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Influence of material selection on finite element analysis and weight of gear box casing

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Abstract— Gearbox casings used in vehicles are subjected to compressive as well as tensile loads. Finite element analysis warrants component's sustenance under actual loading conditions virtually. Behaviour of the component varies with assignment of different material. In this paper results of finite element analysis of gearbox casing with assignment of Al 6061 T6 alloy and EN 1A steel are compared. Finite Element Method (FEM) has been used. The mechanical testing of aluminium 6061 T6 has been performed to obtain more accurate analysis results. Weight of the casing is a crucial parameter when performance of the vehicle is considered. Lesser the sprung mass better is the performance of the vehicle. Finite element analysis of a single speed reduction gearbox casing used in an all-terrain vehicle has been performed using ANSYS Workbench 15.0. The parametric model has been prepared using CATIA V5 R20 software. Use of aluminium 6061 T6 alloy lead to a design weight of 3.7623 kg which is almost 65% lighter than En 1A steel casing .Simultaneously 1.9331 value of static factor of safety has been achieved using Al 6061 T6 alloy compared to 2.01 value using EN 1A steel. The fatigue factor of safety value for aluminium casing is 1.0125 and 1.227 for EN 1A steel, both values are above 1. This warrants the use of aluminium alloy 6061 T6 where weight reduction is prime requirement without compromising strength.

Key words — Gearbox, casing, Al 6061 T6, EN 1A, finite element analysis, FEM, weight reduction, strength, static factor of safety, fatigue.

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1 INTRODUCTION

All-terrain vehicles generally use chain drives to transmit power from engine to wheels. The main motive behind this is to reduce weight. Gear boxes made up of steel prove to be significantly heavy when compared to the overall kerb weight of the vehicle. Excess sprung weight affects the performance of the vehicle adversely[1]. Lightweight aluminium alloys can be used for manufacturing gear box casings in order to reduce weight and provide better performance than chain drives.

Static analysis of a component provides the maximum stress induced at respective cross sections along with deformation and strain using Finite Element Method (FEM). In Finite Element Analysis (FEA) the part body or assembly is discretized into smaller elements which are separated by nodes. Greater the number of elements more accurate is the analysis[2]. FEA provides a solution which facilitates the synthesis of near to actual behaviour of the component in various loading conditions. FEA also facilitates calculation of fatigue life using various theories of failure.

In this paper , FEA of gearbox casing has been performed using inputs from mechanical testing of 6061 T6 grade aluminium for more accurate analysis. The weights of casings made up of EN 1A steel and aluminium alloy are compared. Static analysis of the casing parametric model is performed using Ansys Workbench 15.0.

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2. MATERIALS

2.1 Aluminium 6061 T6 alloy

Aluminium alloy has density equal to 2770 Kg/m^3 and poisson's ratio 0.33.

Tension test of Al 6061 T6 alloy has been performed using ASTM E08 standard. The test results are listed in table 1:

Table 1: Tension testing results

Parameter	Value
Gauge Diameter	11.02 mm
Area	95.42 mm^2
Gauge length	44.08 mm
Yield Load	24000 N
Max load	28400 N
Final Length	45.80 mm
Yield stress	251.53 MPa
Ultimate Tensile Strength	297.64 MPa
% Elongation	10.4 %

2.2 EN1A Steel

Density of En 1A steel is 7850 Kg/m^3 and poisson's ratio is 0.3.

Table 2: Mechanical Properties of EN 1A steel

Parameter	Value
Ultimate Tensile Strength	460 MPa
Yield Strength	250 Mpa

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3 Design of Gearbox Casing

The gearbox casing is used in a two stage reduction gear box. Spur gears are used in this gearbox. Gear box reduction ratio is 10:1 . This gear box is coupled to engine via Continuously Variable Transmission (CVT). The CVT has a low ratio of 3:1 and high ratio of 0.43:1. The role of the gearbox here is to reduce the output rpm from CVT and amplify torque to a specified amount which is slightly higher than the tractive effort calculated to displace the vehicle[1].

The gearbox casing has been designed as per the following procedure:

1) The compound gear train's total maximum length was obtained equal to 353mm

2) Then the clearance value was fixed to be 6mm for lateral as well as radial clearance.

3) The casing thickness has been decided using the following formula:

$$t = 6 + 0.01 \times L$$

Where, *t= Casing thickness (mm)*
L= Total end to end length(in mm)of gear train assembly including clearances[3].

The shape of the casing has been decided while constructing the parametric model using Catia V5 R20.

