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Design, Manufacturing, and Testing of an Aluminum Knuckle Hub for an Electric Off-Road Vehicle.

RUKIREN ANALSEE G K - DEPARTMENT OF MECHANICAL, BANNARI AMMAN INSTITUTE OF TECHNOLOGY,ERODE

SABAREESH H-DEPARTMENT OF MECHANICAL, BANNARI AMMAN INSTITUTE OF TECHNOLOGY,ERODE

ROSHNI S - DEPARTMENT OF MECHANICAL, BANNARI AMMAN INSTITUTE OF TECHNOLOGY,ERODE

VEGASHINI N B - DEPARTMENT OF MECHANICAL, BANNARI AMMAN INSTITUTE OF TECHNOLOGY,ERODE

KARTHICK K N - ASSISTANT PROFESSOR LEVEL III, DEPARTMENT OF MECHANICAL, BANNARI AMMAN INSTITUTE OF TECHNOLOGY,ERODE

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Abstract - A steering knuckle is a critical component in the steering system of a vehicle, connecting the wheel hub to the suspension and steering linkage. It plays a crucial role in transmitting steering forces, supporting the wheel load, and ensuring proper wheel alignment. For rigid axle vehicles, the steering knuckle must withstand significant loads and maintain stability under various driving conditions. This paper delves into the design considerations for a steering knuckle specifically tailored for rigid axle applications. It explores the factors influencing the knuckle's shape, material selection, and stress analysis. The design process encompasses both analytical and computational methods, ensuring the knuckle's ability to handle the demanding requirements of rigid axle steering. The paper begins by outlining the functional requirements of the steering knuckle, emphasizing its role in load transfer, steering actuation, and suspension articulation. It then introduces the design methodology, highlighting the importance of material selection, structural analysis, and optimization techniques. Subsequently, the paper delves into the material selection process, considering the trade-offs between strength, weight, and cost. It evaluates various materials, including cast iron, forged steel, and aluminium alloys, based on their mechanical properties and suitability for rigid axle applications. Next, the paper addresses the structural analysis of the steering knuckle, employing finite element modeling to assess its performance under various loading scenarios. It examines stress distribution, deflection, and fatigue behaviors, ensuring the knuckle's structural integrity under the rigors of rigid axle operation. In conclusion, the paper presents a comprehensive approach to the design of a steering knuckle for rigid axle vehicles.

***Key Words*:**

Knuckle Hub

Load Transfer

Aluminium 6061-T6,

Kingpin

Center Bolt

Finite Element Analysis

Steering Knuckle

Bump Force

1.INTRODUCTION:

In the realm of automotive engineering, the steering knuckle stands as a crucial component, bridging the gap between the wheel hub, suspension system, steering linkage, front axle, and brake caliper mount. Its primary function lies in transmitting steering forces, supporting wheel load, and maintaining proper wheel alignment. For vehicles equipped with rigid axles, the steering knuckle assumes even greater significance, as it must withstand substantial loads and maintain stability under diverse driving conditions. The design of a steering knuckle for rigid axle applications necessitates careful consideration of various factors, including Material selection**,** Structural analysis, and Optimization techniques. While turning the wheel using a tension and compressive force steering act on the Knuckle.

