Comparative Study of Aluminum and Composite Stub Axle Using FEA

Rajnarayan Yadav, Vinayak H. Khatawate, Deval Patel, Sahil Thonse, and Danish Sunsara

Abstract This paper includes the analysis of a front stub axle used in a rear wheel drive BAJA ATV (all-terrain vehicle). An ATV is a vehicle developed to be used on rough terrains and low traction. These types of vehicles are generally known and used for their off-roading ability and maneuverability of the vehicle on rough terrains. The stub axle used in such a vehicle is subjected to different types of loads, depending upon the motion and terrain the vehicle is running on. The analysis of the structure was compared with two different models, on the basis of their strengths and rigidity of the axle during the action of bump force subjected on the tire, change in weight of the axle and cost. This paper deals with the structural analysis of stub axle of BAJA ATV using finite element analysis approach. The objective of this analysis was to study and evaluate the performance of two stub axles made of aluminum and composite material respectively, under severe conditions.

Keywords BAJA · ATV · Stub axle · Structural analysis · FEA

1 Introduction

The Society of Automotive Engineers (SAE) BAJA series is an annual series of competitions, which originated in 1976. The BAJA SAE tasks the students to design, fabricate, and validate a single-seat four-wheel off-road vehicle to take part in a series of events spread over a course of 3 days that test the vehicle for sound engineering practices that have gone into it, the agility of the vehicle in terms of gradeability, speed, acceleration, and maneuverability characteristics, and finally its ability to endure that back-breaking durability test [1, 2]. This durability test checks the structure by dropping the ATV through a 5 ft vertical drop in a pit. This paper specifically deals with the structural analysis of a single component, i.e., the stub axle. The front stub axle is designed and developed based on defined parameters of the suspension,

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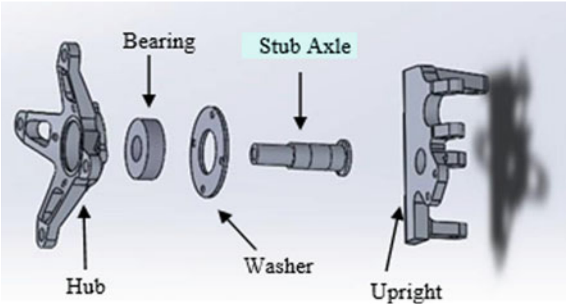


Fig. 1 Assembly of the stub axle

chassis, and brakes that meets the needs for the functional use of the vehicle. The stub axle is one of the major components in the power transmitting system [3]. The stub axle is designed for a BAJA ATV, which is a rear wheel drive. The stub axle designed is used in the front wheel assembly which supports the wheel connected via hub which is supported using deep groove ball bearing on the axle. On the front axle, wheels are mounted, and with the help of steering wheel, the driver can orient the vehicle in different directions [4]. This unit is used to carry the weight of the front part of automobiles as well as for steering and to absorb shocks due to road surface variation [5]. Analysis is made by a finite element analysis software in order to obtain a structure with appropriate value of factor of safety (FOS) and deflection of shaft during the loading condition. The aim of this project is to design a stub axle for front suspension of a rear wheel drive ATV. It should also allow a proper steering control to the wheel so that the driver efficiency is not lost. This component is subjected to discontinuous forces resulting in stress concentration and may result in component failure [6]; hence, the design of the stub axle should consider the forces and moments during 5 ft drop which occurs in an automobile. Figure 1 shows a designed assembly of stub axle.

2 Determination of the Loading Forces

After considering the factors such as calipers mounting point, rim's offset, forces acting on the wheel assembly, bearing support position, available clearance between rotor and the upright and bearing size, a stub axle of 20 mm diameter and length of 70 mm with a desired FOS of 2 is determined. The stub axle is held firmly on knuckle surface by means of tight press fit. The bending force induced on the shaft is observed to be maximum during the 5 ft drop of the vehicle. The magnitude and the direction of the force are calculated to be 4200 N on each front wheel using input parameter velocity: 15 kmp h due to magnitude of force, and center of gravity is considered at same point with respect to weight biasing throughout the motion of the car during the 5 ft drop.