3.1 Chamfers And Fillets

Chamfers and fillets provide better load distribution[3,4]. Ribbed structure is avoided in order to reduce machining cost. Fillets are provided at sharp edges on the inner and outer side of the casing. Chamfers (material addition) around the bearing recess reduces stress concentration areas thus helping increase fatigue life.

4. Finite Element Analysis

The finite element analysis has been performed on single half of the split casing. Similarity between load cases applied on the two halves permits to analyse either of them to get to know their respective behaviour. When the whole assembly is analysed , the load is distributed in a much more better way but the behaviour of the single half is not explored . Hence it is beneficial to analyse each part of the assembly (here, it implies a single half of the two halves which are bolted together to form the casing). FEM is used for analysis of the component. Material assignment plays a critical role while finite element analysis of the component is being performed. Results vary according to selection and assignment of material.

4.1 Mesh

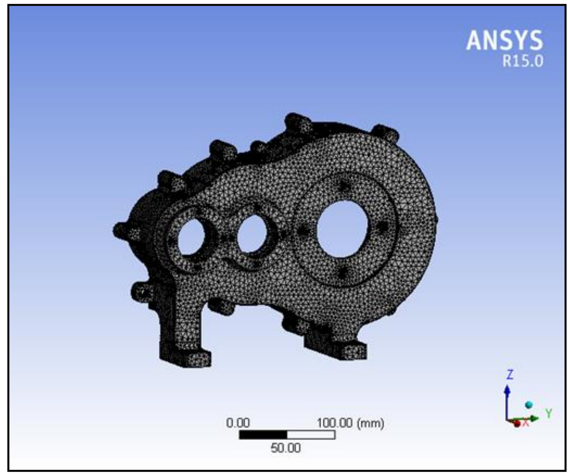

Figure 1: Generation of mesh.

Hex dominant method has been used. An unstructured meshing approach is used by this method to generate a quad dominant surface, later filling it up with a hex dominant mesh. Hex elements are formed generally on the boundary of a chunky part accompanied by use of a hybrid hex, prism, pyramid, or tetrahedral mesh used internally[2]. All the mesh attributes are given in detail in table 3.The main objective has been to get more number of nodes to increase accuracy of the solution. Hex dominant method provides better accuracy and efficiency[5].The mesh generated is shown in figure 1.

Table 3: Mesh attributes and statistics

Mesh Attributes	
Sizing	
Relevance Center	Medium
Element Size	3.0 mm
Smoothing	High
Transition	Fast
Span Angle Center	Fine
Minimum Edge Length	2.3237e-002 mm
Statistics	
Nodes	210892
Elements	122847

4.2 Component loading scenario

The loads applied remain same for both casings assigned with both the materials. These forces are applied on the bearing rest surfaces. The direction and area selected for force vector D is upwards due to the pull between CVT's driven and driver pulley. The force magnitude is equal to the belt tension. The surface beneath the legs of casing has been defined as fixed support. The magnitudes of forces are listed in table 4 and directions can be seen in figure 2.

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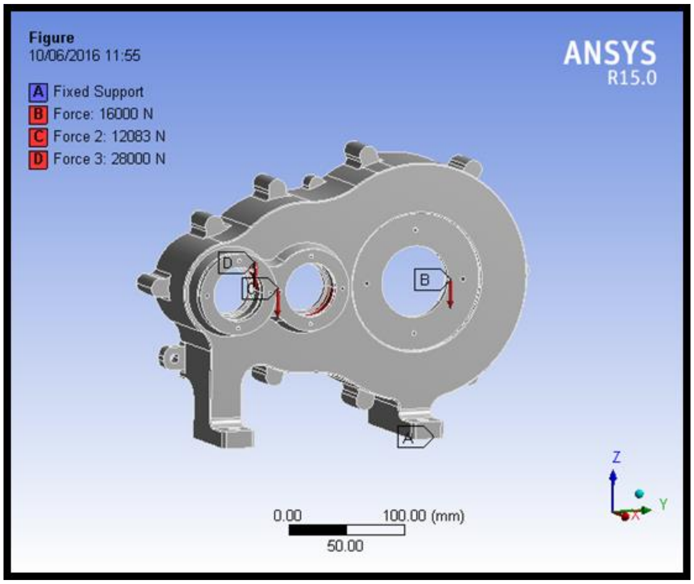

Figure 2: Directions of forces acting on casing.

