Weight Optimization and Experimental Analysis of Front Drive Axle with Composite Reinforcement

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Abstract - *Front Drive Axel is most important systems used in vehicle to transmit the power. Performance of vehicle is equal to power to weight ratio, so intend is to reduce the weight without compromising mechanical strength. This paper focuses on failure of drive shaft in conventional passenger vehicles. Alto car front wheel drive shaft was chosen as the sample of this analysis. The solid model of the drive shaft was constructed using CATIA software. Steel (SM45C) material was selected for the analysis of shaft. The drive axle is analysed using Hyper-mesh and ANSYS software in which Tetrahedral type of meshing with minimum element size of 4mm was used for the analysis. The static loads are applied on the drive axle and analysis is carried out. The similar analysis was done for glass fibre material and results were compared with that of steel (SM45C). The comparison has shown increased stress and deformation for glass fibre material under same loading conditions. The result of comparison indicated that composite reinforcement is to be used, for obtaining required weight optimization of front wheel drive shaft without strength loss. Based on these results, best feasible design solution is proposed and validated experimentally.*

Key Words: **Front Drive Axle, Alto car, FEA Analysis, Static Load, Composite Reinforcement.**

1. INTRODUCTION

A drive front axle is the connection between the transmission and the front wheel of the car. The performance of car is measured by power to weight ratio. In order to get better performance the emphasis is given on reducing weight without compromising mechanical strength. Today's most automobiles use rigid drive front axle to deliver power from a transmission to the wheels. Machine elements and assemblies in the cases of the two variable loads are subject to stress, which under certain circumstances can lead to fractures and ultimately machine failure. Power transmission system of four wheeler and failures caused by dynamic Loading should be analyzed in order to optimize the performance. Hence, optimization of drive shaft with composite reinforcement should be done for reduction in weight. S. A. Mutasher investigated maximum torsion capacity of the hybrid aluminum/composite shaft for different winding angle, number of layers and stacking sequences.

The finite element method has been used to analyze the hybrid shaft under static torsion [1]. P. Satheesh Kumar Reddy worked on design, material selection, optimum stacking sequence, and performance of composite drive shaft for passenger cars, small trucks and vans. Optimum design was made based on Tensional stiffness formula and strength to weight ratio characteristics of solid to hollow shafts. It also aims to compare the performance of the composite drive shaft over steel drive shaft and suggested the suitability of composite materials in the automobile industries [2]. O. Montagnier et. Al. studied the dynamics of a drive shaft at supercritical speeds. The failure strength analysis focuses on the choice of the stress criterion. A composite shell model was developed for the torsional buckling. A comparative study between HM and hybrid solutions on a helicopter tail rotor driveline is also done [3].

1.1 Numerical analysis

In the numerical analysis initially it was done for existing material i.e. SM45C and the same is carried out for glass fiber. The comparisons have shown that glass fiber material has higher deformation for same loading conditions. Thus it was not feasible to make a total drive shaft from composite material. Hence drive shaft was made with composite reinforcement in order to get minimum deformation.

In this paper front axle drive shaft of Alto800 car with diameter 22mm and length 380mm was selected for study. The CAD model was prepared with CATIA software. Fig. 1 shows CAD model of front axle drive shaft under study.

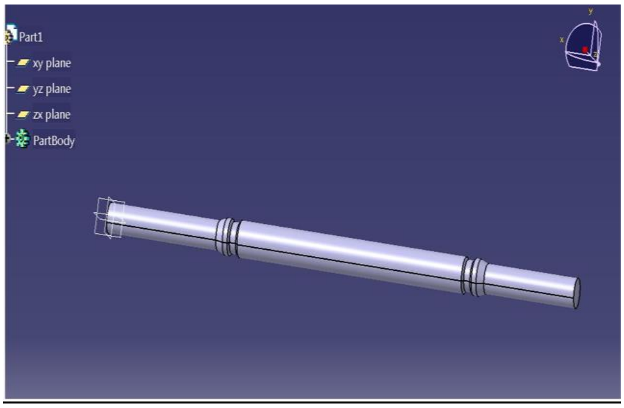


Fig-1: CAD Model of front axle drive shaft of Alto800 car

1.2 Meshing

Hypermesh software was used for meshing. A tetrahedral type of meshing was used. Fig. 2 shows tetrahedral meshing on drive shaft.