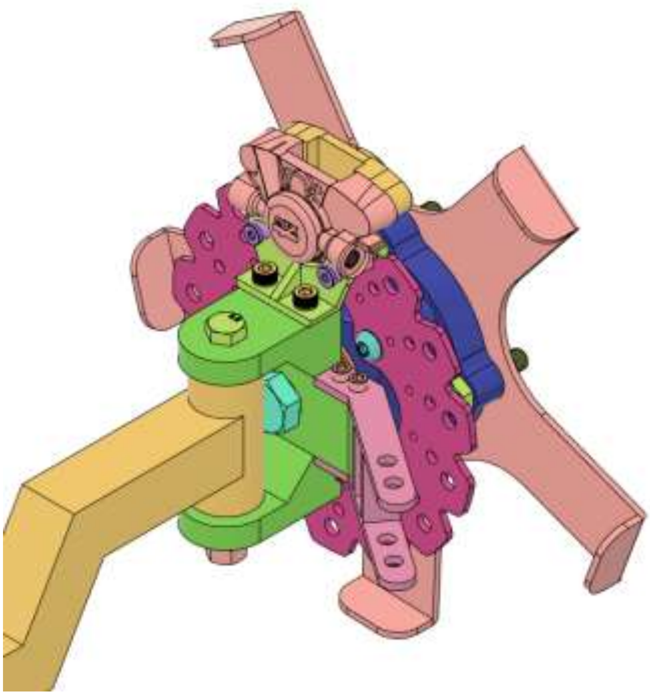

FIGURE.1 KNUCKLE WITH FULL WHEEL ASSEMBLY

knuckle · *Front rigid axle.*
caliper mount · *Kingpin*
Steering connecting rod · *Center bolt.*

2.METHODOLOGY:

Before designing and fabricating the knuckle, the initial step involves recognizing the need. In the case of a vehicle with a rigid axle, a knuckle is essential. If the decision is made to acquire the knuckle from the OEM design, the vehicle must be designed to accommodate the specifications of the OEM knuckle. To design a vehicle around a custom knuckle, the next step is customization and fabrication. The subsequent step in determining the specifications and requirements for this knuckle is to support key elements such as the kingpin, brake mount, steering tie rod mount, and center bolt, and ensuring corrosion resistance, high strength, and support for a rigid axle. Adhering to these specifications, the knuckle is then designed accordingly. The feasibility of the knuckle is assessed by considering factors such as material costs, machining costs, and the availability of both material and machinery. For the material, aluminum 6 series 6061 is selected due to its feasibility and market availability. For machining, a CNC milling machine is chosen for fabrication due to its cost-effectiveness. Once the specifications and feasibility aspects are completed, the next step involves designing the steering knuckle using CAD modeling, specifically SolidWorks 2021. Subsequently, a static and dynamic analysis is performed using ANSYS 2021. If the static and dynamic analysis and design meet the required criteria, the process proceeds. If not, the iteration continues until satisfaction is achieved. Before moving to production, a prototype is constructed to verify the design. If the prototype meets expectations, detailed drawings are created for manufacturing. This comprehensive process ensures that the design is thoroughly validated before entering the production phase.

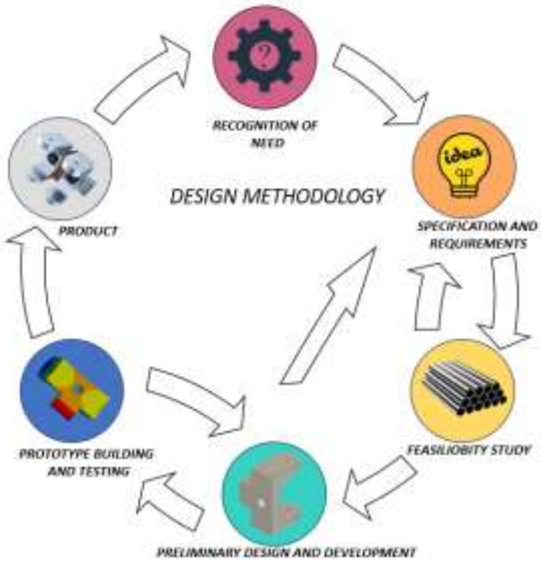

FIGURE.2 DESIGN METHODOLOGY

3.MATERIAL SELECTION:

The selection of material for the steering knuckle is a critical aspect of the design process, and after careful consideration, the aluminum 6 series 6061-T6 material has been chosen. This material is part of the 6 series, known for its excellent combination of strength, toughness, and corrosion resistance. The "T6" designation signifies that the aluminum alloy has undergone a solution heat treatment followed by artificial aging, enhancing its mechanical properties. Aluminum 6061-T6 is renowned for its high tensile strength and good machinability, making it a suitable choice for components subjected to significant mechanical loads. Additionally, this material offers advantageous characteristics such as lightweight and ease of fabrication, contributing to overall efficiency in the manufacturing process. The use of aluminum 6061-T6 aligns with the specific requirements of the steering knuckle, ensuring a balance between structural integrity and practical considerations for performance and manufacturability.

