MAT JOURNALS

Journal of Advancements in Material Engineering
Volume 3 Issue 3

Design and Development of Novel Configuration of Steering Knuckle for an All Terrain Vehicle (ATV)

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Abstract

Steering knuckle or suspension upright is one of the most critical loaded parts in an automobile and especially in all terrain vehicle (ATV) as it has to sustain the forces arising from the braking torque, road bump and the steering pull. Also, in the commercial vehicles, the left knuckle cannot be interchanged with the right knuckle. Therefore there is a need of design and development of a steering knuckle which may be interchangeable and manufactured as a one piece product. Also to reduce the overall weight of an automobile a light weight steering knuckle should be designed. Thus the design and development of a low weight knuckle which is structurally rigid and has the ability to withstand all the forces arising due to bump, cornering, cyclic loading during steering and braking while being interchangeable between front wheels of an Off-Road vehicle is discussed in this article.

Keywords: *Knuckle, upright, interchangeable, Copmuter Aided Design (CAD) and Computer Aieded Engineering (CAE)*

INTRODUCTION

Steering knuckle or upright is an automobile component which is responsible for forming a connection between Wheel, suspension system, steering system and brakes system of the vehicle. The knuckle is often referred as steering knuckle as most of the cyclic loading comes in the vehicle while turning through steering. The failure of the knuckle can prove to be very disastrous as its sudden failure would cause inability of driver to control the vehicle. Thus, immense time should be given for analyzing and testing it.

There are certain problems with the existing design of knuckle used in earlier all terrain vehicles like the higher weight of knuckle which increases the un-sprung mass of a vehicle, the problem of interchangeability of right and left knuckle and the material and manufacturing process used for manufacturing the knuckle. The vehicle has most of the mass concentrated in the un-sprung region at around 13% to 15 % of the vehicle curb mass accounting for un-sprung mass of the vehicle. In the case of a 1750 kilograms vehicle, un-sprung mass may be as high as 250 kilograms. A 250 kilograms mass reacting directly to roadway irregularities at high speeds can generate significant vertical acceleration forces. These forces degrade the ride, and they also have a detrimental effect on handling of the vehicle. Steering knuckle contributes a major share in the un-sprung mass of the vehicle.

E. A. Azrulhisham et al.[5] developed a Pearson system to evaluate the predicted fatigue life reliability by considering the variations in material properties and considering random loads experienced by the steering knuckle, it is found that shortest life appears to be in the vertical

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load direction with the lowest fatigue life reliability between 14000–16000 cycles. Tushar Joshi et.al[6] discussed the various methodologies for analysis of components to check the failure possibilities and main aim is to describe an approach for analysis of different components. Siddesh Gowda et.al found out the fatigue life of a passenger car's Rheocast Aluminium knuckle manufactured by a special technique known as Rheocasting. They measured strain data through RLDA and test data for the durability strength of predicted life with no mean stress correction approach is closer to rig level test result for the selected part and material[11]. Viraj Kulkarni et.al has done the optimization of steering knuckle targeting the reduction of weight as objective function, while not compromising with required strength, frequency and stiffness[12]. The existing design of knuckle of an ATV is heavy or bulky. Also, the current design does not have interchangeability i.e. the left wheel knuckle cannot be interchanged with the right wheel or vice versa of the vehicle.