3 Methodology

Following steps are used for the development of stub axle for analysis:

(1) Manual calculations
(2) Modeling and stub axle with materials
(3) Mesh generation
(4) Application of boundary conditions.

3.1 *Manual Calculations*

Static structural analysis has been performed on the stub axle to find out deformation and factor of safety of the component during 5 ft drop. An ATV of mass 200 kg with driver is considered for analysis.

Input parameters:

5 ft impact force = 4200 N
Rim offset ratio = 3:2
Wheel width = 7 in.

3.1.1 Moment Generated Due to Rim Offset

Cross section of the rim is shown in Fig. 2. In Fig. 3, the distance OA is rim offset displayed.

Ra = 4200 N

Using the free body diagram (Fig. 4), moment = 4200 × 17.78 = 7676 N mm (anti-clockwise)

Force acting on hub = 4200 N, moment on hub = 74,676 N mm.

3.1.2 Force and Moment Transfer on Stub via Hub

The moment and force acting on the bearing cause the bending action of axle. Bearings with inner diameter of 17 and 20 mm were available, and bearing with 20 mm inner diameter is selected considering the constraints of the hub design (Fig. 5).

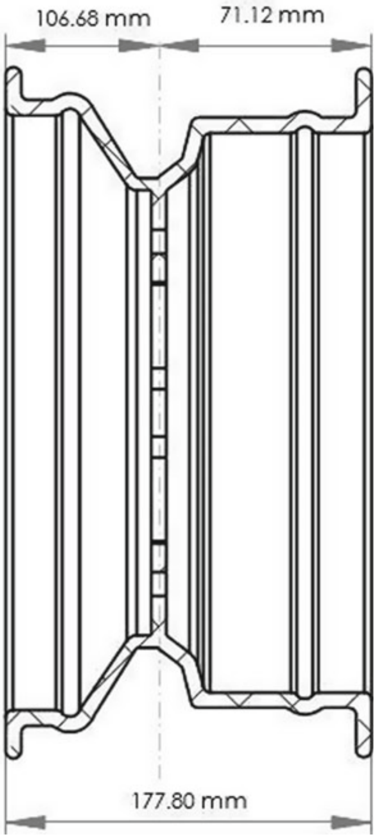


Fig. 2 Cross section of the rim

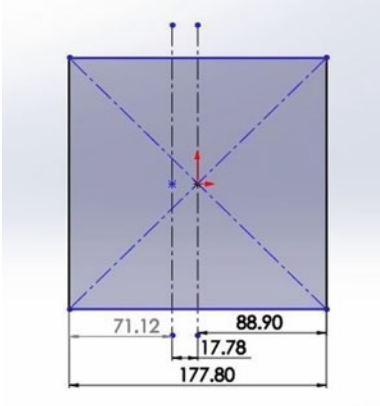


Fig. 3 Rim offset

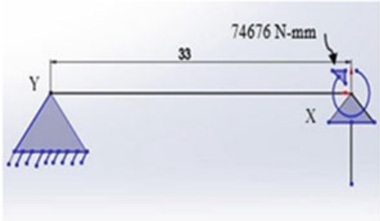


Fig. 4 Free body diagram of the rim offset

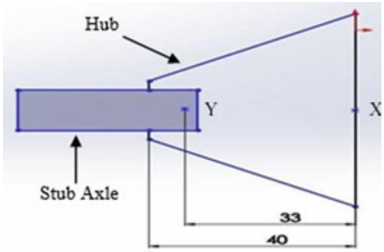


Fig. 5 Bearing support

3.2 Modeling and Stub Axle with Materials

Geometric modeling of the stub axle is done on Dassault SOLIDWORKS software. Based on the considerations mentioned above, two models of the stub axle were designed shown in below figure. The first model designed is of single homogenous material, i.e., aluminum 7075 T6 (Fig. 6), and the second model designed is a composite of aluminum 6061 T6 outer layer and core of EN 19 steel (Fig. 7).