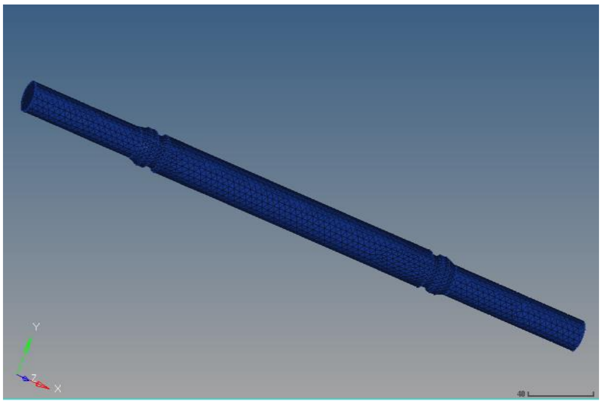


Fig.-2: Tetrahedral meshing on drive shaft.

The following are the specifications of meshing:

Number of nodes: 3937

Number of elements: 15858

Element size = 4 mm

1.3 Torque Calculation

The average speed of alto car was considered i.e. 37 km/hr (10.27 m/s). For this loading conditions torque calculated as:

Following parameters are taken from alto car specifications

1. Maximum horsepower = 47 bhp at 6000 rpm

2. Maximum torque=Engine torque = 62 Nm at 3000 rpm

3. Gross vehicle weight = 1140 Kg

4. Gear ratio (For first gear) = 3.416

Speed of car = π DN

Where,

N = Revolutions of tyre,

D = Diameter of tyre = 0.3048 m

Therefore,

Revolutions of tyre = N = 10.27/ (3.14 x 0.3048)

= 10.73 rev/sec

Drive shaft speed = Revolutions of tyre x Gear ratio

= 10.73 x 3.416

=36.64 rev/sec

Torque in drive shaft

= (engine torque x speed of first gear)/ (drive shaft speed)

= (62 x 50)/36.64

= 84.60 Nm=84600 N-mm

1.4 Boundary Conditions

While applying boundary conditions, one end of front axle drive shaft was fixed and one end was subjected to calculated torque. Table -1 shows list of properties of steel material used in existing front axle drive shaft.

Table- 1: Properties of steel material

Sr.no	Mechanical Properties	Unit	Value
1	Young's Modulus	GPa	207
2	Poisson's Ratio		0.3
3	Density	Kg/m^3	7600
4	Yeild Strength	MPa	370
5	Shear Strength	MPa	275

Fig.3 shows Meshed model with applied boundary conditions.

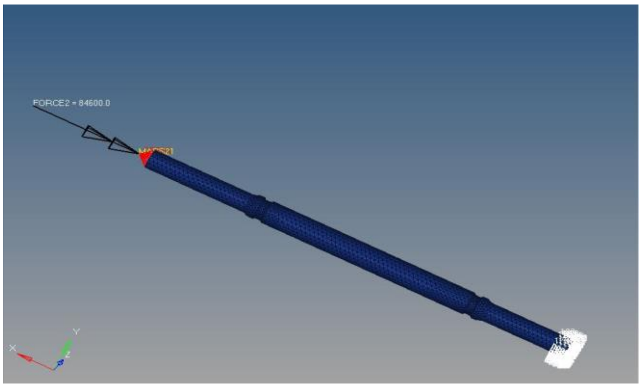


Fig- 3: Meshed model with applied boundary condition

Table-2 shows required properties of glass fiber material used for weight optimization.

Table -2: Properties of Glass Fiber Material

Sr. No	Property	Unit	Value
1	Young's modulus in x-direction	MPa	40300
2	Young's modulus in y-direction	MPa	6210
3	Young's modulus in z-direction	MPa	40300
4	Poisson's Ratio		0.2
5	Density	Kg/m^3	2600
6	Shear modulus in XY plane	MPa	3070

7	Shear modulus in YZ plane	MPa	2390
8	Shear modulus in ZX plane	MPa	1550
9	Tensile Yield Strength	MPa	2500
10	Compressive Yield Strength	MPa	3150

The calculated torque was applied on one end of drive shaft for existing material, glass fiber and by adding a layer of 3mm, 4mm and 5mm composite reinforced material.