S.NO	PROPERTIES	VALUE
1	DENSITY	2.7 g/cm³
2	TENSILE STRENGTH, ULTIMATE	310 Mpa
3	TENSILE STRENGTH, YIELD	276 Mpa
4	MODULES OF ELASTICITY	68.9 Gpa
5	POISSION'S RATIO	0.33
6	SHEAR STRENGTH	207Mpa
7	THERMAL CONDUCTIVITY	167W/mk

TABLE.1 AL6061 PROPERTIES

4. DESIGN MODELING:

Using SolidWorks 2021, the steering knuckle was designed with careful consideration for incorporating essential components such as a brake caliper mount, kingpin, steering tie rod, front axle, and center bolt.

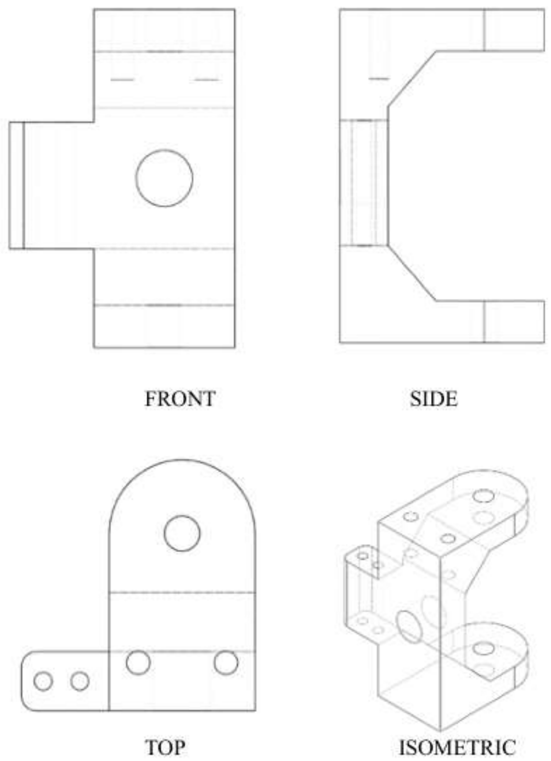

FIGURE.3 KNUCKLE SKETCH

LENGTH	50 mm
WIDTH	85mm
HEIGHT	120mm
KINGPIN MOUNT	⌀12mm
CENTER BOLT MOUNT	⌀20mm
CALIPER MOUNT	⌀8mm
STEERING ROD MOUNT	⌀6mm
WEIGHT	0.65 kg

TABLE.2 DIMENSIONS OF KNUCKLE

5.FEA ANALYSIS:

Analysis is the intermediary step between model design and the final production phase. After creating the knuckle model, a Finite Element Analysis (FEA) is conducted to assess the product's ability to withstand stress and strain before reaching failure, as well as to verify the Factor of Safety (FOS). This process effectively reduces costs. Ansys R2021 is employed for the FEA analysis.

MESH TYPE	SIZING
MESH SHAPE	HEXAHEDRAL
MESH SIZE	5mm
NO OF NODES	27402
NO OF ELEMENTS	17590

TABLE.3 MESH CONDITION

5.1 Meshing condition:

Meshing has been done for the knuckle in a tetrahedral shape because it is a three-dimensional, four-faced polyhedron that is more effective for regular geometry and structures with planar surfaces.

