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Design and Multi-Axial Load Analysis of Automobile Steering Knuckle

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Abstract:- Steering knuckle is an indispensable part of an automobile vehicle, integrating different subsystems like suspension, brakes and steering. Being the pivot point of the vehicle it undergoes diverse stacking under rigorous conditions resulting in failure of the component. The objective of this paper is to perform static structural analysis on the knuckle under diverse loadings. This is achieved by designing a generic steering knuckle of a car in Autodesk Fusion 360 and performing the finite element analysis using Autodesk Nastran. The research is carried out under stressful loadings from cornering, accelerating, braking and bump maneuvering. The analysis is tested out for various materials to obtain the best strength to weight result.

Keywords:- *Steering knuckle, Weight optimisation, finite element analysis, structural analysis.*

I. INTRODUCTION

A steering knuckle is a part of automotive suspension system that detaches the vehicle from roughness and vibrations while keeping the tires in contact with the road surface [1]. Hence, the steering knuckle should be strong enough to endure loads during various maneuvers such as cornering, accelerating, braking and road roughness [2].

Most Common type of suspension system is Macpherson Suspension System. In this steering knuckle is connected to the axle housing by using kingpin, one end is connected to the strut while another end is connected to the steering link or "tie rod". The wheel hub is fixed over the knuckle by using a bearing. The function of the steering knuckle is to convert linear motion of the tie rod into angular motion of the stub axle [3].

Variety of materials are utilised to produce steering knuckle, from cast iron to alloy steels. But because of the booming aluminium industry, most of the automakers are relying on the aluminium alloys for better strength for comparatively lesser weight of the component. Because of low material weight, the component will contribute toward overall mass reduction and decrease in use of fuel and CO_2 production [4-5]. In addition, to light-weight material utilisation, many researchers are using optimisation techniques such as : topology optimisation, shape optimisation and size optimisation [6].

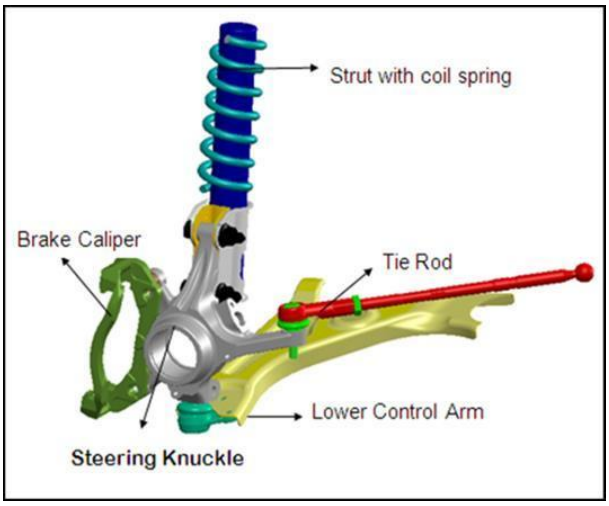

Fig 1:- A representation of Macpherson Suspension System

II. MATERIALS

Due to the desire for present day automakers to utilise less dense materials for each and every component, advance research is being done in the field of material sciences. Due these recent advances in Material Sciences, we have a vast range of materials to use for manufacturing of the steering knuckle component [5-7]. These low density materials can reduce drastically reduce the weight of the steering knuckle, in turn reducing the vehicle and improving its performance and reducing the fuel consumption. Based on density, yield strength, machinability, cost and availability, the steering knuckle materials to be tested were narrowed done to four. These materials are : (1) EN 8 (Steel Alloy) (2) EN 24 (Steel Alloy), (3) Aluminium 2011 T3 allot (4) Aluminium 7075 T6 alloy.

Composition (%)	EN 8	EN 24	Al 2011 T3	Al 7075 T6
Carbon	0.36	0.40	-	-
Silicon	0.25	0.30	0.40	0.40
Manganese	0.80	0.70	-	0.30
Sulphur	0.05	0.04	-	-
Phosphorus	0.04	0.06	-	-
Chromium	-	1.20	0.20	0.30
Zinc	-	-	0.30	5.50
Copper	-	-	5.00	2.20
Lead	-	-	0.30	-
Molybdenum	-	0.30	-	0.10
Bismuth	-	-	0.40	0.20
Magnesium	-	-	0.20	0.30
Nickel	-	1.50	-	-
Titanium	-	-	-	0.20
Iron	98.50	95.50	0.70	0.50
Aluminium	-	-	92.50	90.00

Table 1. Chemical Composition of the materials

Parameter	EN 8	EN 24	Al 2011 T3	Al 7075 T6
Density (g/cm^3)	7.85	7.83	2.83	2.81
Ultimate Stress (MPa)	700	850	450	620
Yield Stress (MPa)	460	680	360	500
Modulus of Elasticity (GPa)	210	210	70	70

Table 2. Mechanical Properties of the materials

III. CAD DESIGN

CAD model of the steering knuckle was designed using Autodesk Fusion 360. The model design consists of brake caliper mounting points, suspension strut mounting point, lower A arm mounting point, stub hole and a steering tie-rod mounting point.