METHODOLOGY

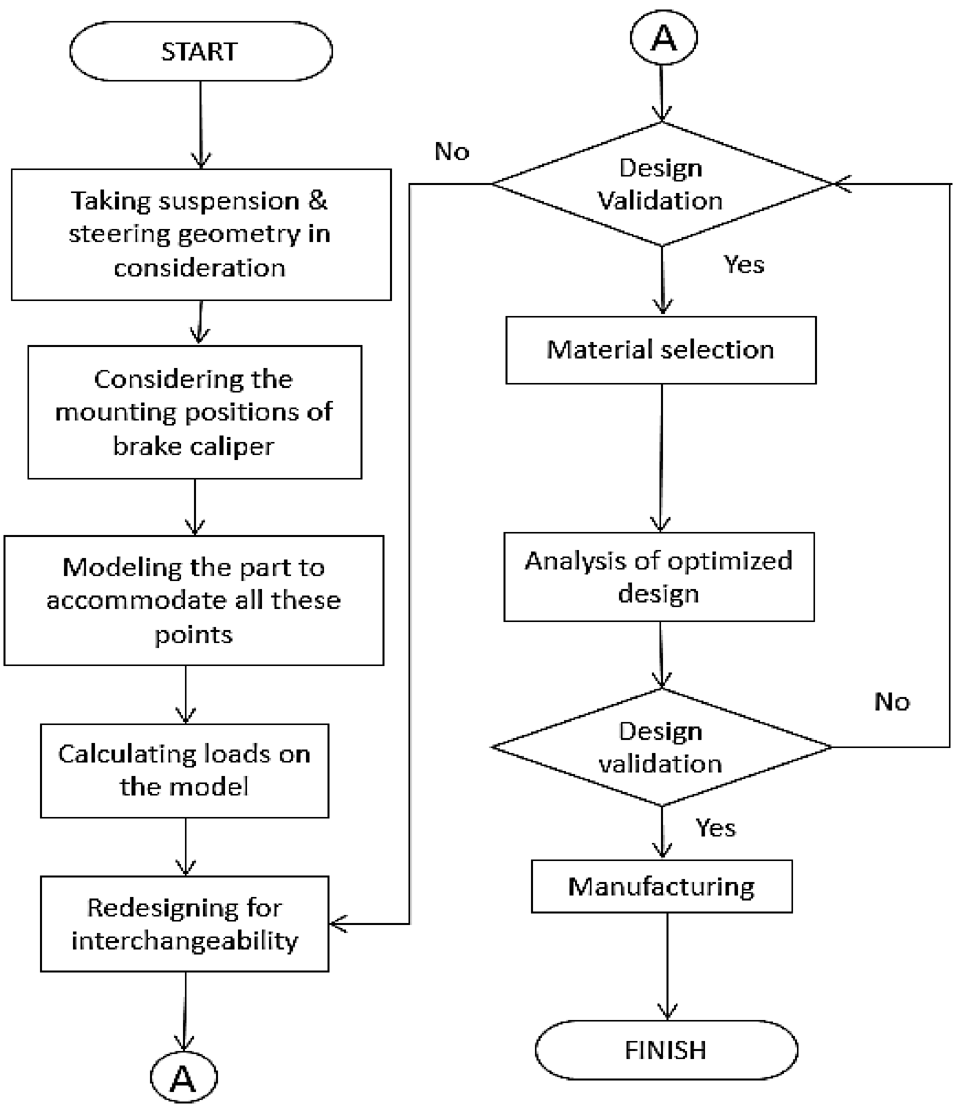

Fig: 1. *Methodology*

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Interchangeable knuckles can ease up manufacturing drastically. It eliminates the need for designing two different components. Thus, an attempt has been made to design a knuckle which is having low weight and is interchangeable. Thus it has eliminated the need for manufacturing of two different knuckles for an ATV. The same knuckle was tested for its design and manufacturing aspects during the actual off road running of the ATV (BAJA Vehicle).

DESIGN OF KNUCKLE

Calculation of loads

The static structural analysis of Knuckle can be done with the forces like Braking Torque, Steering Pull force, Bump force, Cornering force and Lateral forces. In order to maintain the durability of the design, the model is subjected to extreme conditions as suggested by Sharma[3], considering G forces when all the forces are acting simultaneously in case of the vehicle landing on a single wheel. The weight of the vehicle in this case is supposed to be 2800N. Considering the weight, the magnitude of each of the forces were calculated and depicted in the Table 1. The braking torque is calculated as,

Braking Torque = (1.5 x 280 x 9.81 x 0.4 x 0.292)/2
= 250 Nm

In normal condition, not entire load of the vehicle acts on the knuckle. Thus, for doing the fatigue analysis, the loading condition mentioned in Table 2 were multiplied with the weight distribution factor of 0.4 assuming 40:60 weight distribution of the vehicle to find out the life of the component. The steering force remains constant for both static structural and fatigue analysis as it is subjected to more frequent loading.

The formula used for calculating forces acting during fatigue loading is,
Force= (G force x Weight distribution) / 2

The forces for fatigue analysis are mentioned in Table 2.

Table: 1. *Loading Conditions for Static structural*

Bump Force	3g	8240N
Braking Torque	1.5g	250Nm
Lateral	1g	2746N
Longitudinal Force	2g	5492N
Steering Pull Force	-	50N

Table: 2. *Loading Conditions for Fatigue analysis*

Bump Force	3g	1648N
Braking Torque	1.5g	250Nm
Lateral	1g	549N
Longitudinal Force	2g	1098.4
Steering Pull Force	-	50N

Material Selection

Presently several materials are used for the manufacturing of steering knuckle component like grey cast iron, white cast iron, SG iron[1,8]. Forged steel is most demanding material for this application. Now a day's automobile industry has put effort to use aluminum alloy as an alternative due to low weight of this material. The commercial uprights are made up of FCD500-7 Cast Iron. For prototyping, using FCD500-7 and forging it was not feasible so we used EN8 which has physical properties close to that of FCD500-7 for manufacturing the knuckle. The chemical and physical properties of EN8 are depicted in Table 3 and 4

Table: 3. *EN8 Chemical Properties*[1]

Carbon	0.36-0.44%
Silicon	0.10-0.40%
Manganese	0.60-1.00%
Sulphur	0.050 Max
Phosphorus	0.050 Max

Table: 4. *EN8 Mechanical Properties*[1]

Max Stress	700-850 N/mm2
Yield Stress	465 N/mm2 Min
0.2% Proof Stress	450 N/mm2 Min
Elongation	16% Min
Hardness	HB

