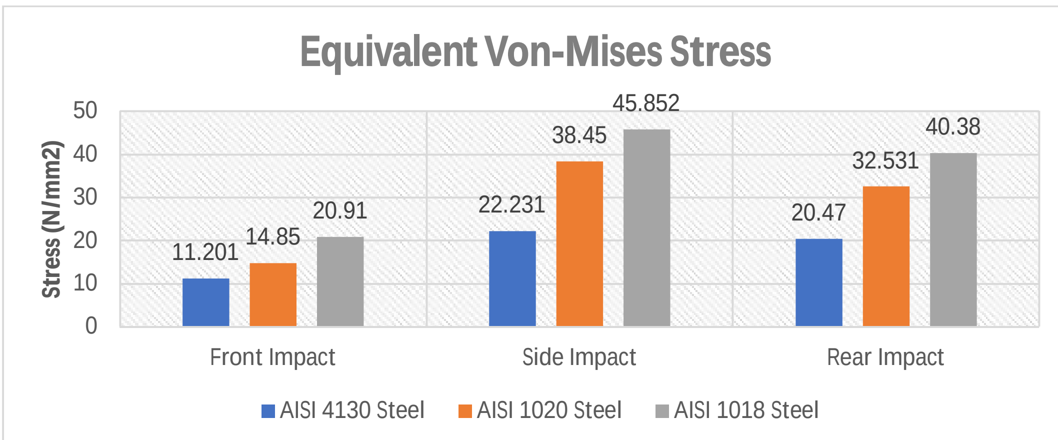


Fig-5 Comparison of Equivalent Von-Mises stress

The comparative analysis of FOS (Factor of Safety) for the three materials under consideration is shown in **Fig-6.** The FOS obtained for AISI 1020 and AISI 1018 are less than safe value of 1.5 [11], [13], [14]. The considerable FOS is obtained for AISI 4130 material ensuring ability of roll-cage to withstand all kind of loads and capable of moving on various terrains

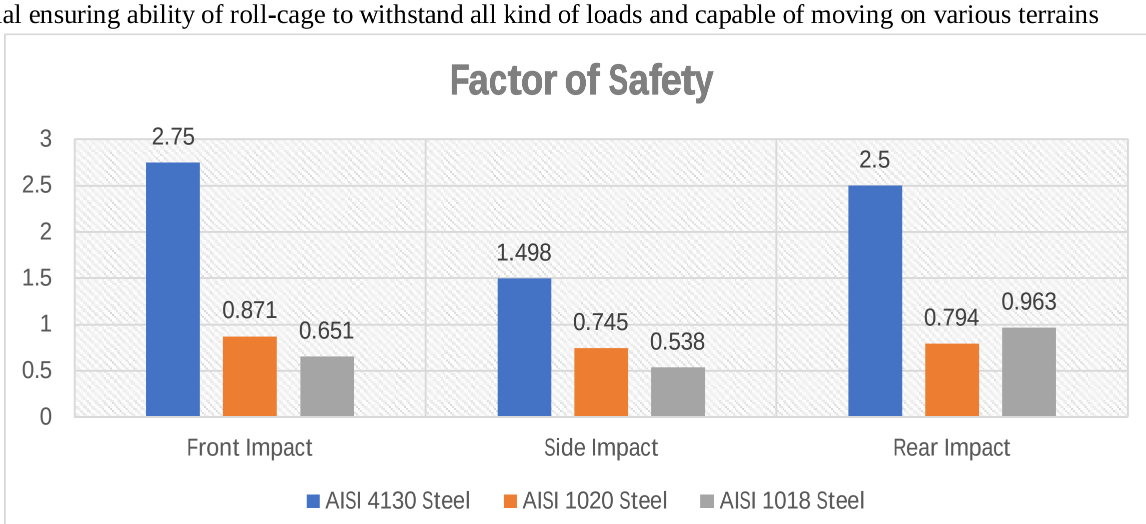


Fig-6 Comparison of Factor of Safety

## V. CONCLUSION

Considering safety in every respect, for the driver, crew & drive components of the 03-seater ATV the results drawn from FE analysis are mentioned below:

*1)* The solution phase of FEA showed lowest values of deformation for AISI 4130 material under all three cases of impact loading. From nominal values of deformation which is 0.5mm for front impact it can be concluded that the roll cage can effectively protect the driver from any injury during the event of a frontal crash of the vehicle.
*2)* The post processing phase of FEA showed least equivalent Von-mises stress for AISI 4130. The developed stress is 25% and 46% lower than AISI 1020 and AISI 1018 material under front impact loading.
*3)* A considerable Factor of Safety (FOS) or design factor which is above 1.5 is obtained for AISI 4130 this will minimize the risk of failure and possible resulting injury**[11]**. FOS value implies the safe value of applied loads and deformations.

