International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 06 | June - 2021 ISSN: 2582-3930

Design and Analysis of Rear Wheel Hub and Steering Knuckle using Computer Aided Design (CAD) and Computer Aided Engineering (CAE).

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Abstract - The paper describes process of design and analysis for rear wheel hub & steering knuckle. In automotive system Wheel hub & steering knuckle system are attached to motor shaft (axle) and provide the support to the tie rods, and connect the trailing arm from chassis to the rear wheel, and fastening of brake calliper respectively. While designing the wheel hub & steering knuckle we have to work on overall shape, material specification, size, surface finish and appearance, and also ease of fastening & handling. As rear wheel hub & steering knuckle is undergoing radial load, axial load, tangential load, fatigue load during running condition in the various automotive system. The Design of Rear wheel hub and Steering Knuckle is done by using computer Aided Design software Creo 5.0, The Finite element analysis (FEA) is done by using Computer Aided Engineering software Ansys Workbench, FEA is used after designing process for checking the factor of safety and possible changes that can provide adequate safety design. And also for selecting the exact material by which we can make light weight wheel hub & steering knuckle with adequate properties so that it will survive against different load conditions with higher factor of safety.

Key Words: Wheel Hub, Steering Knuckle, Creo 5.0, Ansys Workbench, Safety, Light Weight.

1.INTRODUCTION

Wheel assemblies used in automobiles consist of Hub, Knuckle, Bearings and it is integrated as unibody or part components. Wheel hub and Steering Knuckle are important parts in automotive system, the main aim behind the study of design and analysis for rear wheel hub & steering knuckle is to evaluate the importance of wheel hub & steering knuckle in automotive system and how to make adequate design with required material. And in every automotive we have to count wheel hub & steering knuckle as a critical part because both help to connect chassis to wheel. So, we can't imagine any automotive system without wheel hub & steering knuckle because while transmitting the motion from engine to wheel, the wheel hub & steering knuckle must be necessary. Wheel hub is located between brake caliper and knuckle. While knuckle is located between trailing arm i.e. rear suspension system only. Creo 5.0 is used for the 3-D modeling of hub and knuckle. After modeling we are going to test wheel hub & steering knuckle again with all the load conditions by performing stress-strain analysis using ANSYS 15.0 Workbench. The reason behind conducting stress-strain analysis is that the vehicle wheel hub & steering knuckle are undergoing various torque, thrust, and different load condition So, we can make adequate changes in the material selection for manufacturing the same and also for design with higher factor of safety.

2. Methodology

Product Designing and Analysis is one of the most important and through process. At different design stages, and During the Analysis various problems occurred that need to be solved. This study has been followed in two parts. First part of this study includes modelling of Wheel Hub and steering knuckles component and In Second Part the analysis of both the parts under different loading condition is tested. CAD models of Wheel Hub and steering knuckle were developed in 3D modelling software, such as Creo 5.0. While the second part is of the models were then compared using finite element analysis (FEA) by ANSYS WORKBENCH 15.0