The model is of generic design replicated from the design of Maruti Suzuki Swift. Thus, hard points were measured using conventional instrument with reference to an origin. The CAD model was then converted into STEP format in order to carry out finite element simulation in Autodesk Nastran.

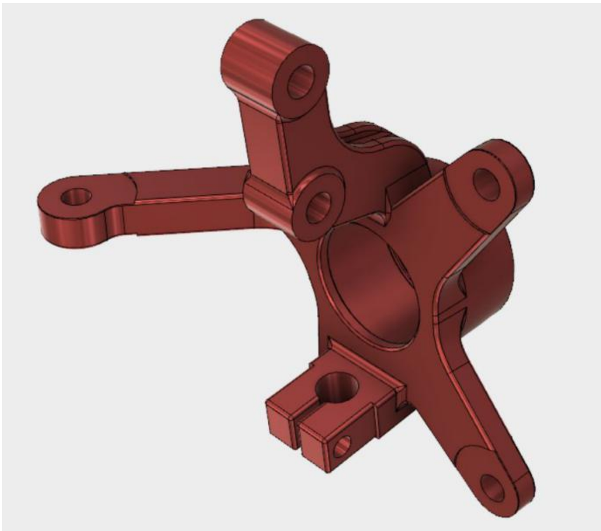

Fig 2:- CAD design of the Steering Knuckle

IV. MULTIAXIAL LOAD CONDITIONS

The loads on the steering knuckle connection points during various maneuvering conditions emanating from those generated at the tire-road contact surface and varying with vehicle specifications. Four load conditions namely : acceleration, braking, bump and cornering are being considered for further calculations. And furthermore, due to varying center of gravity the forces on all knuckles will not be the same. Hence a scenario is considered where the vehicle taking is left turn with respect to the driver while going into a bump simultaneously braking. Therefore Front-Left Knuckle(with respect to the driver) is considered for all the load cases.

Smith (1978) proposed that the center of gravity of the vehicle is not fixed but varies according to mass transfers during different load cases. Hence, varying center of gravity was considered while calculation of the forces.

A. Acceleration :

While accelerating, an inertia force acts on the center of gravity, and as a result of this a weight transfer takes place from front to rear. Considering a gravity force 0.5g and the forces acting on the vehicle along the wheel base, hence reaction forces will generate on both the wheel : front and rear. The reaction force for the front tire is given by the

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Equation (1). C.G. is 10% increased in length and 5% decreased in height (Front tire contact being the origin).

$$W_f = \frac{1}{2}*m*g\frac{a_1}{L} - \frac{1}{2}*m*g*\frac{h_2}{L}*\frac{a}{g} \quad (1)$$

Where,

L = Wheelbase
a = Acceleration of the vehicle (0.5g)
g = Acceleration due to gravity
m = Mass of the vehicle

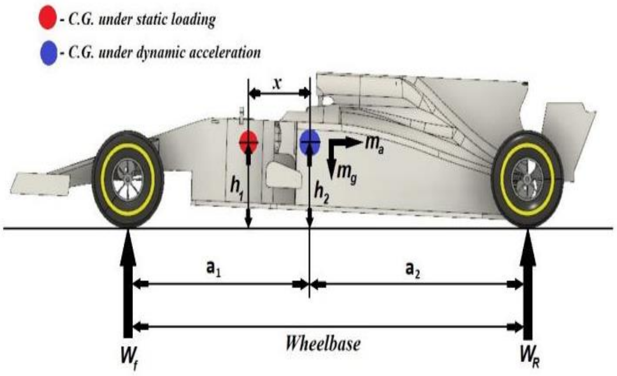

Fig 3:- Acceleration scenario from side view

B. Braking

An inertia force acts on the center of gravity during braking and result in a mass transfer from rear to front. Considering a gravity force of 1.1g, the equilibrium equation is given by Smith (1978) shown in Equation 2.

$$W_f = \frac{1}{2}*m*g\frac{a_1}{L} - \frac{1}{2}*m*g*\frac{h_2}{L}*\frac{a}{g} \quad (2)$$