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DESIGN OF CAD MODEL

Design of Knuckle Body

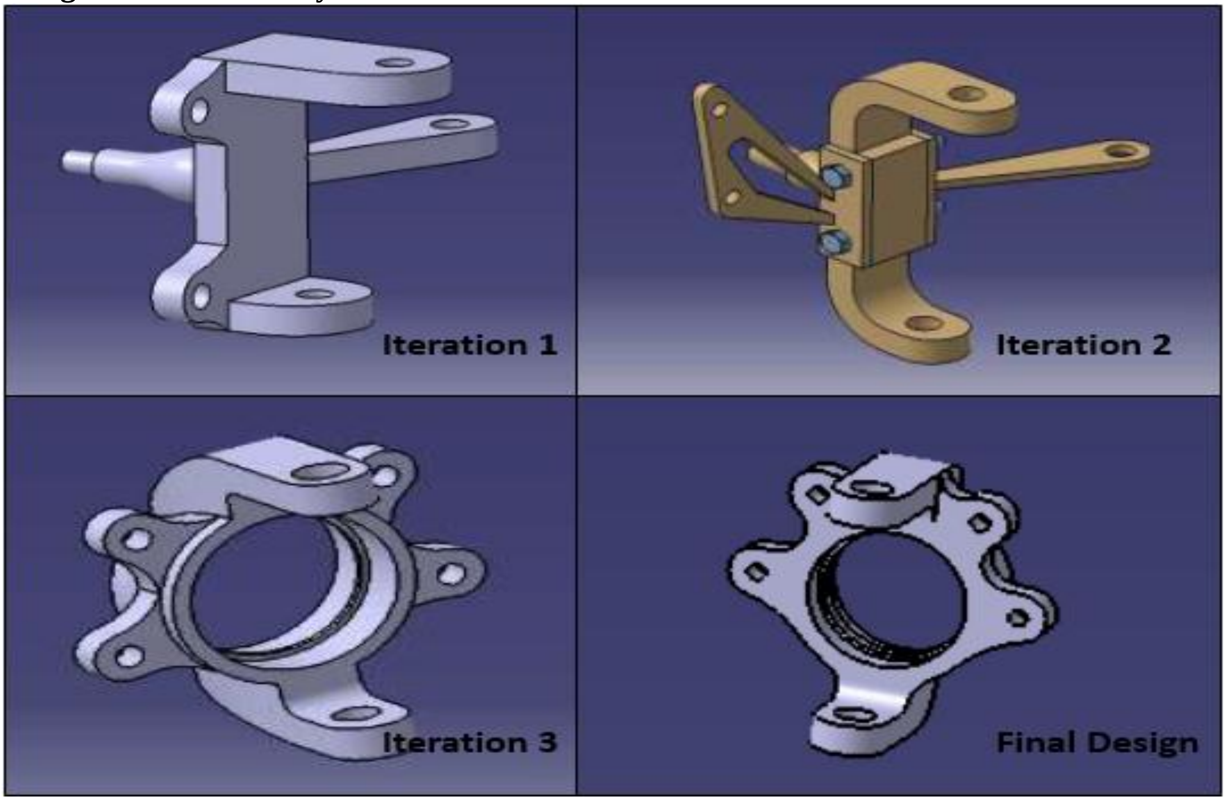

Fig: 2. *Iterations for Knuckle Design*

The Figure 2 shows the iterations that were performed before the design was finalized. In the first iteration, a basic design was made that could accommodate the suspension geometry, steering geometry and brake caliper mounting. The design was heavy and also it did not have interchangeability. So, in the second iteration to accommodate the interchangeability the knuckle body was made symmetric along the XZ plane and the steering arm and calliper mount were made detachable and were bolted to the knuckle body. For bolting, internal threads were considered primarily, but it was later learned that internal threads alone had poor performance under vibrations. So, to prevent loosening, bolting with internal threads along with metallic lock nuts was decided. The problem with the second iteration was that it could not be used if a vehicle had front wheel drive.

Thus, in third iteration the knuckle body was designed such that it could accommodate front wheel drive and also had interchangeability. The bearing was selected considering the commercially available hub. But it was not fit for manufacturing as it had a lot of sharp edges and was not tool friendly. In the final design, the sharp edges were replaced with fillets and the design was finalized with ease in manufacturing.

Design steering arm

The need for designing a separate steering arm was because detachable steering arm was required for interchangeability. The Figure 3 shows the different iterations for steering arm. In the first iteration, the steering arm was made by considering the mounting of the ball joint. For primary design, a flat plate of 6mm thickness which is easily available in market was decided to be welded at an angle of 21˚ which was required for proper steering geometry.

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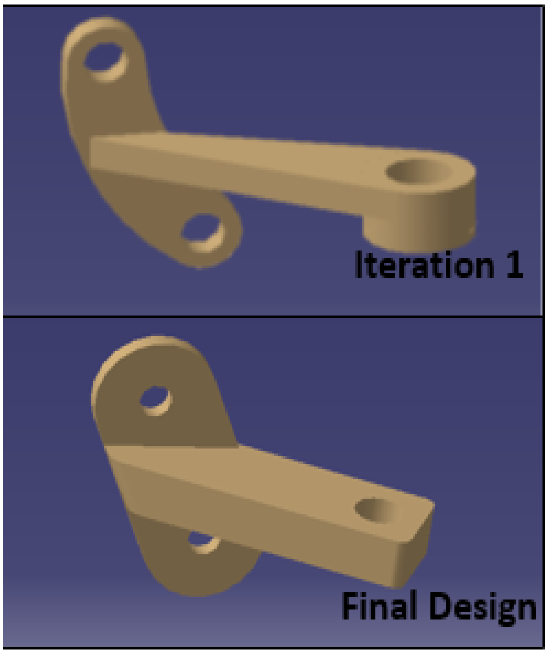

Fig: 3. *Iterations for Steering arm*

The hole locations were given according to the mounting points on the main knuckle body, and a sufficient clearance of 1.5D was provided from the hole center up to the outer edge. To accommodate the ball joint, the width of at the end of the plate was increased to 12mm. The analysis of the steering arm was done and it was found to fail due to the bump forces. So, in second iteration the entire 6mm plate was replaced by a 12mm plate. The designed sustained and was decided to be final[7].

Design of Caliper mounting plate

To mount the caliper there was need to mount a connecting plate between brake caliper and the main knuckle body which is called as 'caliper mounting plate. The shape of the plate is so designed, that it will not hit the brake caliper. Also, the thickness of the brake caliper mounting was decided as 8mm initially and it was found to be safe after the analysis. Moreover, if the brake torque is more for any other kind of vehicle, the thickness of plate can be increased or a superior material can be used.

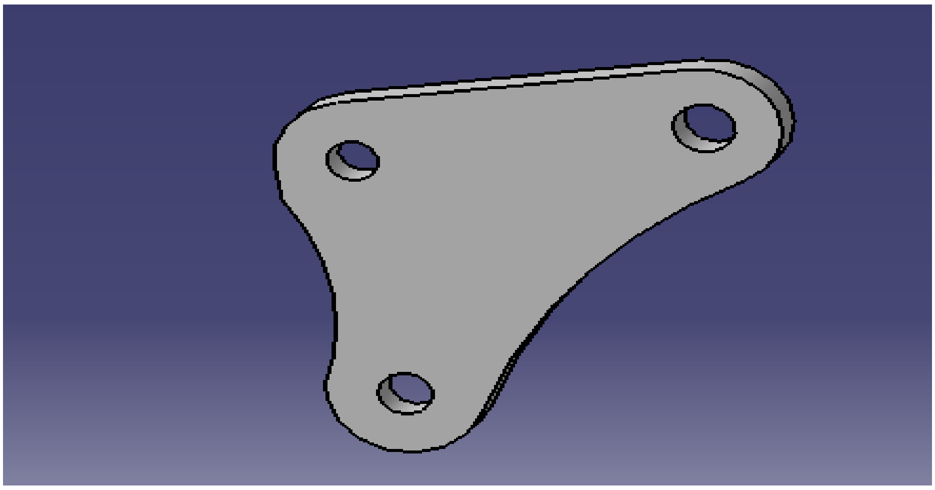

Fig: 4. *Caliper mounting plate*

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STATIC STRUCTURAL ANALYSIS

For performing FEA, Ansys Workbench was used. In the static structural analysis, the loading conditions mentioned in Table 1. were applied to the knuckle body, Steering arm and the caliper plate to check their sustainability individually.[9, 10]