Approach of Study Shown in fig.1

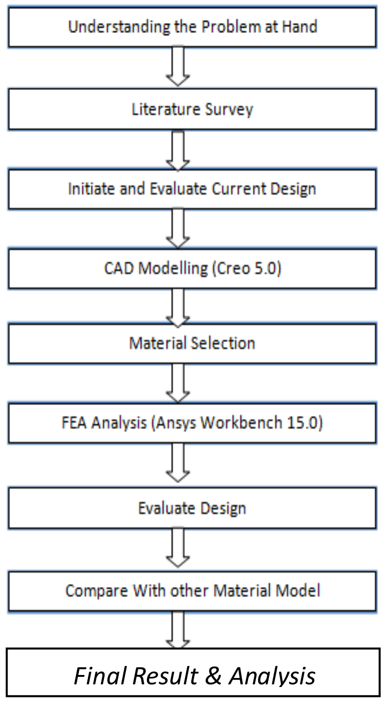

Fig -1:Approach of Study

3. Material Selection

While we design any part of automotive system it involves ~~so~~ many things such across section determination, adequate strength, light weight, higher factor of safety. Among them material selection is very important because its effect on total cost, power transmission efficiency, density, material availability, total weight, manufacturing methods. The wheel hub is to be manufactured to take high axial, longitudinal and lateral loads from road surface, and during steering and turning the steering knuckle is subjected to compressive and tensile loads and due to the wheel rotation it is also subjected to torsional load. This above conditions can only be satisfied if the wheel hub and Steering Knuckle materials have high yield strength and ultimate tensile strength, Higher Factor of Safety, Young Modulus and Fatigue Strength.

The table below shows the material used for Wheel hub and Steering Knuckle,

Mechanical Properties	Aluminium 6061 T6	EN8 Mild Steel	Grey Cast Iron
Density (Kg/ mm^3)	2710	7850	6900
BHN	95	201	200
RHN	40	93	50
Ultimate Tensile Strength (MPa)	310	620	350
Tensile Yeild Strength (MPa)	276	415	100
Young Modulus (GPa)	70	190	80
Poisson Ratio	0.33	0.27	0.3
Fatigue Strength (MPa)	96.5	74.6	68.9
Melting Point (°C)	582-652	1500	1127-1204

Table -1: Material for Wheel Hub

Mechanical Properties	Aluminium 7075 T3	Forge Steel EN47	Grey Cast Iron
Density (Kg/ mm^3)	2770	7700	6900
BHN	150	150	200
RHN	87	90	50
Ultimate Tensile Strength (MPa)	310	650	350
Tensile Yeild Strength (MPa)	280	350	100
Young Modulus (GPa)	70	200	80
Poisson Ratio	0.33	0.3	0.3
Fatigue Strength (MPa)	96.5	275	68.9
Melting Point (°C)	572-632	1425	1127-1204

Table -2: Material for Steering Knuckle

4. Design and Finite Element Analysis

4.1 Rear Wheel Hub

The design of Wheel Hub is done with the help of Computer Aided Drawing (CAD) Wheel Hub is prepared in Creo Parametric 5.0, which is a computer graphics system for modeling various mechanical designs and for performing related design and manufacturing operations. The system uses a 3D solid modeling system as the core, and applies the feature-based, parametric modeling method. In short, Creo Parametric is a feature-based, solid modeling system with many extended design and manufacturing applications.

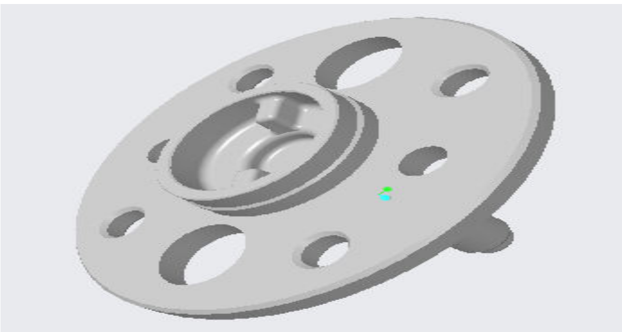

Fig -2:3D CAD Model

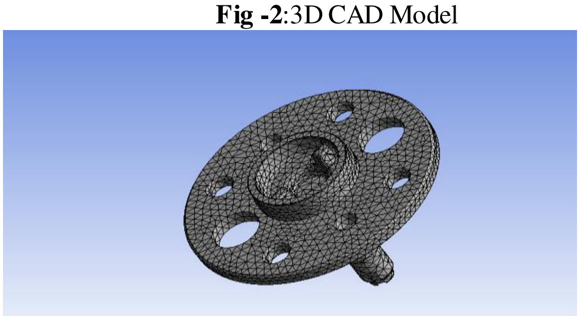

Fig -3:Meshing of Wheel Hub

Tetrahedral free meshing was done, as the component had smooth curves, and cylindrical topology. The meshing was automatically refined at the points where there was discontinuity in the form of step, hole etc.

