International Conference on Mechanical, Industrial and Materials Engineering 2015 (ICMIME2015)
11-13 December, 2015, RUET, Rajshahi, Bangladesh.

Paper ID: MS-08

Prospect of Mild Steel as CNG Auto Rickshaw Drive Shaft

Md Emdadul Hoque[1], Robiul Islam Rubel[2,*], Md. Jafor Iqball [3], Md. Kamal Uddin[4]
[1,2,3,4]Department of Mechanical Engineering, Rajshahi University of Engineering & Technology (RUET), Rajshahi-6204, Bangladesh
[a]emdadulhoque@gmail.com, [b,]rubel.ruet10@gmail.com, [c]jafor.rajshahi@gmail.com,*
[4]kamaluddin.me10@yahoo.com

Abstract

The use of CNG auto rickshaws as passenger car is growing in Bangladesh. These vehicles are usually seen to operate under overload condition. As a result several components fail randomly through service. For it, drive shaft rotates and transmits power from engine to rear wheels directly in absence of any intermediate differential gear box. Therefore, it is subjected to fluctuating loads of combined bending and torsion with various degrees of stress concentration. Hence failure of its drive shaft is common a common phenomenon. Though significant number of these vehicles is on service through the country the change of spare parts facility is not only insufficient, but also time consuming specially in case of drive shaft. It has to import from abroad, thus replacement becomes costly. Substituting costly imported conventional drive shaft by locally manufactured shaft is a promising job to lower the maintenance cost of the CNG auto rickshaw. In this work locally found mild steel mechanical properties are developed through hardening process to study the prospect of using it as drive shaft. In this regard shear stress, stress intensity, is measured using FEA (ANSYS) to come in decision of using locally made shaft.

Keywords: Drive Shaft, FEA, Material Development, Stress Analysis.

1. Introduction

Drive shaft is power transmitting components in vehicles use most of the motorized vehicle due to its high torque transmitting capacity with less vibration at high speed. Drive shaft is defined as a rotating member that transmits power from engine to wheels [1]. Figure 1 show a typical drive shaft used in CNG auto rickshaw.

Drive shaft must operate through constantly changing angles between the transmission and axle. Most shafts are subjected to fluctuating loads of combined bending and torsion with various degrees of stress concentration [2,3]. Shaft failure leads to heavy loss due to stoppage and repairing cost associate with the breakdown and extensive boring journey experience. Thus, substituting high costly conventional drive shaft by locally made shaft is an important criterion for depressing the maintenance cost of the CNG auto rickshaw. CNG shaft is a single short piece solid bar transmitting power between engines to wheel directly in absence of any intermediate differential gear box. Thus the shaft is made shorter to avoid the buckling and vibration with reliable torque bearing capacity. But practically this shaft does not meet the design concept, rather 1/4th failure related with it. Being short, the critical speed is not as vital as torsional shear stress. Austin H. Bonnett [4] discusses the causes of shaft failures. Among the most available reasons corrosion (29%), fatigue (25%), brittle fracture (16%) and over load (11%) are vital. The essential mechanical properties for a drive shaft are stresses, deflection, buckling load, critical speed etc. The CNG auto rickshaw shafts are designed on the basis of strength, rigidity and stiffness. Miss Priya Dongare concludes that, in metallic shaft design, knowing the torque and the allowable shear stress for the material, the size of the shaft's cross section can be determined and vice versa [5]. The statement stands that, material properties are vital for shaft design and service life. According to Sandeep Gujaran et al. [6] in deciding on an approach to shaft sizing, material and method of manufacturing, it is necessary to realize that a stress analysis at a specific point on a shaft can be made using only the shaft geometry in the vicinity of that point. Thus the geometry of the entire shaft is not needed. In designing, it is usually possible to locate the critical areas, size to meet the strength requirements, and then size the rest of the shaft to meet the requirements of the shaft-supported elements [7]. In this work the shaft material properties is determine by different laboratory testing machine. FEA tool is used to estimate the torsional shear stress, equivalent stress and stress intensity over the shaft because, FEA analysis is easier, required boundary conditions only. It eliminates costly experimental prototype testing. Later locally found Mild Steel is also tested, same as the original one. Decision is taken either the selected material is suitable for shaft. If not, heat treatment (Hardening)


(a)


(b)


(c)

Fig. 1. (a) Simple shaft; (b) Broken drive shaft; (c) Broken drive shaft edge.

- is employed for enhancing the shaft mechanical properties material. If the shaft is possible to make in locally, cost of manufacturing and replacement will reduce to a greater extend, providing a long lasting serviceable shaft.