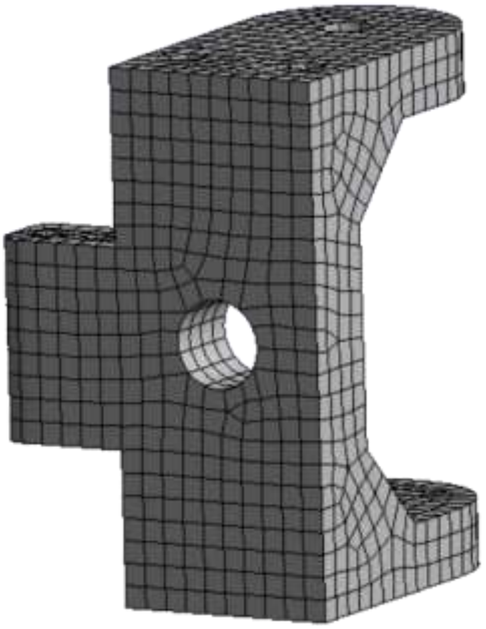

FIGURE.4 HEXAHEDRAL MESH

After completing the mesh, boundary conditions were specified. These conditions encompass various loads acting in different directions with distinct forces, such as bump force, steering force, brake torque, cornering force, weight transfer, and vertical impact load.

5.2 Boundary condition:

Boundary conditions involve forces acting with different magnitudes and directions, as well as the type of support provided with specific magnitudes.

In knuckles, several forces act with varying magnitudes, such as bump force acting on the center bolt or stub axle, cornering force, weight transfer, steering force, impact force, braking torque, and fixed support at the kingpin mount.

FORCE ACTING	LOCATION
BUMP FORCE	CENTER BOLT
CORNERING FORCE	CENTER BOLT
WEIGHT TRANSFER	CENTER BOLT
STEERING FORCE	STEERING ARM
BRAKING TORQUE	CALIPER MOUNT
FIXED SUPPORT	KING PIN MOUNT

TABLE.4 FORCES

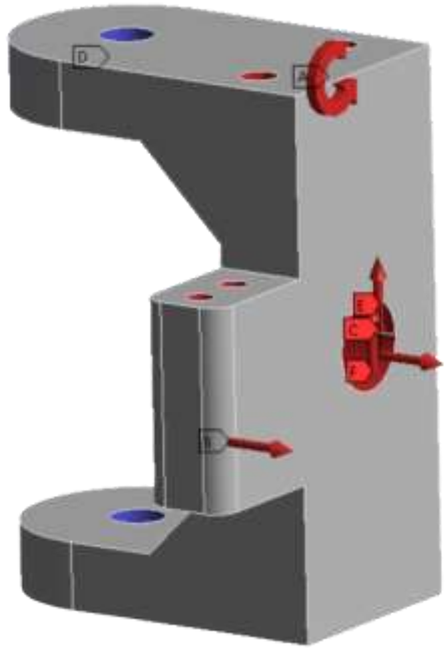

FIGURE.5 FORCE ACTING MAGNITUDE AND DIRECTION

FORCE ACTING	TAG
BUMP FORCE	E
CORNERING FORCE	C
WEIGHT TRANSFER	F
STEERING FORCE	B
BRAKING TORQUE	A
FIXED SUPPORT	D

TABLE.4 FORCE MAGNITUDE

5.2 Forces:

5.2.1WEIGHT TRANSFER:

In weight transfer, the gross vehicle mass is considered, including the occupants. The mass of the vehicle without passengers is 1000 kg, and the considered occupant mass is 130 kg, so the total mass is 1130 kg. Due to the powertrain and motor placement on the rear side, the load distribution on the front side is 282.5 kg. By dividing this mass in half, the load acting on a single knuckle is determined.

WEIGHT TRANSFER = 282.5 KG = *2771.3 N*

5.2.2FIXED SUPPORT: Fixed support is located on the kingpin mount because in this magnitude, the knuckle is fixed with the front axle.

6.3.3BRAKE FORCE:

The brake caliper mount is placed on top of the knuckle with the help of two M8 bolt when the vehicle is moving forward the disc attached to the wheel hub is rotated in an anti-clock direction, so the twisting momentum act in the anti-clockwise direction.
The force acted on the caliper mount is calculated.