The analysis confirms the vehicle's roll-cage durability in harsh environments and assist in material selection. Although it is challenging to continue with the designing and analysis of only roll cage, because there are numerous tests required to be performed under practical conditions.To maximize the material's effectiveness and strength, both the primary and secondary components of the roll cage will be made from the same material, i.e., 4130 AISI. The chassis design showed it’s ability to support a wide range of loads and manoeuvre over the marshy terrain found at Gujarat's Frontiers and Creeks.

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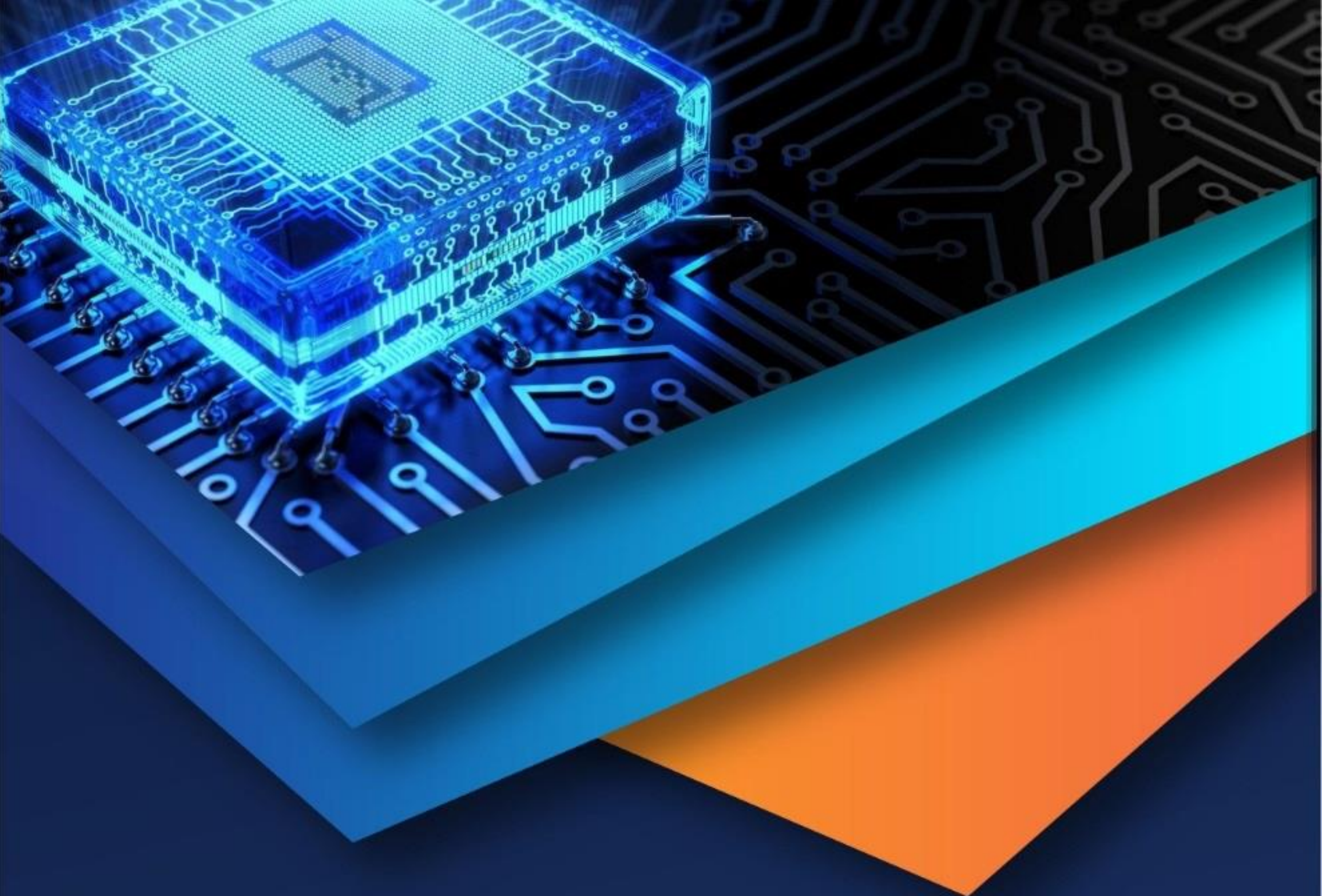


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