2. Methodology

Test specimens are prepared from both existing and locally found material. The dimensions of the test specimens are found from the testing machine manual. In this work Universal testing machine is used for tensile, bending and compression test. The cyclic number is estimated by using Rotating Cantilever Bending Fatigue Test Machine at constant load amplitude. Hardness is measured by Rockwell hardness tester. Standard torsion testing machine is used for estimating the torsional stress. The material properties obtained by the tests is tabulated in Table 1 are used as input in FEA analysis. Later Identical FE model of a *Bajaj 3W RE-4 strokes* drive shaft is designed by ANSYS 14.0 workbench modeler. Using FEA tools the boundary conditions are applied on its different portion. The post processer of ANSYS solves the problem, with different parameter consistence with the model and boundary condition that has been already meshed. Depending on the analysis results, decision is taken either collected material can be employed directly as shaft material. For this case, result is negative. Therefore properties enhancement is done by hardening.

Bending test

Smooth cylindrical specimens without notches were used for bend testing under three-point bend arrangement. Under three point bending, strain is confined in the mid span area of the specimen which finally leads to yielding of the bar. The bending moment and bending stress can be found by Eq. (1) and Eq. (2). Since tensile test is conventionally used for determining material characteristics, in this case only ultimate bending stress has calculated. Figure 2 shows that, original and hardened mild steel have low bending tendency.

$$\text{Bending moment } M_b = \frac{FL}{4} \tag{1}$$

$$\text{Bending stress } f_b = \frac{32M_b}{\pi d^3} \tag{2}$$

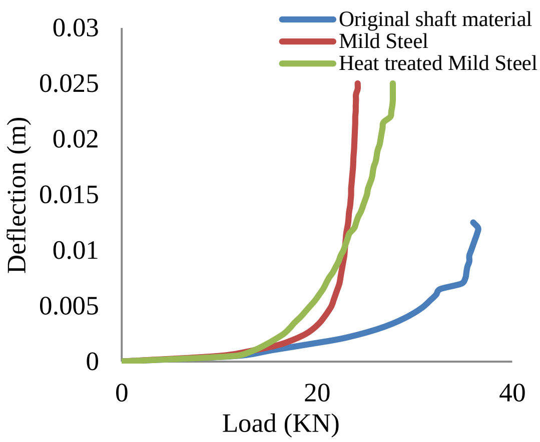


Fig. 2. Deflection vs. Load curves

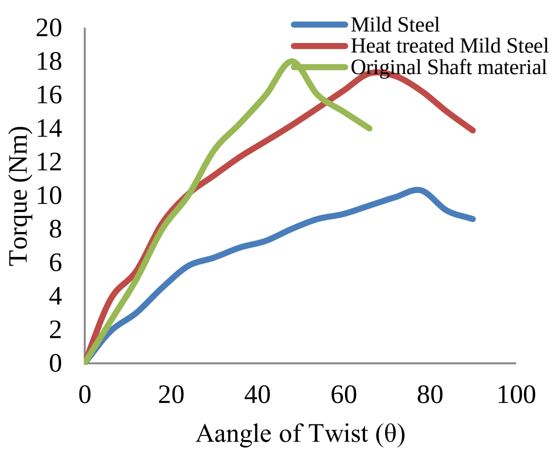


Fig. 3. Relationship between Torque and Angle of twist

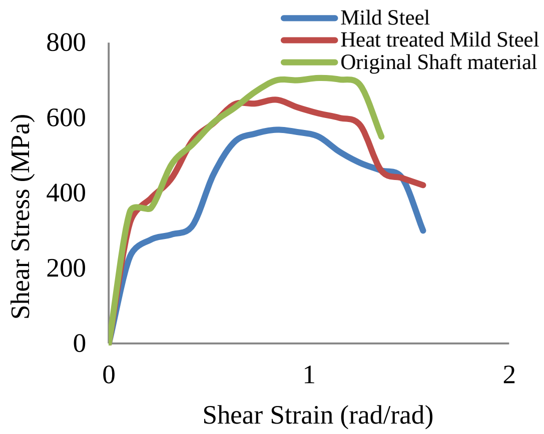


Fig. 4. Shear stress vs. Shear strain curves

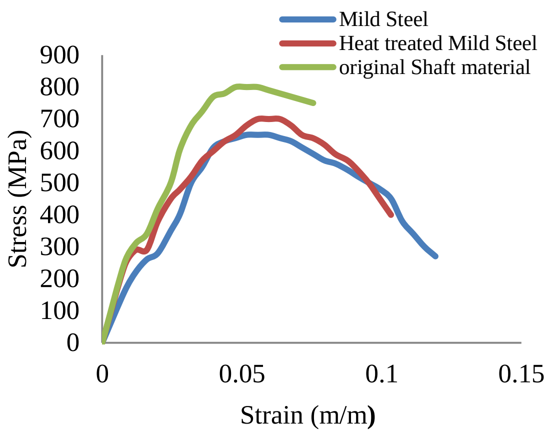


Fig. 5. Stress vs. Strain curves

Torsional test

Generally, torsion occurs when the twisting moment or torque is applied to a member. The subsequent results are depicted in Fig. 3 and Fig. 4. Drive shaft undergoes torsion when transmitting power. The three common forms that torsion testing take include failure, proof and operational. A torsion test for failure requires that, the test sample be twisted until it breaks and is designed to measure the strength of the sample [8]. The deformation and torsional stress can be calculated by Eq. (3) and Eq. (4).