All units in the meter

Bore Area of the master cylinder = πd^2/4
*= 3.14*243.36/4 = 191.0376 = 191.0376/1000*
=0.191038 m

Bore Area of the piston = πd^2/4
*=3.14*144/4 =113.04 = 113.04/1000*
=0.11304 m

Force on master cylinder = Force applied * pedal ratio
*=300*5 = 1500 N*

Pressure Generated by Master cylinder.
= Force on the master cylinder * Bore Area of the master cylinder
*=1500*0.191038 = 7851.857N/m^2*

Torque To find Clamping Force
Tc = 2*Pressure*Coefficient of friction*area of Piston*Radius Mean*Number of pistons (Should not Include 2 pistons)
*= 2*7851.857*0.4*0.11304*0.0925*6 =394.0828 Nm*

Clamping Force
=Torque Tc / 2*Coefficient of friction*Radius mean *=394.0828/2*0.4*0.0925 =5325.444 Nm*

Rotating Force
= Clamping force*coefficient of friction*No of caliper
*=5325.44*0.4*4 =8520.71Nm*

Braking force
=Disc Radius*Rotating Force
*=0.15125*8520.71 =1288.757 N*

BRAKING FORCE = *1290 N*

5.2.3 BUMP FORCE:

Bump force is the normal force action on the vehicle in the upward direction due to a bump. This force can be found using the Force formula, but a little consideration in this time taken is the time taken for the vehicle to reach the bump at the maximum acceleration.

Impact force = K.E=1/2mv2
For falling object, the velocity will be = $\sqrt{2gh}$
h = *0.55 m*
V= $\sqrt{2*9*81*0.55}$ *= 3.28 m/s*
K.E = *1/2/*412*3.82^2 = 2222.94 N*
Bump Force = *2223 N*

5.2.4 STEERING FORCE:

Steering force is when the occupant should apply the steering wheel to turn in the direction of the vehicle. To calculate this force

The force of friction on the one-wheel
= weight transfer * 0.8(coefficient of friction)
= 2452.5 * 0.8
=*1962 N*

Input torque from the ground (on one wheel)
= force of friction x perpendicular distance from contact patch to kingpin axis
= *1962 *0.12831*
= *251.71 Nm*

NOTE: perpendicular distance from contact patch to kingpin axis found using Lotus software.

The total force on the rack
= Force on tie rod * 2
=*1762.03 Nm*

The radius of the pinion = *0.0261m*

Torque on pinion = 1762* 0.0261 = *45.04 Nm*

5.2.5.CORNERING FORCE:

It is the force generated by your wheels while turning in the lateral direction. To calculate the cornering force,

CORNERING FORCE = *4443.31 N*

FORCE	VALUES
WEIGHT TRANSFER	*2771.3 N*
BRAKE FORCE	*1290*
BUMP FORCE	*2223 N*
STEERING FORCE	*204.76 N*
CORNERING FORCE	*4443.31 N*

TABLE.5 FORCES VALUE

6: FEA REASULT:

For the result, static analysis and the addition of dynamic analysis were applied with the above-mentioned boundary conditions to ensure real-time scenarios. This mainly focused on Von Mises stress, strain, and the factor of safety. Initially, static and dynamic stress, strain, and FOS were calculated separately to understand how the design reacts to each condition individually. Finally, the system was simulated by applying all the forces in the same model to check real-time scenarios