Where,

L = Wheelbase
a = Acceleration of the vehicle (0.5g)
g = Acceleration due to gravity
m = Mass of the vehicle

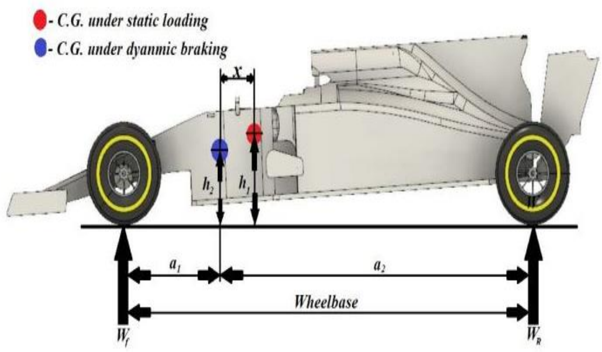

Fig 4:- Braking Scenario from side view

C. Bump Load

The most damage that could happen to the steering knuckle happens when the vehicle goes through a bump. According to Smith (1978), the lower A arm connection point suffers a load of about 2.5G (*1G = 1*m*g, hence 2.5G = 2.5*m*g*). While the upper connection point or the strut mounting point takes a load of about 1.1 G.

Unlike acceleration and braking there is no effect of center of gravity on the force accumulation on the steering knuckle.

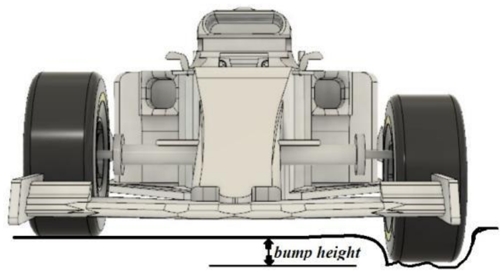

Fig 5:- Vehicle going through a bump (Front View)

D. Cornering

During cornering, the vehicle takes a turn of certain radius of curvature about a center, this makes in the load transfer in lateral direction from outer wheel to inner wheel. Smith (1978) proposed an equilibrium condition (Equation (3)), given by a gravity force of about 1.2g while cornering.

$$m*g*a_2 + C.G._{height} * m * a = W_L * L \qquad (3)$$

Where,

L = Track Width
W_L = Load on front left tire
a = Acceleration of the vehicle (1.2g)
m = Mass of the Vehicle

Since a lateral load transfer is taking place in this case, there will be a shift in the center of gravity : height will decrease by 7% while the lateral shift decrease by 5%. Origin being the front left tire (with respect to the driver).

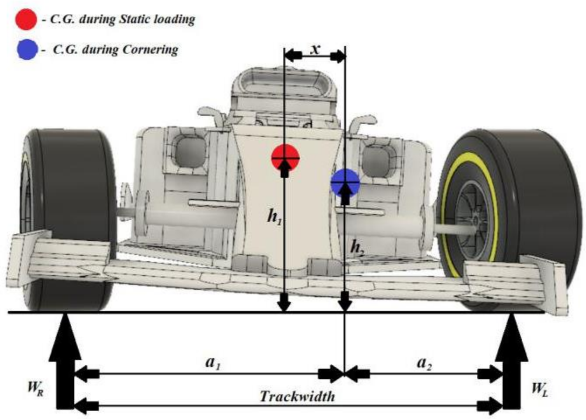

Fig 6:- Cornering Scenario from front view

*NOTE : The notations in the Fig 6 are with respect to driver.

V. FINITE ELEMENT ANALYSIS

Steering Knuckle failure occurs solely due to application of multiaxial loads on connection points, during long service of the vehicle. Thus, it is important to failure locations for design optimizations. Autodesk Nastran is used to carry out the structural Analysis of the steering knuckle, asit provides information with stress concentration regions on applications of loads and variation of the materials.

The passenger car specifications are listed in Table 3. It is observed from the above conditions and specifications that the load acting on the lower A arm connection point is the highest, about “5.7 G”. Using the load transfer conditions, the forces acting during rigorous maneuvering was calculated for the steering and are depicted in the figure (7).

Parameter	Specification
Mass (kg)	1075
Wheelbase (mm)	2390
Track Width (mm)	1470
Center of Gravity (mm)	X : 950, Y :570, Z: 0
Ground Clearance (mm)	170
Wheel Travel - Bump (mm)	300

Table 3. Maruti Suzuki Swift Specifications

NOTE : C.G. is calculated by keeping front left tire contact point to the ground as the Origin (left with respect to the driver). X axis extends to rear side, while Y axis is Height and Z axis extends towards right side.