Analysis Type	Structural Analysis
Element Type	Tetrahedral
Mesh Type	3D
Number of Nodes	31928
Number of Elements	19232

Table -3: Analysis Parameter Setup for Rear wheel Hub

The baseplate is bolted on to the wheel rim and hence constrained in 3 Degrees Of Freedom. Loads are applied on the other base plate.

Forces applied on Rear Wheel Hub are calculated as

Pedal force	=	600 N
Pedal ratio	=	6.5
Master cylinder bore diameter	=	20 mm
Calliper bore diameter	=	28.44 mm
Ratio of bore areas	=	56.64 mm
Calliper pad and disc friction coefficient	=	0.35

Braking force = 2 × Pedal force × Pedal ratio
× Ratio of bore areas
× Calliper pad and disc friction coefficient
= 2 ×600×6.5×0.35×2.23
Braking Force = 6087.9 N

Vehicle mass considered for calculation (m)	=	1240 kg
Vehicle mass for One wheel	=	310Kg
Deceleration (ad)	=	0.9 g
Traction coefficient (μ)	=	0.8
C.G. height	=	21 inch (533.4mm)
Wheel base	=	54 inch (1371.6mm)
C.G. height/ wheelbase (γ)	=	0.388
Weight distribution	=	front - 45%; rear - 55%

Dynamic normal load on the front axle (FzF,yn)
$= (1 - v + \gamma ad) \times g$
= (1-0.45×0.388×.9) × 310 × 0.98
= 2734.557 N

Dynamic normal load on each tyre $= \frac{FzF,dyn}{2} = 1367.278 N$

Tractive force = 2734.557 × 0.80 = 1093.82 N

Braking torque = 1093.82 × 11× 0.0254 = 305.61 Nm

Braking torque on front wheel = 305.61 × 1.50 = 450.42 Nm

Calculation of cornering force for Wheel hub

Vertical mass considered for calculation (m) = 310 kg

Gross weight of vehicle (G) = m × g = 310 × 9.81 = 3041.1 N

Longitudinal Force $(F\mu 1) = G \times = 2432.88\ N$

Lateral Force $(F\mu 2) = F\mu 1 \times \mu 1$ = 310× 9.81 × 0.80 × 0.80

= 1946.30 N

We have the Equation,

$$F\mu 1 \times rh + F\mu 2 \times rh + (G + Fdec) \times ras - Ns1 \times (ras + ras) = 0$$

(2432.88 + 1946.30) × 0.432−$Ns1$ × 1.244 + (3041.1 +2432.88) × 0.622 = 0

$Ns1$=4222.95 N

Cornering force $(Ka) = (Ns1) \times 0.80 = 4222.95 \times 0.80$

$= 1689.18\ N$

Factor of safety=1.48

Cornering force (Ka)=1689.18 × 1.48 N = 2500 N

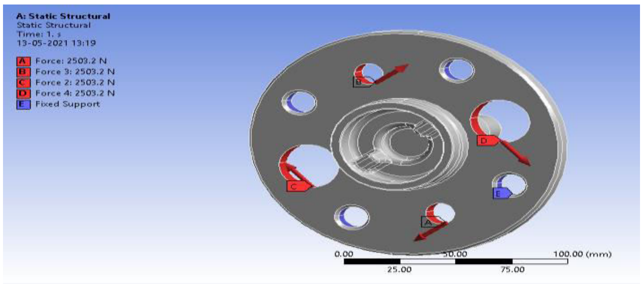

Fig -4:Constraint and Load Applied on wheel hub

After applying load on the Rear Wheel hub the analysis is taken place with the help of ANSYS Workbench for finding Deformation, Stress generated and the factor of safety by using different materials as mentioned in table 1.