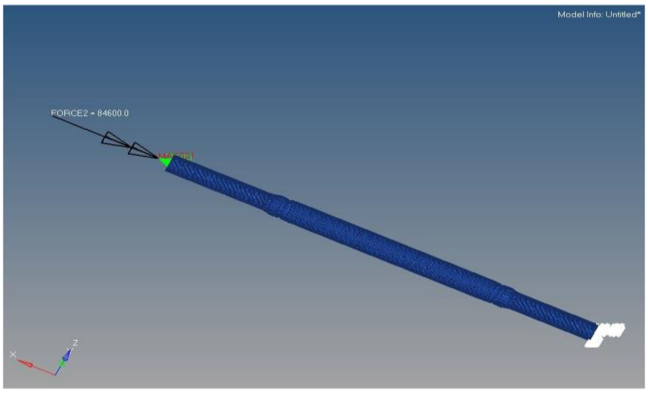


Fig. 4 Glass fiber

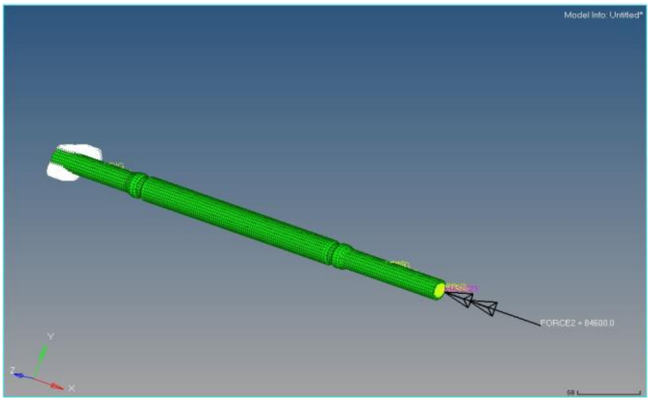


Fig. 5 Composite Reinforcement (3mm layer)

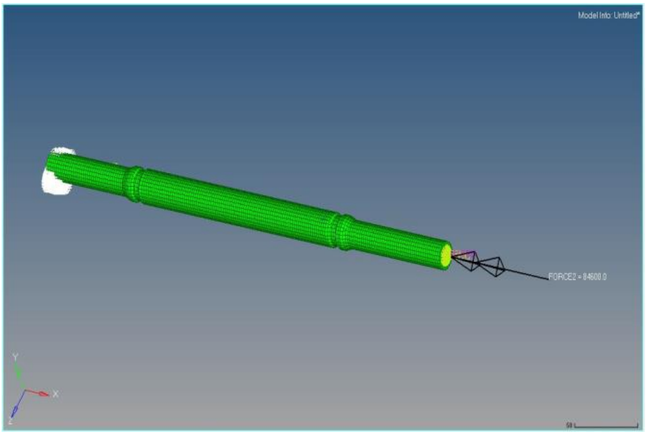


Fig- 6: Composite Reinforcement (4mm layer)

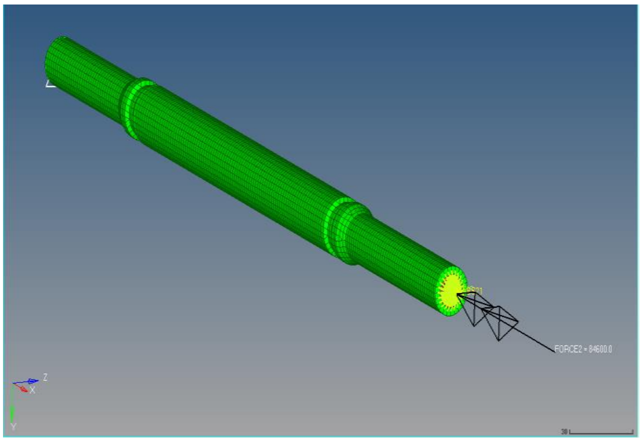


Fig-7: Composite Reinforcement (5mm layer)

Fig. 4 to Fig. 7 shows Meshed model with applied boundary condition for respective materials.