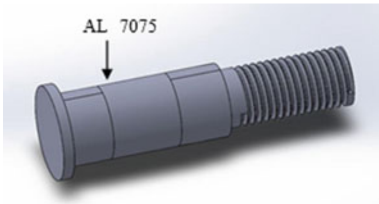


Fig. 6 Full aluminum stub axle

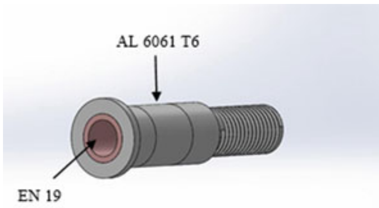


Fig. 7 Composite stub axle

Table 1 Properties of the materials used

Parameters	Al 7075 T6	AL 6061 T6	EN 19
Cost (RS/kg)	750	350	40
Yield strength (N/mm^2)	455	276	755
Ultimate tensile strength (N/mm^2)	525	310	1200

The material used for single stub axle is 7075 T6, whereas the materials used for composite stub axle are aluminum 6061 T6 as outer layer with EN 19 as an inner core. The properties of both the materials are shown in Table 1.

3.3 Mesh Generation

Tetrahedral elements can model most of the solid objects irrespective of complexity of the model. Therefore, three-dimensional tetrahedral elements with eight nodes were used for the following model. Mesh with average size of 2 mm was used. The initial mesh of the single stub axle is shown in Fig. 8, while that of the composite stub axle is shown in Fig. 9.

Fig. 8 Meshed single stub axle

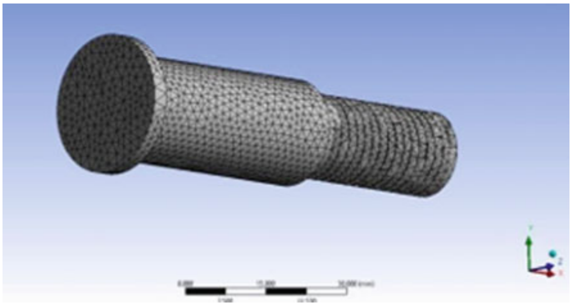
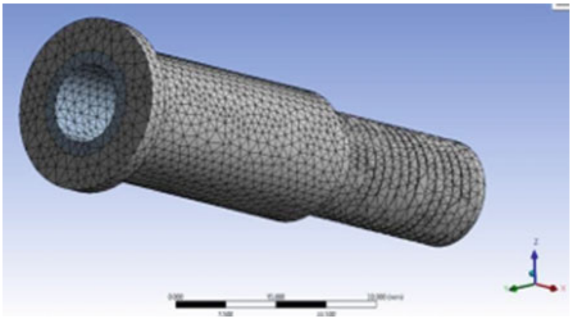