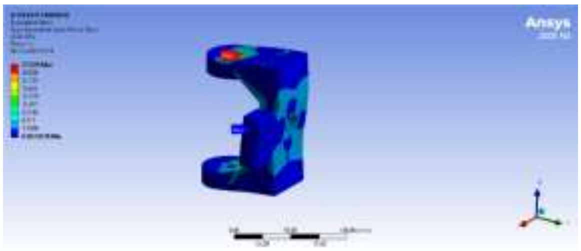

FIGURE.6:STRESS

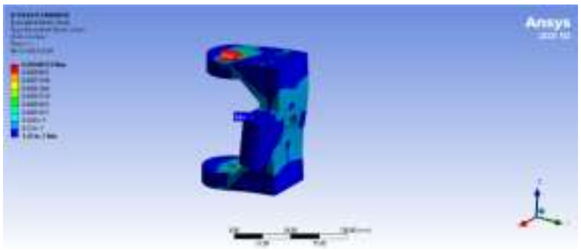

FIGURE.7 STRAIN

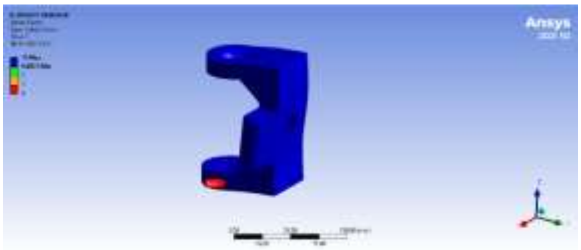

FIGURE.8: FACTOR OF SAFETY

For an extreme condition, the force is taken four times greater than the actual force.

RESULT

SOLUTION	MIN	MAX
STRESS	*0.00726 Mpa*	*27.929Mpa*
STRAIN	*1.76e-7mm/mm*	*0.00040mm/mm*
FOS	*9.88*	*15*

TABLE.6 WEIGHT TRANSFER RESULT

6.1:STEERING FORCE:

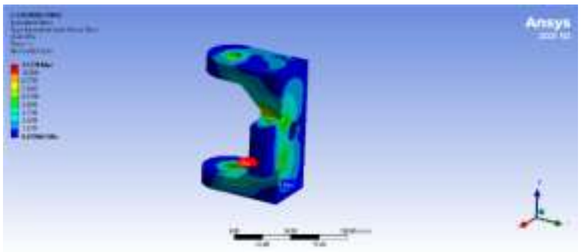

FIGURE.9: STRESS

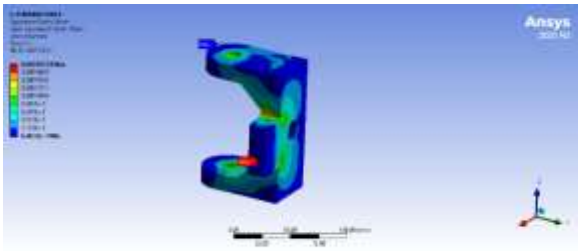

FIGURE.10: STRAIN

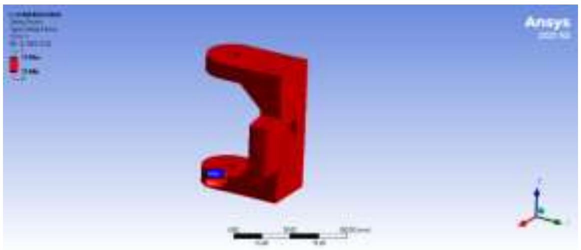

FIGURE.11: FACTOR OF SAFETY

For an extreme condition, the force is taken four times greater than the actual force.

RESULT

SOLUTION	MIN	MAX
STRESS	*0.028 Mpa*	*11.29Mpa*
STRAIN	*6.46e-7mm/mm*	*0.00018mm/mm*
FOS	*15*	*15*