Knuckle Body

For the static structural analysis of Knuckle Body, the suspension points were fixed which replicates a non-favourable condition of a completely stiff (rigid) spring. With this boundary condition forces were applied on the inner surface of the knuckle where bearing is fitted, this replicates the wheel forces coming from the ground through the wheel hub. The forces which were considered are the maximum forces which will be imparted on the main knuckle body.[9,10,11] Forces were applied on the knuckle as shown in figure 5. The mesh type used was fine with element size of 0.5mm.

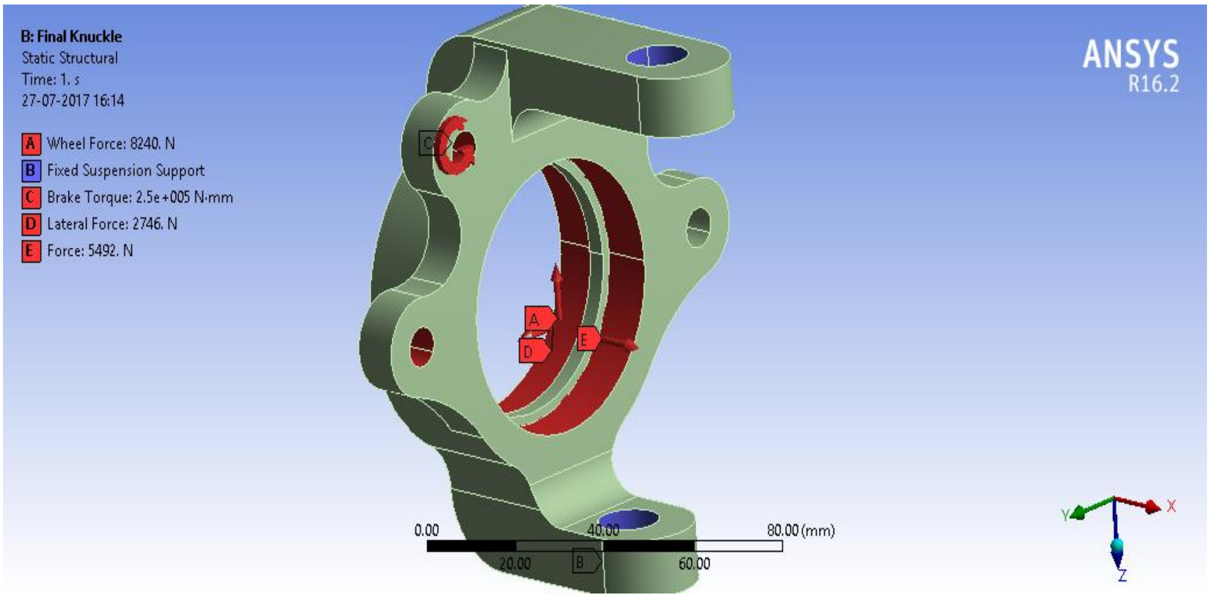

Fig: 5. *Boundary Conditions For Knuckle Body*

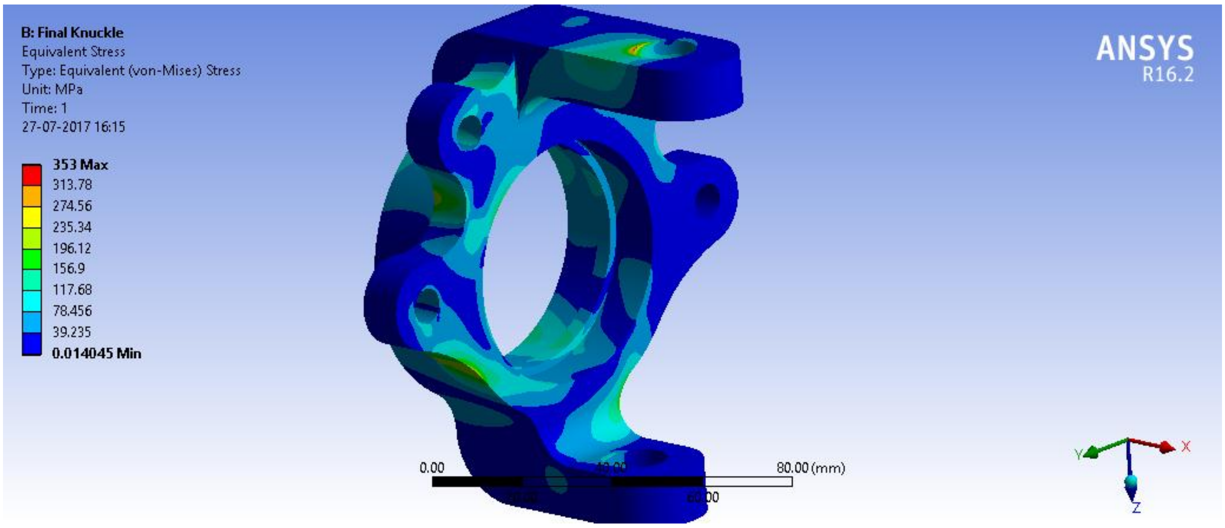

Fig: 6. *Result for static structural analysis of knuckle body.*

The result of the analysis of knuckle body was taken as stresses generated in the knuckle, which was von-Mises Stress. It was found that the stress generated was

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equal to 353Mpa. As the material selected for the Knuckle is EN8 (Syt=450 MPa) FOS turned out to be 1.27.

$$FOS = \frac{Tensile\ strength\ of\ material}{Maximum\ stress\ generated\ in\ component}$$

= (450/353) = 1.27

Steering Arm

For the static structural analysis of Steering arm, the bolting points were fixed and a steering pull force of 50N was applied along with a 1.5g force acting during a weight transfer in front because of braking only.