Table 4: Component loading characteristics

Object Name	Fixed Support	Force	Force 2	Force 3
State	Fully Defined			
Scope				
Scoping Method	Geometry Selection			
Geometry	6 Faces	1 Face	2 Faces	1 Face
Definition				
Type	Fixed Support	Force		
Suppressed	No			
Define By		Vector		
Magnitude		16000 N (ramped)	12083 N (ramped)	28000 N (ramped)
Direction		Defined		

5 RESULTS

5.1 Total Deformation

The total deformation values are listed in table 5.

Table 5: Total deformation results

Material	Total Deformation (mm)	
	Maximum	Minimum
Al 6061 T6 alloy	0.58826	0
EN 1A Steel	0.20917	0

5.2 Equivalent stress (von-Mises stress)

The use of chamfering and filleting has led to less stress concentration sites at the periphery of the bearing pockets. It can be observed in figure 3 and figure 4 . The magnitudes of maximum and minimum von-Misses stress has been listed in table 6.

Table 6: Equivalent stress results

Material	Equivalent stress (von-Misses Stress) (MPa)	
	Maximum	Minimum
Al 6061T6	127.88	0.00036136
EN 1A Steel	129.33	0.00031897

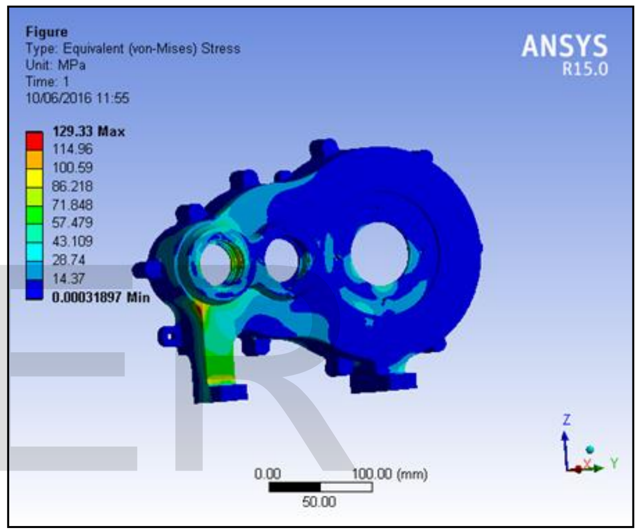

Figure 3: Magnitude of Equivalent stress for EN 1A steel casing

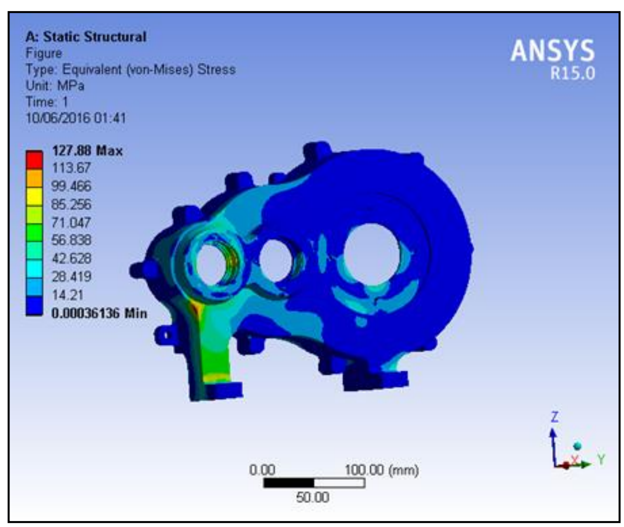

Figure 4: Magnitude of Equivalent stress for Al 6061 T6 casing

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5.3 Equivalent elastic strain

Table 7: Equivalent elastic strain magnitude.

Material	Equivalent Elastic Strain (mm/mm)	
	Maximum	Minimum
Al 6061 T6	0.0018019	9.4498e-9
EN 1A Steel	0.0006469	2.9196e-9

5.4 Static factor of safety for maximum loading condition

Static factor of safety has been analysed using stress tool in Ansys Workbenxh 15.0. The static factor of safety was nearly similar for both types of materials. The results are listed in Table 8. The regions with minimum safety factor are shown in Figure 5 and Figure 6.

Table 8: Results for static factor of safety.