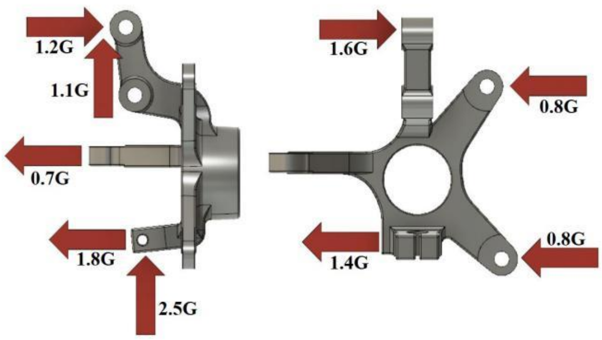

Fig 7:- Application of loads on the steering knuckle

Forces shown in the Figure 7, act solely on the connection or mounting points and not the outer surface. The stub hole where the bearing assembles is kept fixed.

Since loads for only one knuckle is to be calculated, the load distribution for this case will be different hence the standard equation of “1 G” will change to :

$$1\ G = \frac{m*g*1}{4} * 0.35 \qquad (4)$$

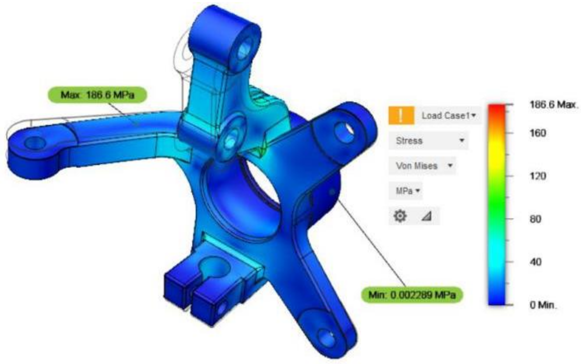

Fig 8:- Max stress in EN-8 material (186.6 MPa)

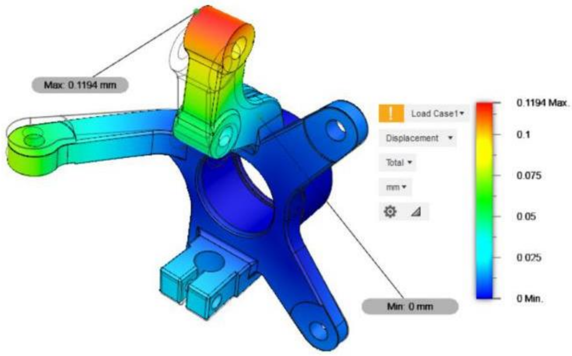

Fig 9:- Max Displacement in En-8 Material (0.119 mm)

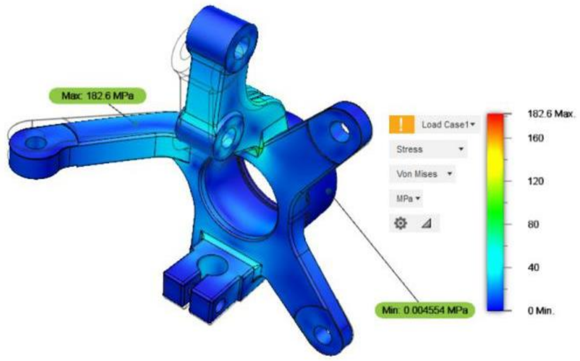

Fig 10:- Max stress in EN-24 material (182.6 MPa)

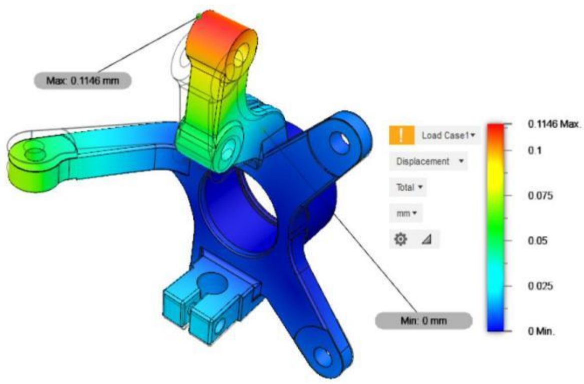

Fig 11:- Max displacement in EN-24 material (0.114mm)