Following figure shows analysis for Rear Wheel hub by using Aluminium 6061 T6 -

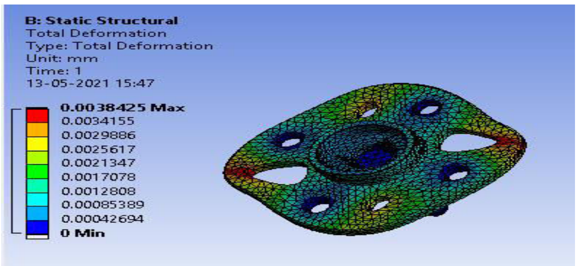

Fig -5:Total Deformation on wheel hub

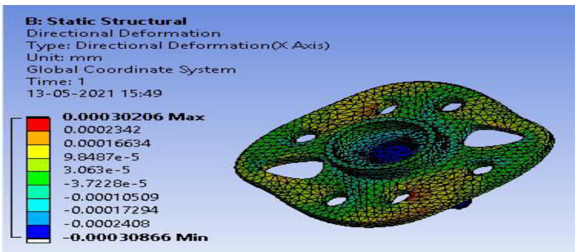

Fig -6:Directional Deformation on wheel hub

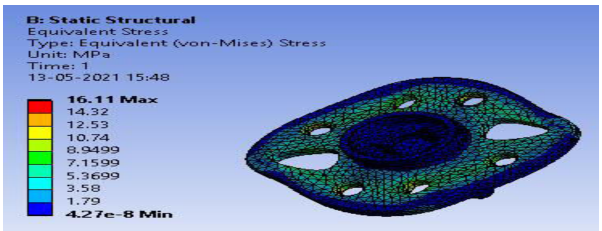

Fig -7:equivalent Von-Mises Stress on wheel hub

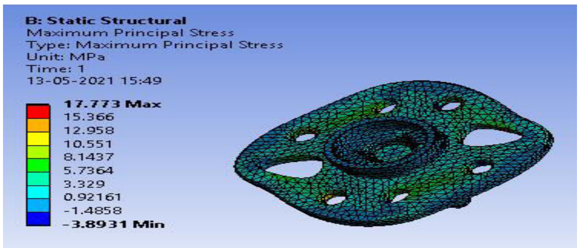

Fig -8:Maximum Principal Stress on wheel hub

Similar analysis is done for the other material as mentioned in Table 1 for EN8 Mild Steel, and Grey Cast Iron.

4.2Steering Knuckle

The design of Steering Knuckle is done with the help of Computer Aided Drawing (CAD). Steering Knuckle is prepared in Creo Parametric 5.0 which is used for 3D modeling.

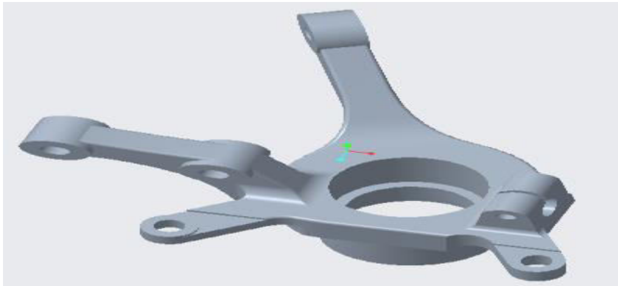

Fig -9:3D CAD Model

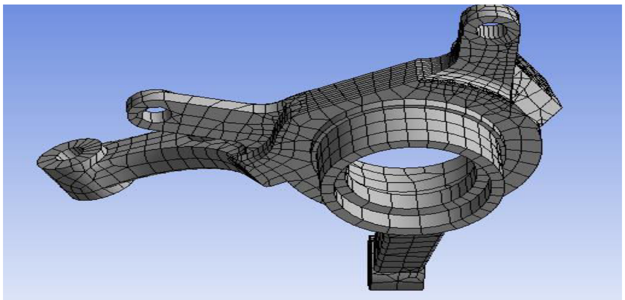

Fig -10:Meshing of Steering Knuckle

Hexahedral free meshing was done, as the component had smooth curves, and cylindrical topology.