Force due to weight transfer = (1.5 x 280 x 9.81)/2 =2060N

The Loading condition for the steering arm is as shown in Figure 7. The mesh type used was fine with element size of 3mm.

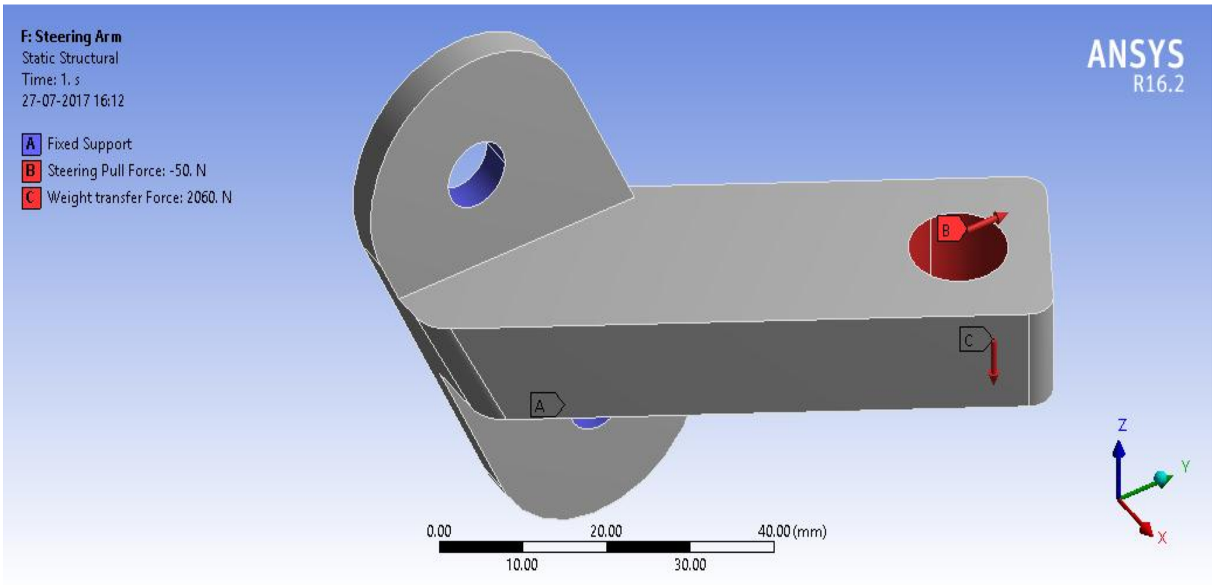

Fig: 7. Loading condition for Steering arm

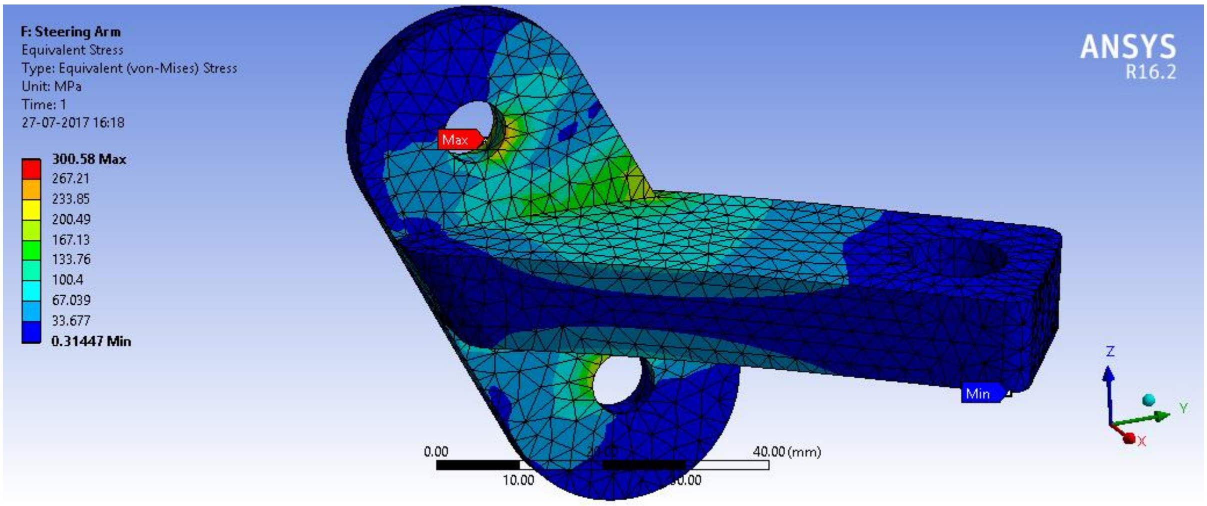

Fig: 8. Result for static structural analysis of Steering arm

The result of the analysis of steering arm was taken as stresses generated in the steering arm, which was von-Mises Stress. It was found that the stress generated was equal to 109.73 MPa. As the material selected for the steering arm is EN8 (Syt=450 MPa) FOS turned out to be 4.

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$$FOS = \frac{Tensile\ strength\ of\ material}{Maximum\ stress\ generated\ in\ component}$$

= (450/109.73) =4

Caliper Mounting Plate

For the static structural analysis of caliper mounting, bolting points were fixed and braking torque of 250Nm as mentioned in table I. was applied at the Caliper mountings. The loading conditions are as shown in figure 9. The mesh size used is fine with element size of 3mm.