2. Results

Deformation and Von-mises Stresses were obtained by applying calculated torque at one end of drive shaft keeping other end fixed. Table-3 shows results of different iterations considered for same loading conditions. Fig. 8 to Fig. 17 shows deformation and Von-mises Stresses for existing material, glass fiber and by adding a layer of 3mm, 4mm and 5mm composite reinforced material respectively.

Table- 3: Deformation and Von-Mises Stresses

Iteration No.	**Material of drive shaft**	**Von-mises Stress (in MPa)**	**Deformation (in radian)**
1	Steel (Existing Material)	126.43	0.21
2	Glass Fiber	220.04	1.33
3	Composite Reinforcement (3mm layer)	539.80	0.256
4	Composite Reinforcement (4mm layer)	389.6	0.182
5	Composite Reinforcement (5mm layer)	182.64	0.042

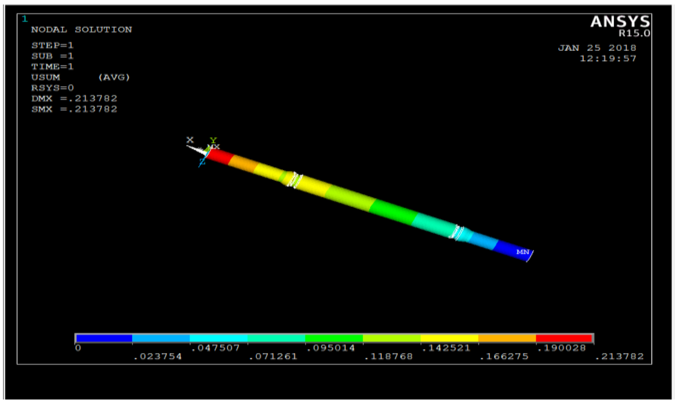


Fig. 8 Deformation plot for existing material

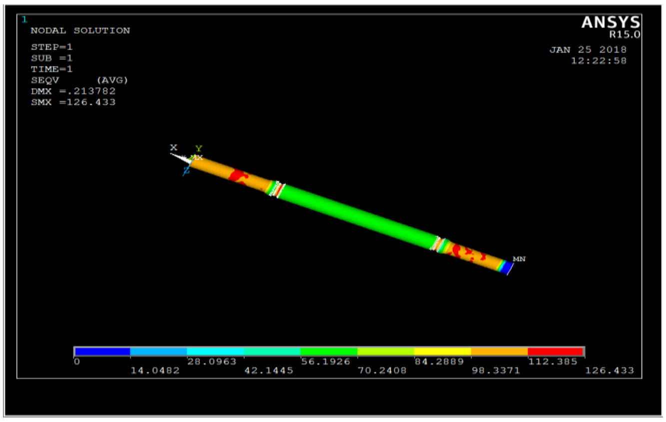


Fig. 9 Von-mises stresses for existing material

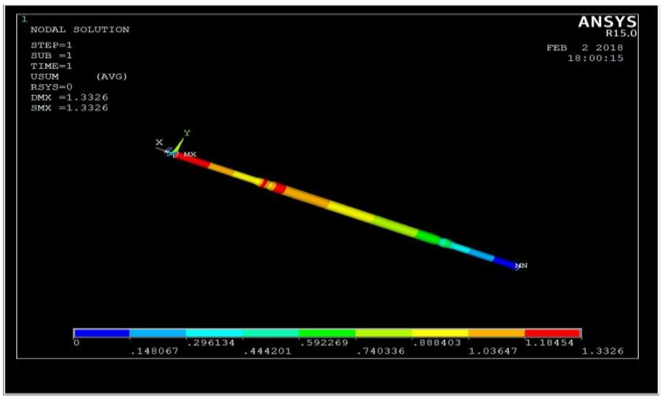


Fig-10: Deformation plot for glass fiber material

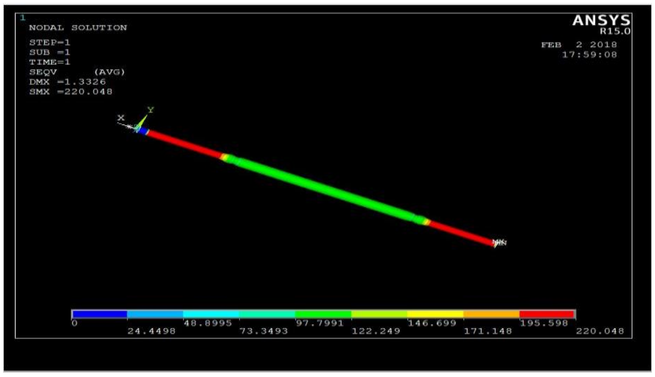


Fig -11: Von-mises stresses for glass fiber material

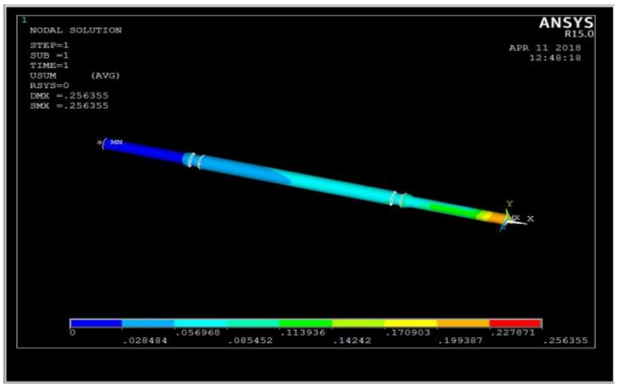


Fig -12: Deformation plot for Composite Reinforcement (3mm layer) material