Analysis Type	Structural Analysis
Element Type	Hexahedral
Mesh Type	3D
Number of Nodes	29391
Number of Elements	16212

Table -4: Analysis Parameter Setup for Steering Knuckle

There are various forces acting on Steering Knuckle such as braking force, moment, lateral force, steering force as well as loads on knuckle hub in X, Y and Z direction.

Forces applied on Steering Knuckle are calculated as:

Calculation of Stresses

i. Stress Due to Axial Loads

The force of resistance per unit area, offered by a body against deformation is known as stress.

This is given by, Stress (σ) $=\frac{P}{A}$

ii. Stress due to Inertia bending force

Inertia bending load sets up a stress which would be tensile on one side of the knuckle and compressive on the other side and these stresses change sign in each half revolution. The bending moment (M) at any section 'X' from the small end is given by,

$$M = \frac{x}{a}\left[1 - \left(\frac{x^2}{L^2}\right)\right]$$

The Stress is calculated by $\sigma = \frac{M}{Z}$

$$M = \frac{I}{2.5\times t}$$

$$I = 419\times t^4$$

Loading Condition on Knuckle

For the calculation of load acting on steering knuckle component, the required loading condition which are as follows:

Loading Condition	
Braking Force	1.5 ×m× g
Lateral Force	1.5 ×m× g
Steering Force	45-50N
Force on the Knuckle hub in X-Direction	3 ×m× g
Force on the Knuckle hub in Y-Direction	3 ×m× g
Force on the Knuckle hub in Z-Direction	1 ×m× g

Table 5. Loading Condition on Steering Knuckle

If the knuckle is designed for the vehicle of 1240kg weight, the braking force acting on it produced a moment, which calculated as:
Braking force = 1.5mg = 1.5×310×9.81

= 4561.65 N

For calculation of braking force acting on one wheel is 1240/4=310kg, and considering perpendicular distance of 94mm:

Moment = Braking force × perpendicular distance

= 4561.65×94

= 428795.1 N-mm (for one wheel)

Thus the resultant force is given by,

$$F = \sqrt{X^2 + Y^2 + Z^2}$$

X = Y = 3×m×g = 3×310×9.81

= 9123.3 N

Z = 1×m×g = 1×310×9.81

= 3441.1 N

$$F = \sqrt{(9123.3)^2 + (9123.3)^2 + (3441.1)^2} = 13255.84 \text{ N}$$

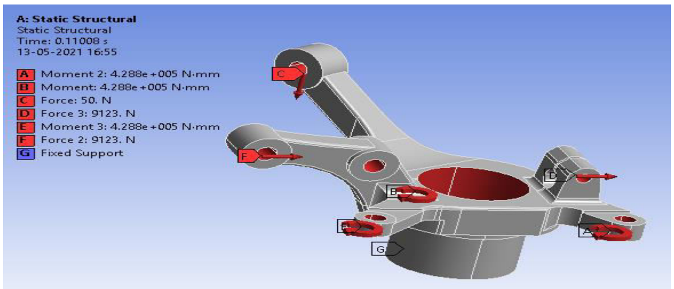

Fig -11:Constraint and Load Applied on Steering Knuckle

After applying load on the Steering Knuckle the analysis is done with the help of ANSYS Workbench for finding deformation, stress generated and the factor of safety by using different materials as mentioned in table 2.