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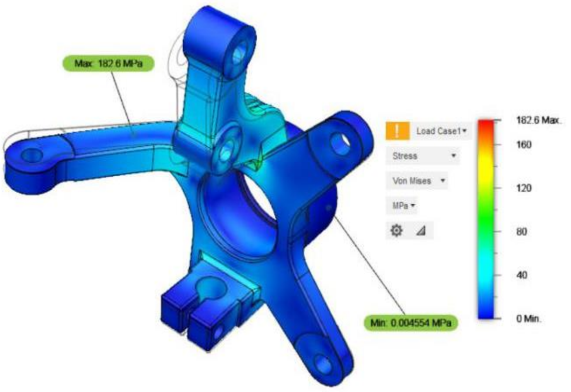

Fig 12:- Max stress in Al 2011 T6 (182.6 MPa)

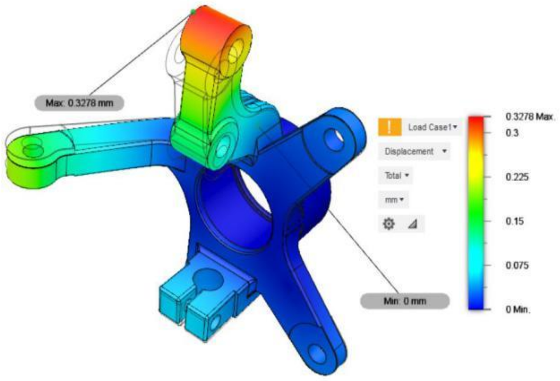

Fig 13:- Max displacement in Al 2011 T6 (0.32 mm)

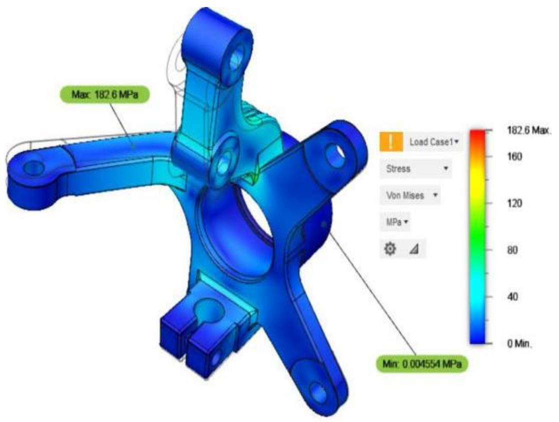

Fig 14:- Max stress in Al 7075 T6 (182.6 MPa)

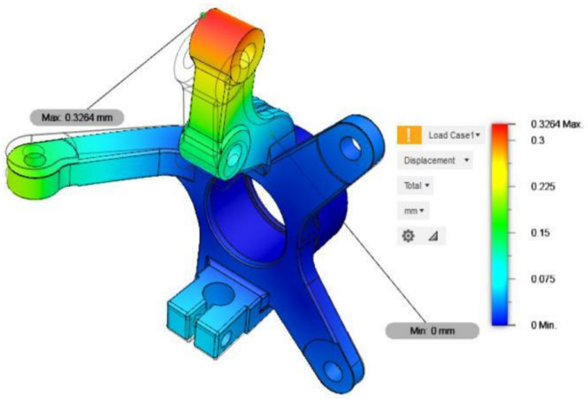

Fig 15:- Max displacement in Al 7075 T6 (0.326 mm)

VI. RESULT & DISCUSSION

A successful multiaxial load structural analysis was performed on the generic design of the steering knuckle and the results are tabulated in Table 4.

Parameter	EN8	EN24	Al 2011 T6	Al 7075 T6
Max Stress : Von-Mises (MPa)	186.6	182.6	182.6	182.6
Max displacement (mm)	0.119	0.114	0.328	0.326
Factor of Safety	2.47	3.73	1.98	2.74
Weight (kg)	2.24	2.21	0.824	0.782

Table 4. Simulation results of different materials

VII. CONCLUSION

From the simulation results, it have been found that regardless of the material selected the maximum stress induced in the steering knuckle remains same, but the maximum displacement varies. The displacement is almost same of the same materials regardless of their grades. The only thing that truly changes is the factor of safety, due to the unique yield strength of each material.

EN 24 has the highest factor of safety but it cannot be chosen as the best material because the factor of safety is too high to be considered as optimum. If the size and shape of the material is to be optimised then EN24 is the best, but if only material is to be optimised keeping the strength constant then Aluminum alloys are the best.

Many researcher have chose Al 2011 T6 as the best material for the steering knuckle, but from the above results it is evident that for a small increment in budget could improve the strength and further reduce the weight by utilising Al 7075 T6 alloy. Hence, it is being concluded that Aluminium 7075 T6 alloy is the best material for Steering Knuckle acting under multiaxial loads.

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