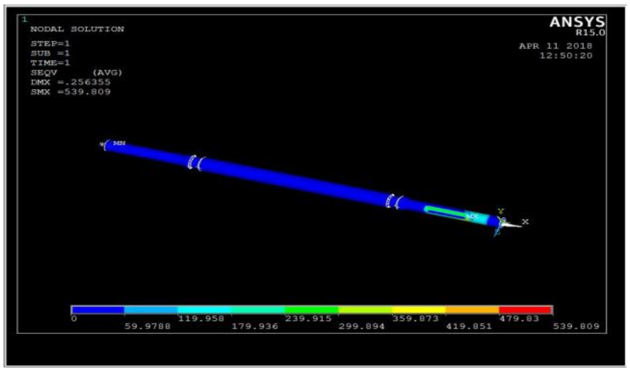


Fig-13: Von-mises stresses for Composite Reinforcement (3mm layer) material

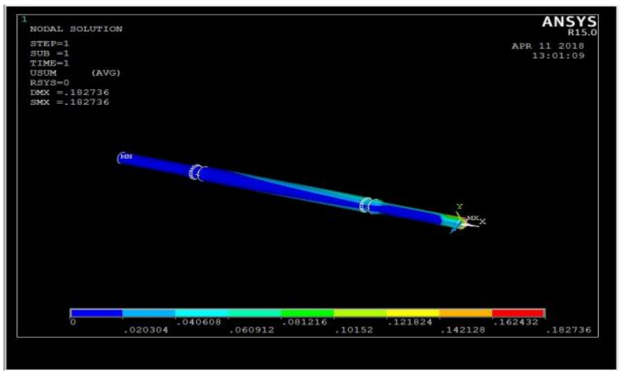


Fig-14: Deformation plot for Composite Reinforcement (4mm layer) material

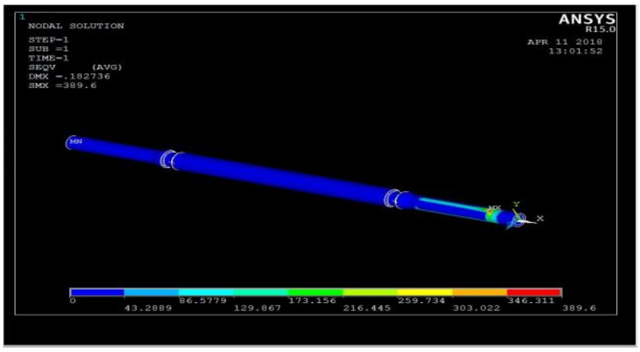


Fig- 15: Von-mises stresses for Composite Reinforcement (4mm layer) material

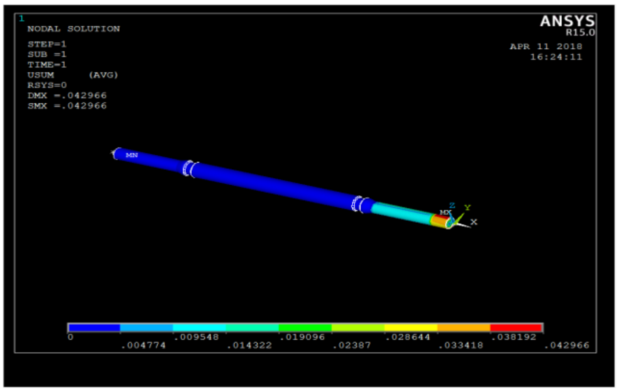


Fig-16: Deformation plot for Composite Reinforcement (5mm layer) material

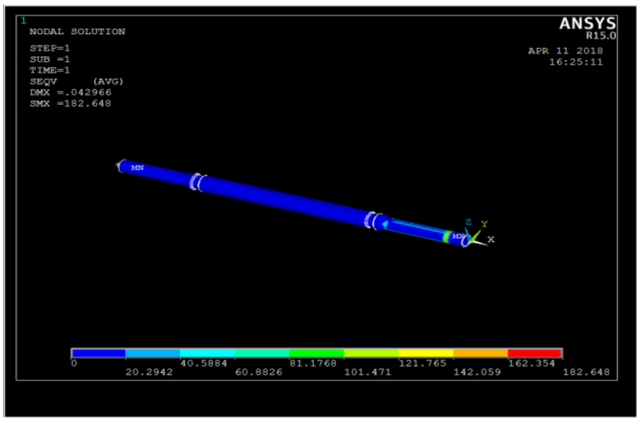


Fig-17: Von-mises stresses for Composite Reinforcement (5mm layer) material

From deformation and Von-mises Stresses plot it was observed that drive shaft with 5mm composite reinforced material is most feasible for considered loading conditions. Thus drive shaft with 5mm composite reinforced glass fiber is highly recommended for fabrication.

3. EXPERIMENTAL SETUP

3.1 Fabrication of Test Model

From numerical analysis it was decided to fabricate drive shaft with 5mm composite reinforced glass fiber for validating results obtained numerically. The fabrication of test shaft model was done at K.K. Engineering works, Narhe, Pune-41. The steel shaft with 12 mm diameter was taken and glass fiber reinforcement has been done layer by layer to achieve 5mm thickness. The orientation of glass fiber was kept around 45^0.

The glass fiber sheets were cut in proper shapes to do glass fiber reinforcement then it was fixed to the shaft. The epoxy resin was used as an adhesive with the added cobalt 10% and hardener 10% to increase the rate of drying process. Once the reinforcement process is completed the assembly was allowed to dry for nearly 48 hours. The shaft was then turned to required dimensions on lathe machine. The machining is done only for smoothing the shaft and to make grooves. There is no any influence on the material properties. Fig. 18 shows manufacturing of glass fiber reinforced drive shaft.

Fig-18: Manufacturing of glass fiber reinforced drive shaft

Fig- 19: Fabricated glass fiber reinforced drive shaft

Fig. 19 shows fabricated glass fiber reinforced drive shaft. The provision in the form of small rod is made on one end of the shaft for applying torque with Universal Testing Machine.

3.2 Testing of fabricated model

Testing of fabricated model was done on Universal Testing Machine (UTM) at Praj Metallurgical Lab, Kothrud, Pune-38. The model was tested for o to 115kN load. Fig. 20 shows UTM used for testing.