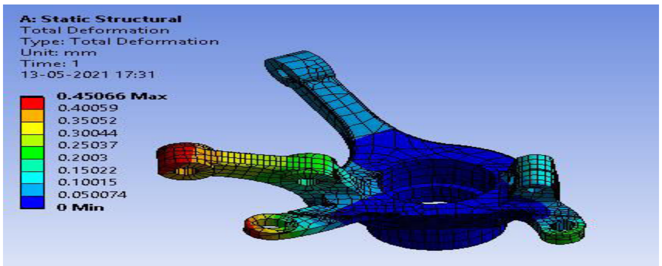

Fig -12:Total Deformation on Steering Knuckle

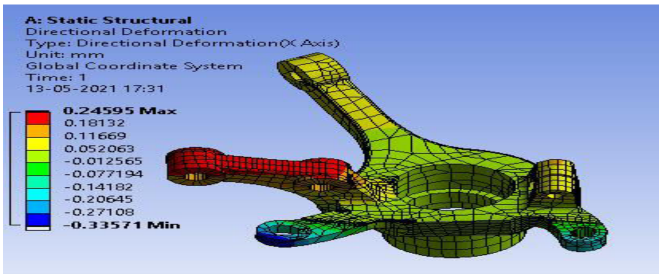

Fig-13: Directional Deformation on Steering Knuckle

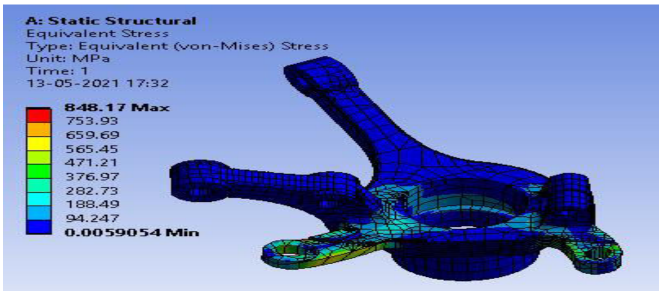

Fig -14:Equivalent Von-Mises Stress on Steering Knuckle

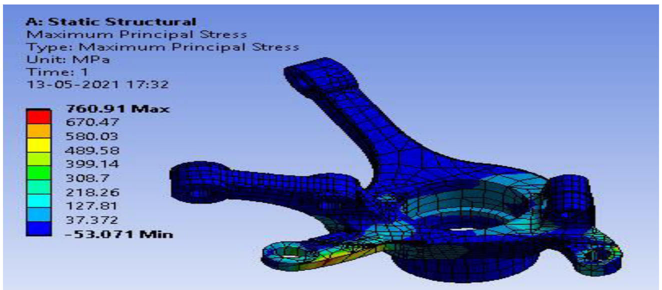

Fig -15: Maximum Principal Stress on Steering Knuckle

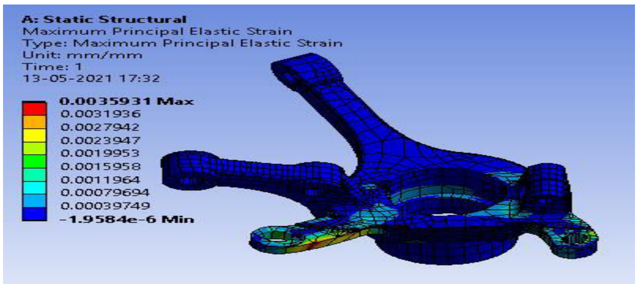

Fig -16:Maximum Principal Elastic Strain on Steering Knuckle

Similar analysis is done for the other materials as mentioned in Table 2 for Grey Cast Iron and Aluminium 7075 T3.

5. Result and Discussion

5.1 Result for Rear Wheel Hub

From the Comparision Between the material which are used for the Static Analysis of Rear Wheel Hub We can conclude that Apart from the materials like Grey Cast Iron, Wrought Iron which are generally used for manufacturing the same can be replaced by the materials like Aluminium 6061 T3 and EN8 Mild Steel which are lighter in Weight and also having high strength. Reliability and other physical properties are also better than regular materials. By using materials like EN 8 Mild Steel, and Aluminium Weight of the wheel hub get reduced and also it will help to reduce the total weight of Assembly and overall Manufacturing cost and improve Power transmission Efficiency.