Fig. 9 Meshed composite stub axle



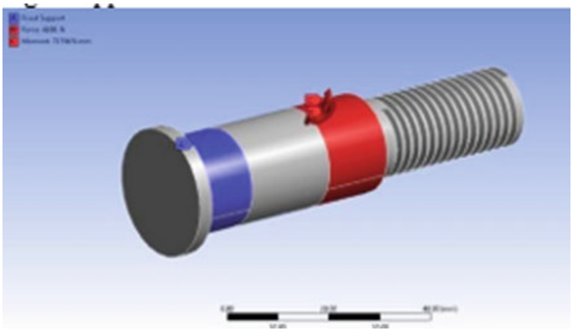


Fig. 10 Application of forces on Al 7075 T6 stub axle

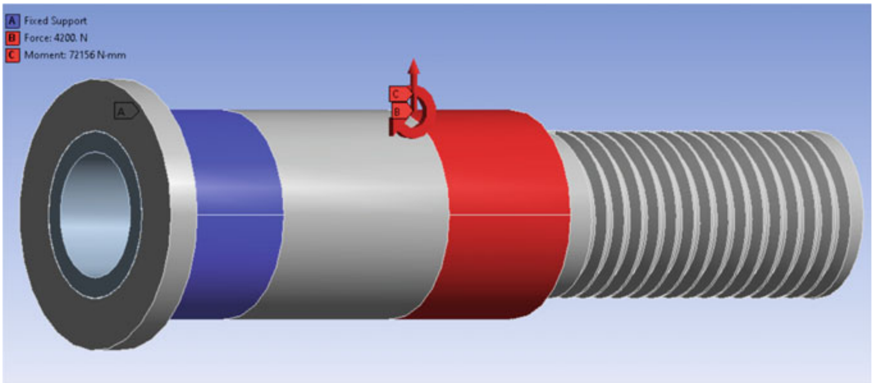


Fig. 11 Application of forces on composite stub axle

3.4 Application of Boundary Condition

The first 12 mm (red region) of the stub axle (Figs. 10 and 11) is where the force of 4200 N and a moment of 74,676 N mm are applied since that part of the axle is completely locked with the knuckle. The last 14 mm (blue region) of the stub axle is where the bearing provides support. Same boundary conditions are fed to both the stub axles in comparison.

4 Results and Discussion

Based on the above calculations, input parameters and results obtained are shown in Table 2.

From result table and analysis, overall stock weight was found to be 5 g more for composite stub axle as compared to aluminum stub axle which was around 8.10%. FOS of composite stub axle is increasing by 15.30% as compared to aluminum stub axle as shown in Figs. 12 and 13. The cost of composite stub axle is 49.86% less ten aluminum stub axle.

Table 2 Result table

Parameters	Aluminum	Composite
Materials	Aluminum 7075 T6	Aluminum 6061 T6 and EN 19
Stock dimension	Díameter 30 mm Length 100 mm	AL: Díameter 30 mm Length 100 mm EN: Díameter 20 mm Length 50 mm
Stock weight	200 gm	AL: 200 gm EN: 130 gm Total: 330 gm
Stock cost	0.200×750 $=$ Rs 150	$0.200 \times 350 +$ 0.130×40 $=$ Rs 75.2
Spindle weight	61.32 gm	66.29 gm
Factor of safety	2.306	2.652
Deformation	0.0651 mm	0.02023 mm