TABLE.7 STEERING FORCE RESULT

6.2:BRAKING TORQUE

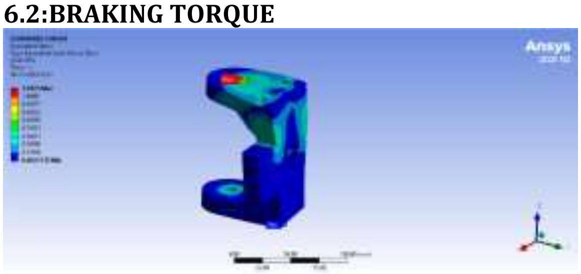

FIGURE.12: STRESS

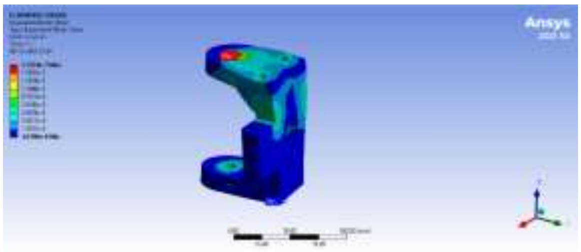

FIGURE.13: STRAIN

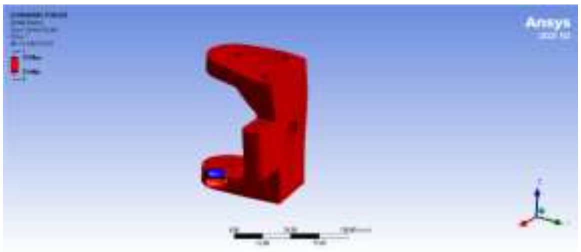

FIGURE.14: FACTOR OF SAFETY

For an extreme condition, the force is taken four times greater than the actual force.

RESULT

SOLUTION	MIN	MAX
STRESS	*0.02126 Mpa*	*1.29Mpa*
STRAIN	*3.96e-8mm/mm*	*0.000017mm/mm*
FOS	*15*	*15*

TABLE.8 BRAKING TORQUE RESULT

6.3: BUMP FORCE:

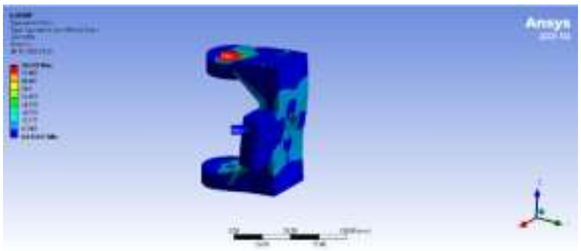

FIGURE.15: STRESS

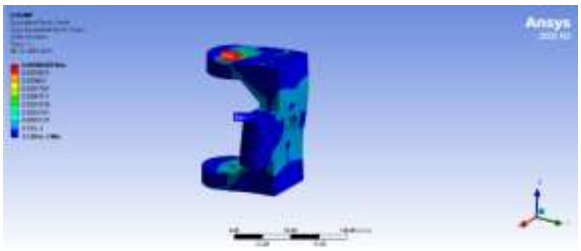

FIGURE.16: STRAIN

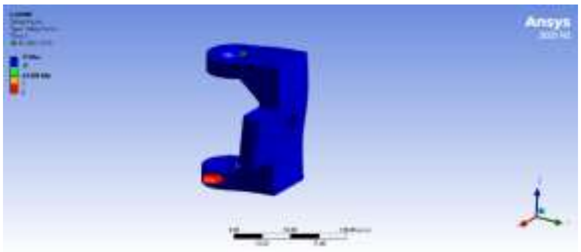

FIGURE.17: FACTOR OF SAFETY

For an extreme condition, the force is taken four times greater than the actual force.

RESULT

SOLUTION	MIN	MAX
STRESS	*0.012126 Mpa*	*59.24 Mpa*
STRAIN	*3.76e-7mm/mm*	*0.00086mm/mm*
FOS	*4.65*	*15*

TABLE.9 BUMP FORCE RESULT

6.4: CORNERING FORCE:

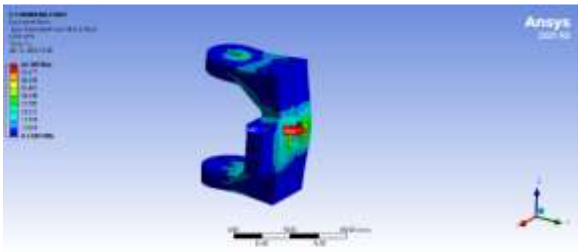

FIGURE.18: STRESS

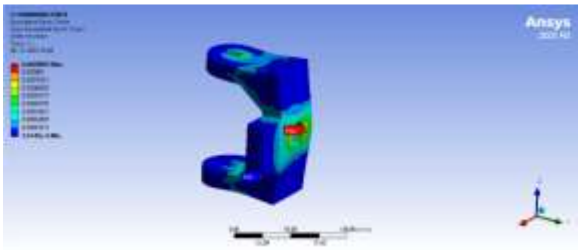

FIGURE.19: STRAIN

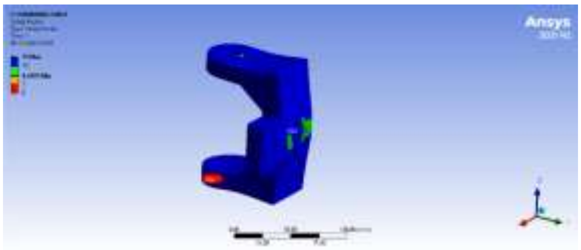

FIGURE.20: FACTOR OF SAFETY

For an extreme condition, the force is taken four times greater than the actual force.