Aluminium 6061 T6 Possesses high strength, good corrosion resistance, weldability, and machinability. This alloy can be strengthened by heat treatment, which allows it to reach much higher levels of strength than non-heat treatable alloys. When 6061 aluminium is heat treated, they are great for general purpose uses and find many applications in structural materials, electronics and chemical equipments. Its versatility as a material comes from its characteristics and is regarded as a tough, resistant and easily-machined metal.

En 8 Mild Steel Possesses good corrosion resistance, high strength, weldability, and machinability, EN8 steels can be further surface-hardened by induction process, producing components with enhanced wear resistance. EN8 steel, in its heat treated form possesses good homogenous metallurgical structure, giving consistent machining properties.

Sr No.	Parameter	Aluminium 6061 T6	EN 8 Mild Steel	Grey Cast Iron
1	Total Deformation	0.00384mm	0.001388mm	0.003329mm
2	Directional Deformation	0.000302mm	0.00009414mm	0.0000243mm
3	Equivalent (Von-Mises) Stress	16.11Mpa	16.208Mpa	16.159Mpa
4	Maximum Principal Stress	17.773Mpa	16.98Mpa	17.349Mpa
5	Factor of Safety for Stress	4.82	4.96	4.52
6	Factor of Safety for Stress	2.2393	2.51	2.15

Table 6. Comparision of material used for Static Analysis of Rear Wheel Hub.

Table 6 shows the comparison between the materials which are used for the Static Analysis of Rear wheel hub using Ansys Workbench 15.0

5.2 Result for Steering Knuckle

From the comparison between the materials which are used for the Static Analysis of Steering Knuckle, we can conclude that the materials like Grey Cast Iron, White Cast Iron, which are generally used for manufacturing this component can be replaced with the materials like EN 47 Forged Steel and Aluminium 7075 T3, which are lighter in weight and also having high strength, reliability and other physical properties. The various parameters such as total deformation, directional deformation, maximum principal stress, and maximum shear stress are completely analyzed. The study of steering knuckle component gives the small change in directional deformation and reduced the overall weight of the vehicle due to decrease in weight of steering knuckle component as well as save the material and cost, and overall improvement in vehicle performance and fuel economy.

Sr No.	Parameter	EN 47 Forged Steel	Grey Cast Iron	Aluminium 7075 T3
1	Total Deformation	0.4506mm	1.1258mm	1.2869mm
2	Directional Deformation	0.2459mm	0.6107mm	0.7020mm
3	Equivalent (Von-Mises) Stress	848.17Mpa	794.13Mpa	791.33Mpa
4	Maximum Principal Stress	760.91Mpa	827.23Mpa	832.23Mpa
5	Maximum Principal Strain	0.003593	0.009826	0.01101

Table 7. Comparision of material used for Analysis of Steering Knuckle.

Forge steel EN 47 is used, as it offers a better strength and lightweight for the steering knuckle component. Forge Steel materials are generally used where high tensile strength and toughness is required thus the Forge Steel EN 47 materials are suited for the steering knuckle component. Due to this low weight of materials, it can decrease the fuel consumption and it has low density and sufficient yield strength.

Aluminium 7075 T3 Possesses high strength, good corrosion resistance, weldability, and machinability, and this alloy can be strengthened via heat treating, which allows it to reach much higher levels of strength than non-heat treatable alloys.

6. CONCLUSIONS

We can conclude from this paper ~~is~~ that when we are designing any part, material selection is very important, and by FINITE ELEMENT ANALYSIS (FEA) we can check its strength, rigidity and factor of safety for the product. FEA is very important when we design steering knuckle & wheel hub because both are very critical and crucial in the automobile system. And by using the 3-D modeling software we can know the weight of the designed part, and modify it fast, with time and cost savings. By using FEA we don't have to perform multiple destructive tests for various load conditions and save analysis time. We can also know about the weak cross section regions, so that we can take precautions from failure. So using Creo 5.0 and ANSYS Workbench software it is very helpful to make adequate design with high strength, rigidity, light weight and higher factor of safety.

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