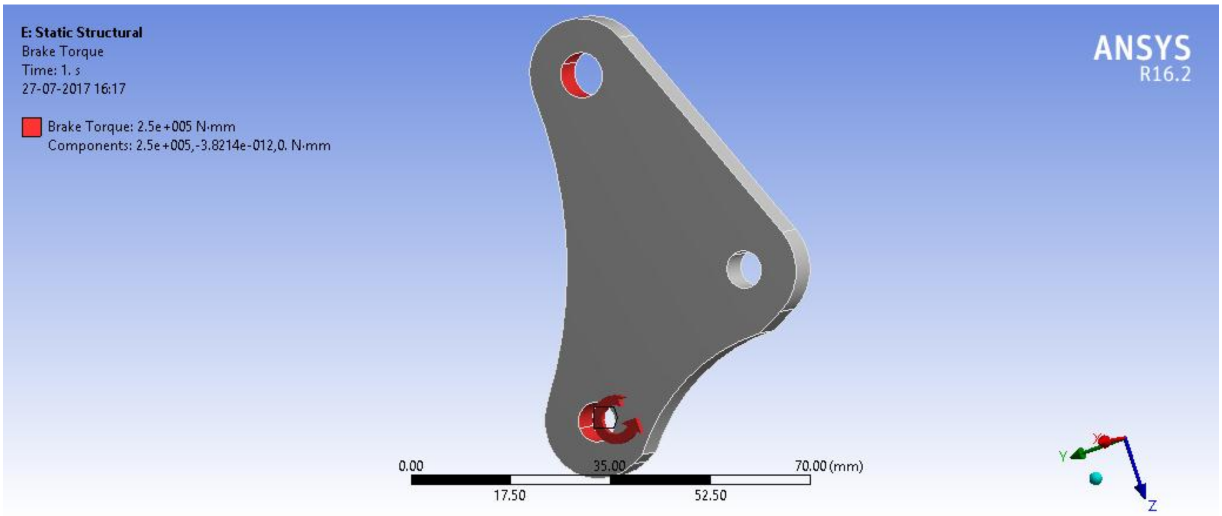

Fig: 9. *loading condition for Caliper mounting plate*

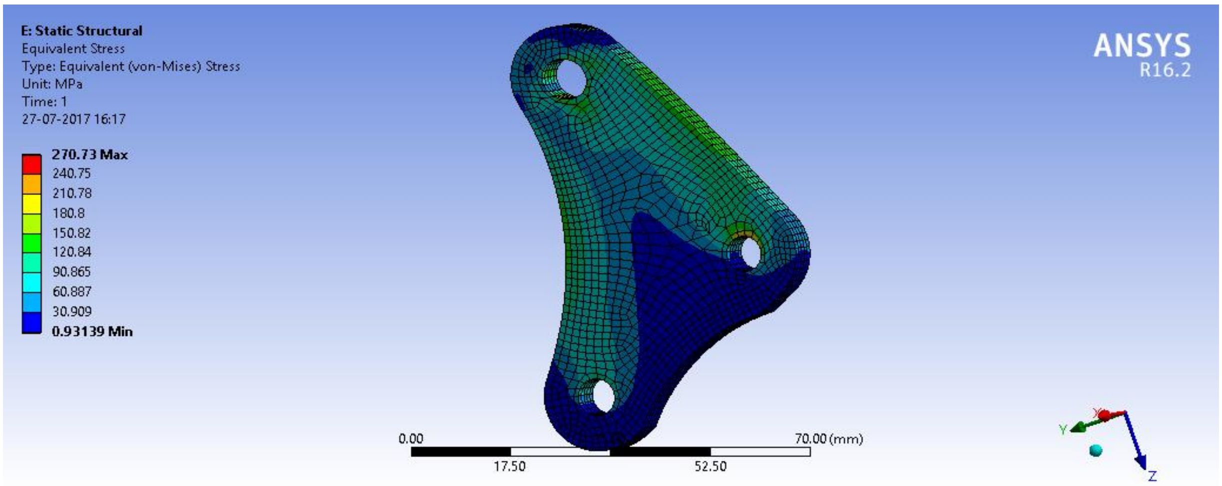

Fig: 10. *Result for static structural analysis of Caliper Mounting Plate*

The result of the analysis of Caliper Mounting Plate was taken as stresses generated in the Caliper Mounting Plate, which was von-Mises Stress. It was found that the stress generated was equal to 270.73 MPa. As the material selected for the steering arm is EN8 (Syt=450 MPa) FOS turned out to be 1.67.

$$FOS = \frac{Tensile\ strength\ of\ material}{Maximum\ stress\ generated\ in\ component}$$

= (450/270.73)= 1.67

FATIGUE ANALYSIS

The Steering knuckle is often subjected to repetitive loading thus, it was necessary to perform fatigue analysis[8]. The fatigue analysis was performed on the entire assembly of knuckle. The fatigue life of the component was checked in case of the knuckle assembly being subjected to simultaneous loading while a vehicle takes a turn.[10, 11]

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Normally, the suspension points act as a pivot while a vehicle takes a turn. There are 5 forces acting simultaneously in this case i.e. longitudinal force, braking torque, steering pull force, cornering force and forces arising due to irregularities of the road. Thus, bump and lateral forces are applied at 292.1mm from the wheel hub center (Assuming tire diameter to be 584.2mm for an off-road vehicle), steering pull force is applied at the steering arm, driving torque is applied at wheel hub, braking torque is applied at brake disc mount and caliper mount while fixing the suspension a-arm mounts. The magnitude of force applied is according to table 2.