Material	Factor of safety (minimum)
Al 6061 T6	1.9331
EN 1A Steel	2.0104

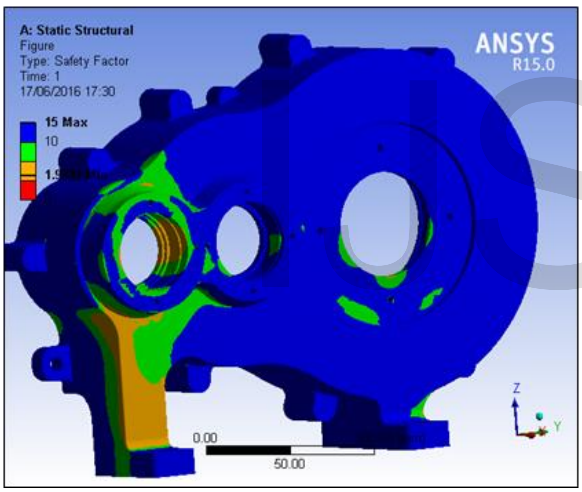

Figure 5: Safety factor for Aluminium casing.

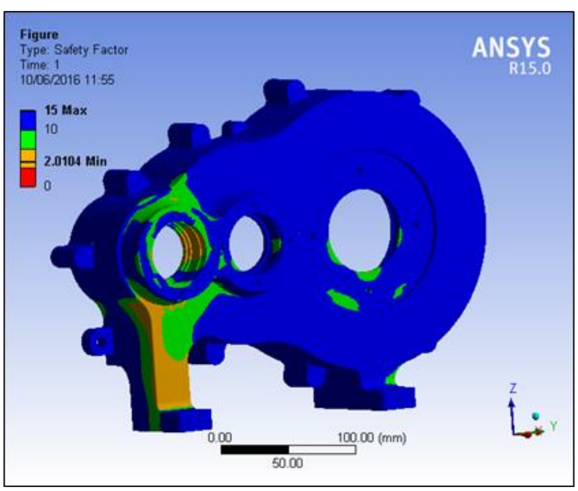

Figure 6: Safety factor for EN 1A steel casing.

5.5 Fatigue analysis

Fatigue analysis of the component has been performed based on Goodman mean stress theory. Zero based loading has been adopted. The results obtained using fatigue tool are listed in table 9.

Table 9: Fatigue analysis results.

	Material	
	Al 6061 T6	EN 1A Steel
Equivalent alternating stress (Max)	81.44 MPa	75.24 MPa
Factor of safety (Min)	1.0125	1.1227
Fatigue life (Min)	1e8 cycles	1e8 cycles

5.6 Weight of gear box casing

In Ansys Workbench the weight of the gearbox casing (considering both halves) was calculated to be 7.24 kg for Al and 21.8 kg for EN 1A steel casing. In actual the aluminium casing weight has been measured to be 7.29 kg after machining.

6. Experimental Validation

Al 6061 T6 casing has been manufactured using Vertical Machining Center and used in an ATV (all-terrain vehicle) during SAE BAJA 2016 event. The gearbox casing sustained on-field testing. The gear box endured the actual loading conditions as it was predicted using ANSYS Workbench R 15.0. One split part of the gearbox casing after machining is shown in figure 7.

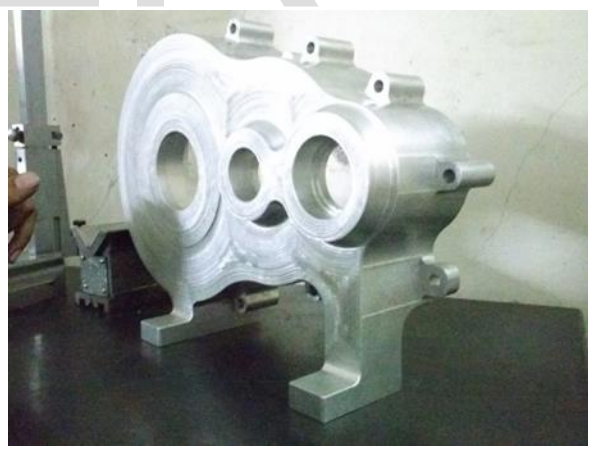

Figure 7: Gear box casing (one split part) after machining.

7. CONCLUSION

In this research, it has been proved that 6061T6 grade aluminium can be used in applications where weight reduction is of prime importance. Components made of EN 1A steel provide similar strength as compared to Al 6061 T6 components. The gear box casing was manufactured using Al 6061 T6 alloy. Rigorous testing validated the design and finite element analysis performed. Light weight casing enhanced the performance of the vehicle. The static factor of safety for Al 6061 T6 casing is

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1.9331 and 2.0104 for EN 1A steel. The fatigue factor of safety was 1.0125 for aluminium 1.1227 for steel casing.

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