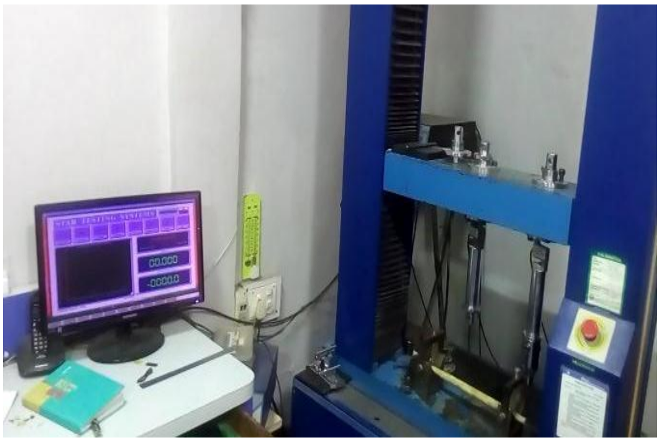
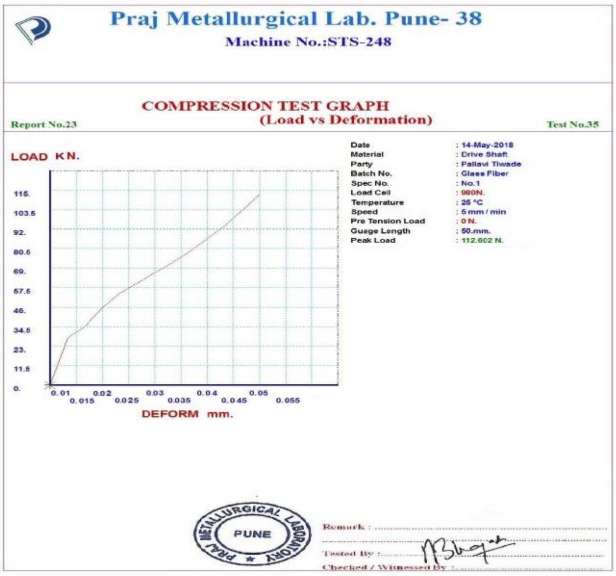


Fig-20: Testing on Universal Testing Machine

3.3 Results of Testing

Fig. 21 shows Compression test graph for load Vs deformation generated by UTM. It shows that drive shaft shows deformation of 0.04mm at the load of 84.6 kN.



Praj Metallurgical Lab. Pune- 38
Machine No.:STS-248

COMPRESSION TEST GRAPH
(Load vs Deformation)
Report No.23
Test No.35

Date : 14-May-2018
Material : Drive Shaft
Party : Pallavi Tiwade
Batch No. : Glass Fiber
Spec No. : No.1
Load Cell : 980N.
Temperature : 25 °C
Speed : 5 mm / min
Pre Tension Load : 0 N.
Guage Length : 50.mm.
Peak Load : 112.602 N.

Remark :
Tested By :
Checked / Witnessed By :

Fig-21 : Compression test graph for load Vs deformation generated by UTM.

4. RESULT AND DISCUSSION

Table 4 shows numerical and experimental results for tested drive shaft. It was observed that numerical and experimental results shows good conformity.

Table -4: Numerical and Experimental Results

Test type	Deformation (mm)	Angular Deformation (radian)
FEA Method	--	0.042
Experimental Method	0.4	0.044

Deformation in radian= $\tan^{-1}$*(Deformation in mm/radius of rod at end* r_1*)*

$$=\tan^{-1}(0.4/9)$$

$$=0.044\text{radian}$$

From the Experimental test plot Deformation of around 0.4 mm has been observed. In radian it is equal to 0.044 which is almost nearer to FEA results of 0.042 radian hence the results are in same limit. Thus, a numerical and experimental result shows good conformity.

Table 5 shows weights of existing and reinforced drive axle shaft. It was observed that weight of glass fiber reinforced shaft has been reduced considerably than the existing steel material shaft

Table- 5: Weight Reduction

Sr. No.	Component	Weight(Kg)
1	Existing	0.977 Kg
2	Glass fiber reinforcement	0.569 Kg

The percentage reduction in weight can be calculated as below,

Percentage Reduction = (weight of Steel shaft – weight of Glass fiber shaft)/ (weight of steel shaft)

= (0.977 – 0.569)/(0.977)

= 41 %

5. CONCLUSIONS

In this paper, the front drive axle of Alto 800 car was replaced by composite glass fiber reinforced material. The Finite Element Analysis has been performed for both steel (SM45C) and Composite reinforced (with 5 mm thick Glass Fiber layer) materials. The results of numerical analysis were verified with experimental setup. The comparison is listed in table-II have shown that experimental results are in well arrangement with FEA results with error of 4.76%. The following were the conclusions drawn from this study

- It was rust free operation.
- The weight has been reduced approximately by 41%.
- The stresses are within the limits and design is safe.

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