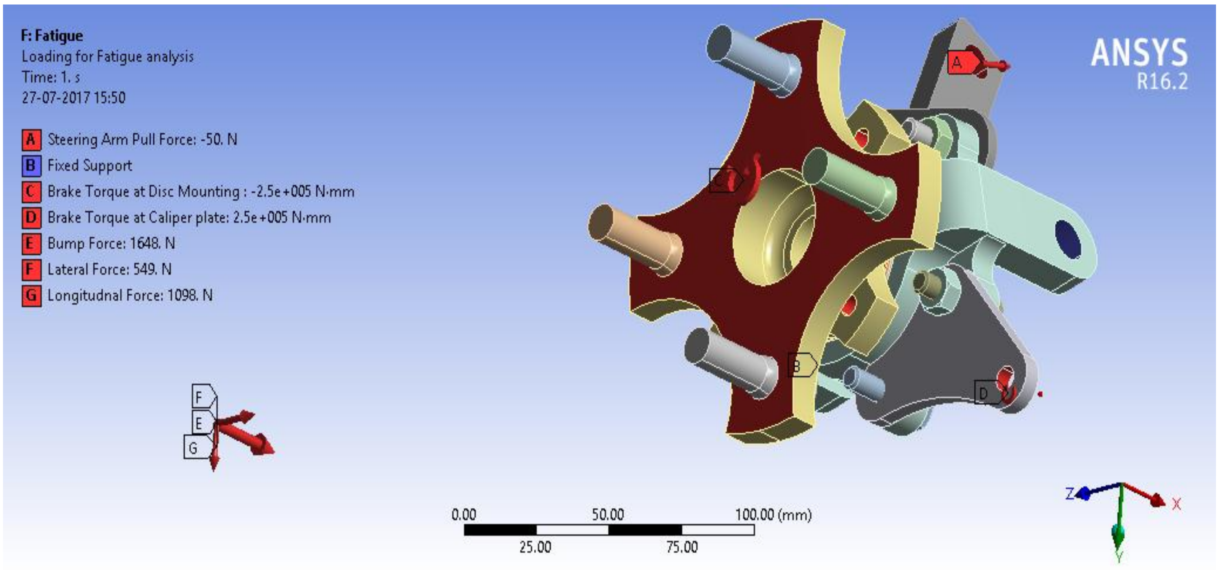

Fig: 11. *Loading Condition for Caliper Mount*

The Fatigue analysis[9] was performed in Ansys Workbench. Separate material properties were created for bolts, bearing and remaining knuckle component and their alternating stress data were provided. The loading applied is according to figure 11. The results of the fatigue analysis are shown in figure 12 and figure 13.

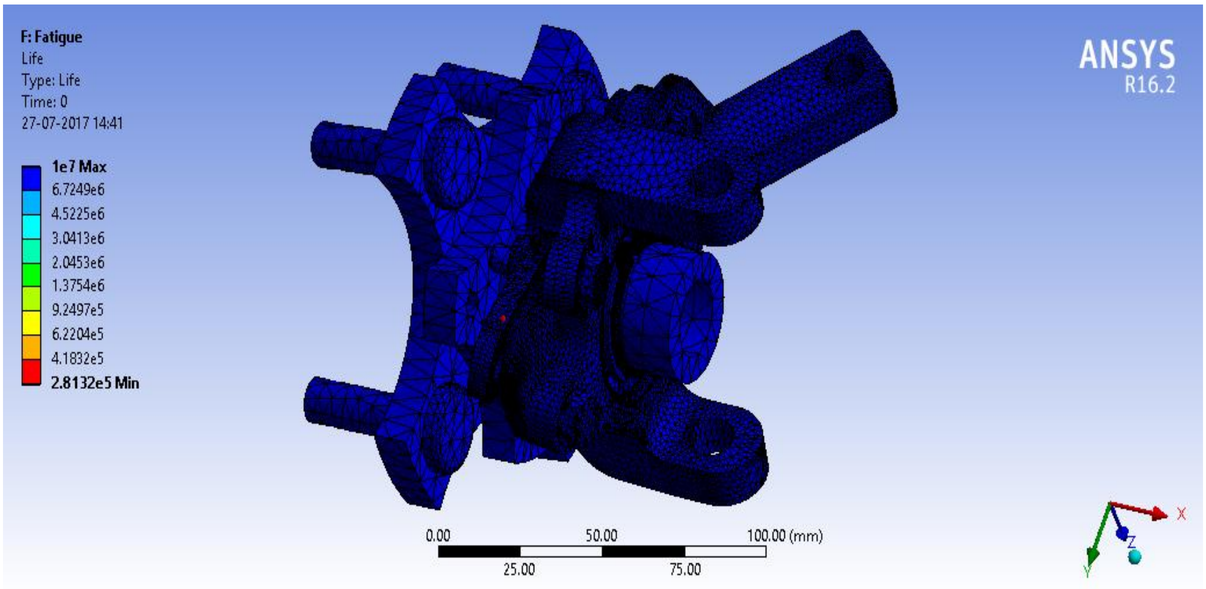

Fig: 12. *Fatigue life of Knuckle*

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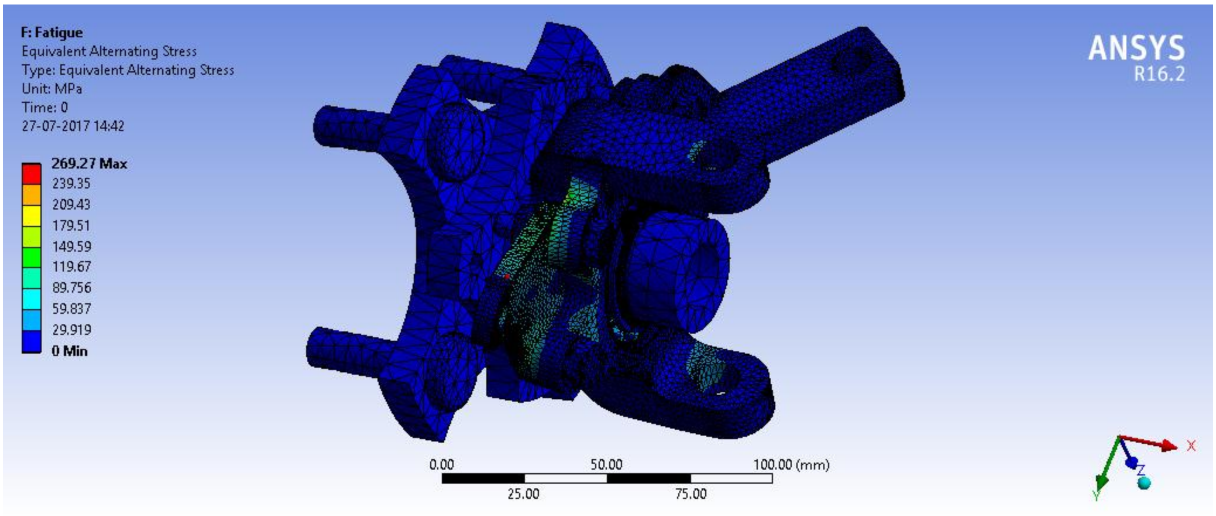