RESULT

SOLUTION	MIN	MAX
STRESS	*0.13126 Mpa*	*62.169 Mpa*
STRAIN	*5.01e-6mm/mm*	*0.000909mm/mm*
FOS	*4.439*	*15*

TABLE.10 CORNERING FORCE RESULT

6.5: ALL THE FORCE AT SAME TIME

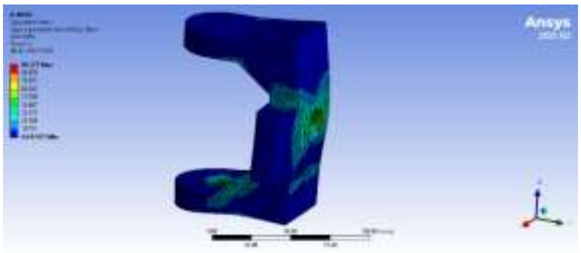

FIGURE.21: STRESS

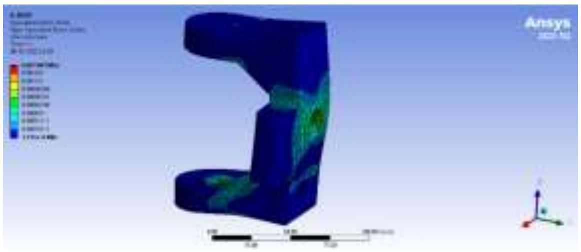

FIGURE.22: STRAIN

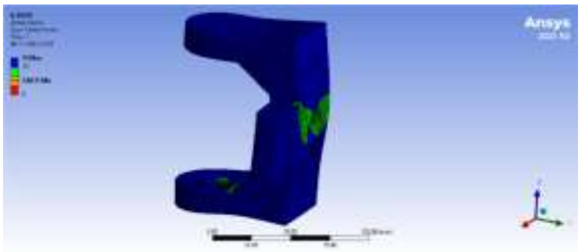

FIGURE.23: FACTOR OF SAFETY

For an extreme condition, the force is taken four times greater than the actual force.
RESULT

SOLUTION	MIN	MAX
STRESS	*4.74e-002 Mpa*	*96.24 Mpa*
STRAIN	*1.136e-6mm/mm*	*1.44e-003mm/mm*
FOS	*2.83*	*15*

TABLE.11 ALL THE FORCE RESULT

7. MD AND PRODUCT:

Many iterations have gone through FEA analysis until the desired value is reached. In every iteration, some modification has been made in the CAD model according to stress, strain, and FOS value. After many iterations, the final CAD model was shown in the figure.3 After FEA the prototype of the Steering knuckle was 3D printed and physically verified.

For the Fabrication of the steering Knuckle Manufacturing drawing (MD) was drafted in Fusion 360 software. In manufacturing drawings, the tolerance limits and Datum plane details are mentioned in the figure.
Manufacturing a piece of Knuckle takes 6 days total of 48 hours in a CNC milling machine. The final product is shown in the figure

FIGURE.24: PROTOTYPE

8. CONCLUSION

The steering knuckle was successfully designed and fabricated using aluminum 6 series 6061 with the help of Solid-works 2021, Ansys R2 2021, and CNC milling mechanics. The main purpose of designing the steering knuckle was for electric four-wheeler design competitions conducted by SAE India's southern section. With proper design and engineering calculations, the steering knuckle withstood the load in all conditions during dynamic tests such as bump tests, range tests, brake tests, acceleration tests, gradability tests, and maneuverability tests, securing an overall 2nd position in this competition.

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