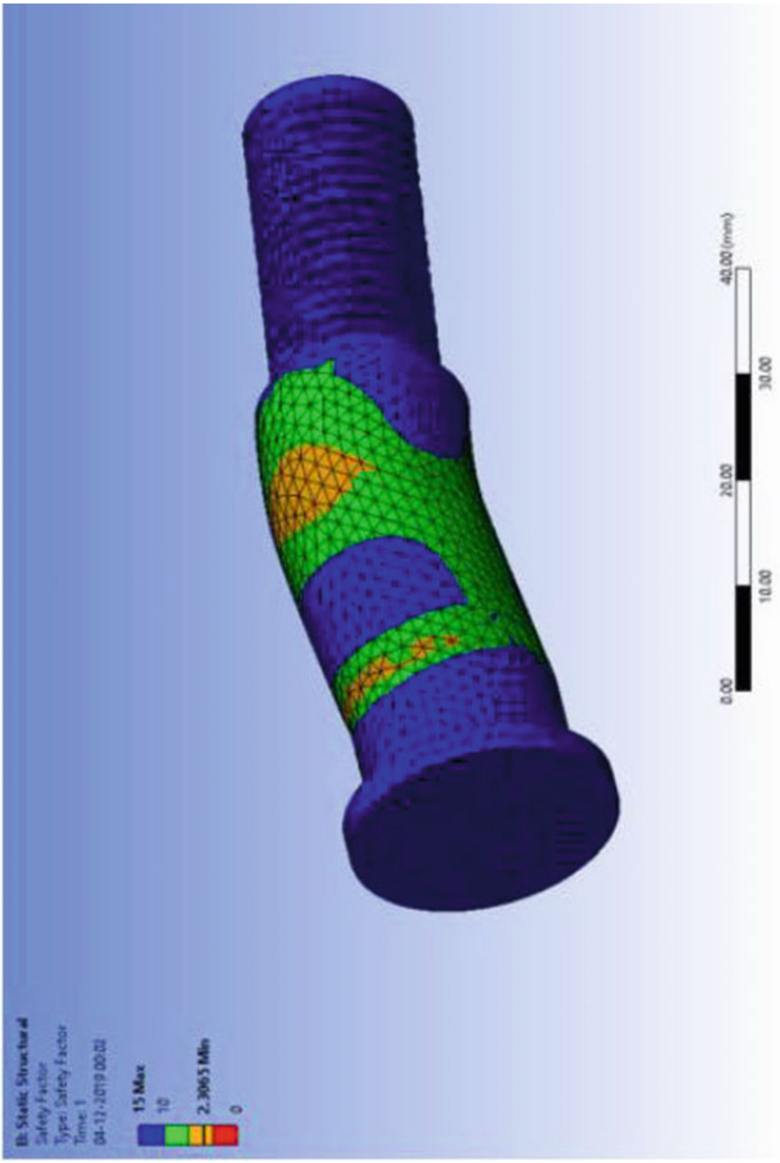


Fig. 12 FOS of AL 7075 T6 stub axle

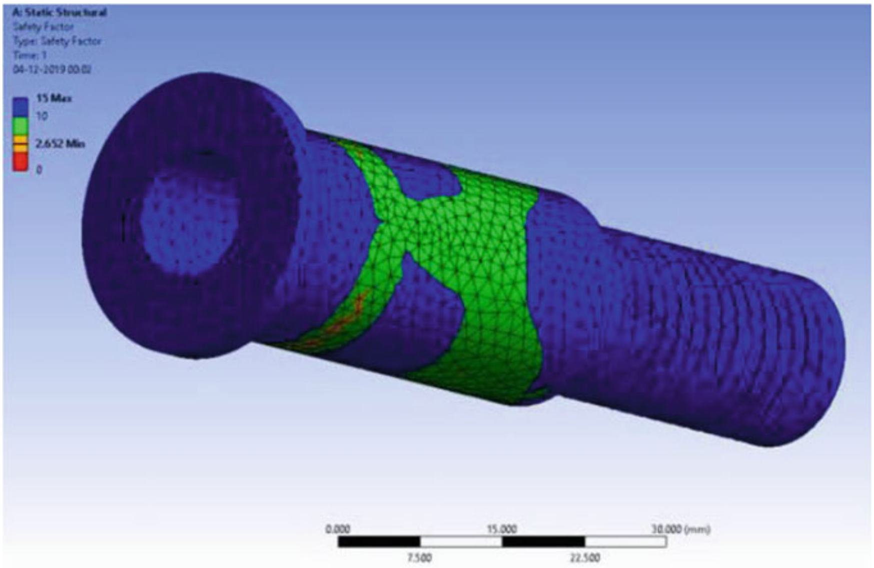


Fig. 13 FOS of composite stub axle

5 Conclusion

In this paper, comparative analysis of the stub axle of the vehicle was done. It was found that the FOS of composite stub axle is more than aluminum stub axle. The comparison shows that composite stub axle gives more safe design than aluminum stub axle. The cost of the composite stub axle is less than aluminum stub axle. Overall stock weight of composite stub axle is found to be more than aluminum stub axle. Though there is an increase in weight, the composite stub axle delivers better performance in terms of FOS, and there is a noticeable difference in the cost when compared to aluminum stub axle.

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