***Fig: 13.** Equivalent Alternating Stress on Steering Knuckle Assembly*

The assembly sustained the infinite life cycle criteria. Also the Equivalent alternating streess less than the yield strength of EN8. The FOS is 1.67.

$$FOS= \frac{Tensile\ strength\ of\ material}{Maximum\ stress\ generated\ in\ component}$$
$$=(45/270.73)=1.67$$

FINAL DESIGN

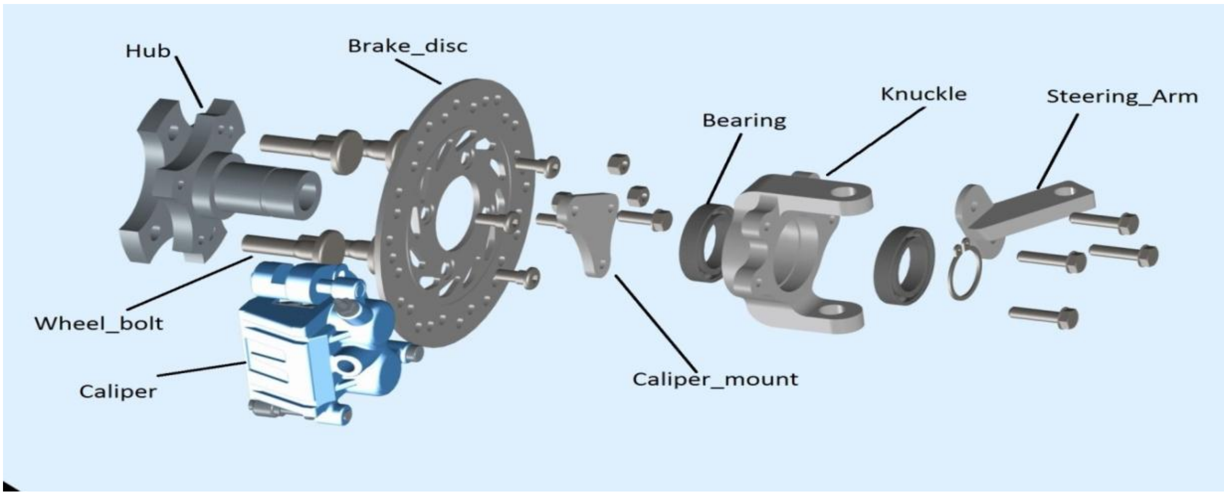

***Fig: 14.** Rendered exploded view of Assembly of final design*

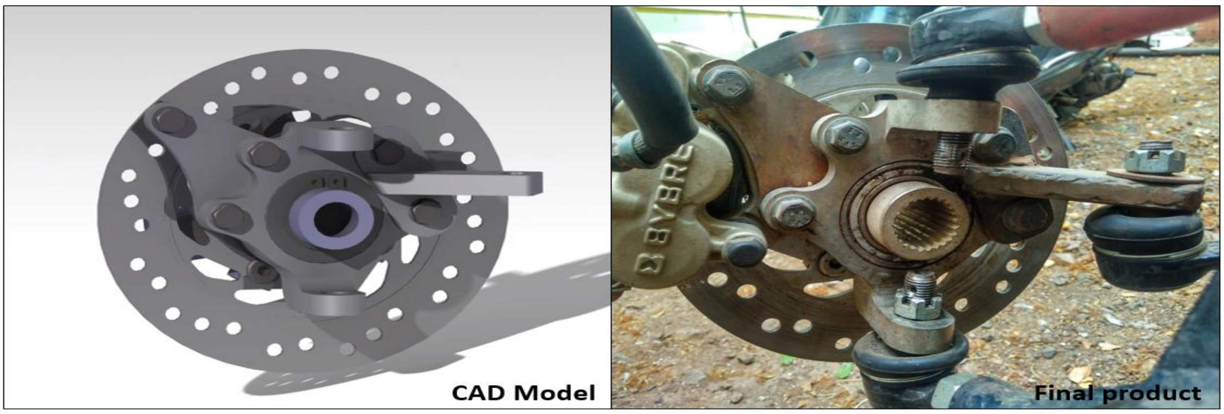

***Fig: 15.** CAD Model and Final Manufactured & Tested Component in BAJA Vehicle*

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TESTING

The knuckle was manufactured and installed on the MINI BAJA vehicle participating in SAE BAJA INDIA 2017. The vehicle ran for more than 500 km with no failure and was tested in extreme harsh off-road conditions offered by NATRIP Endurance Track for SAE BAJA INDIA competition at Indore, Pithampur. The track comprises of all types of terrains a vehicle might face. The knuckle sustained the rigorous testing without any failure.

CONCLUSION

The knuckle designed is an interchangeable and can be used for any side of the ATV (All terrain Vehicle) as a connection between the wheel and suspension system.

The novel design of knuckle is very MUCH sturdy and can withstand the various static and dynamic loading conditions while running in conditions of an ATV.
Also the Finite Element Analysis of the knuckle shows that the design of knuckle is able to withstand the static and dynamic forces in a proper manner and will not fail in running in conditions.

CONFLICT OF INTEREST

This work is original and not under consideration elsewhere and there are no conflicts of interests regarding the work carried out in this project.

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