$$\text{Torsional deformation } \theta = \frac{TL}{GJ} \quad (3)$$

$$\text{Torsional stress } f_s = \frac{16M_t}{\pi d^3} \quad (4)$$

Tensile test

Tensile testing [9,10] also known as tension testing, is fundamental materials science test in which a sample is subjected to a controlled tension until failure. Tensile testing provides valuable information about a material and its associated properties. The test results is shown in Fig. 5 and calculated by Eq. (5), Eq. (6) and Eq. (7).

$$\text{Tensile stress } \sigma_t = \frac{F}{A} \quad (5)$$

$$\text{Strain } \epsilon = \frac{\delta}{L} \quad (6)$$

$$\text{Modulus of elasticity } E = \frac{\sigma_t}{\epsilon} \quad (7)$$

Compression test

A compression test is any test in which a material experiences opposing forces that push inward upon the specimen from opposite sides or is otherwise compressed, squashed, crushed, or flattened. The result obtain is similar as tensile test. Compressive force in CNG auto rickshaw shaft is negligible. Thus compressive ultimate stress is calculated by Eq. (8).

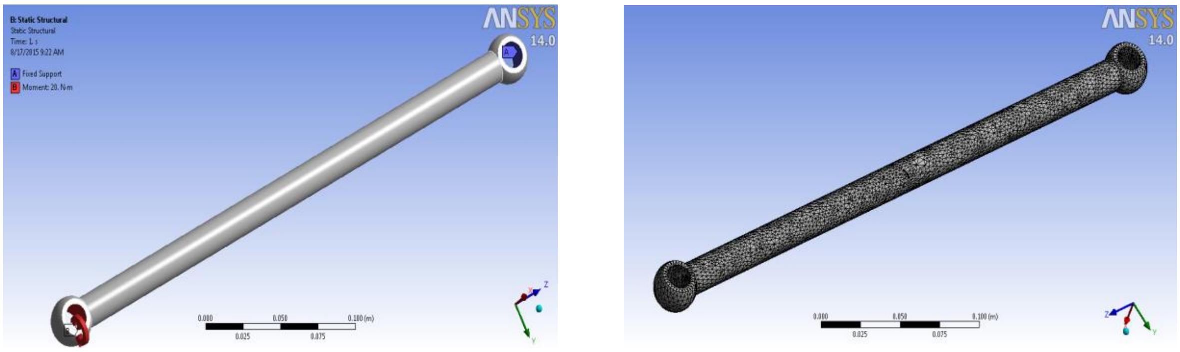
$$\text{Compressive stress } \sigma_c = \frac{F}{A} \quad (8)$$

Fatigue test

It is a method for determining the behavior of materials under fluctuating loads [11]. Fatigue failures often occur quite suddenly with catastrophic (disastrous) results and although most insidious for drive shaft. In constant-amplitude fatigue test method, amplitude obtained by applying reversals of stress of constant-amplitude to the test-piece until failure occurs. Different specimens of the test series may be subjected to different stress amplitude but for each individual item, the amplitude will never be varied [12]. Applied stresses were flexural (bending) in nature. The energy cycle taken for input in FEA is 80% of the fatigue failure cycle.

Heat treatment

Heat treatment is a process of increasing hardness of material. It is the combination of heating and cooling operations, timed and applied to a metal or alloy in the solid state in a way that will produce desired properties [13]. In this case hardening and quenching involves the following criteria. (i) Quenching medium-Water. (ii) Medium temperature-30 ºC. (iii) Heating time-1 hr. (iv) Temperature-800 ºC.



a. b.

Fig. 6. (a) FE Model and Boundary Condition, (b) Meshed body

User → Computer → User

Preprocess → Process → Post process

Build a FE model → Conduct numerical analysis → Results

Fig. 7. Flow chart of FEA

Table 1. Mechanical Properties of original shaft material and Mild Steel (without and with heat treatment)

Test items	Tensile yield stress (MPa)	Ultimate Tensile stress (MPa)	Ultimate Compressive stress (MPa)	Max. Bending stress (MPa)	Modulus of Elasticity (GPa)	Fatigue cycle	Rockwell Hardness
Original Shaft material	280	790	774	2462	193	8.1e5	44
Ordinary Mild Steel	210	650	627	1668	176	4.48e5	34
Heat treated Mild Steel	265	700	720	1960	188	7.7e5	41

Table 2. Features of model and meshed body

Model dimension	Magnitude	Unit	Meshed body Statics
Diameter	1.82	cm	Type of Element: Tet10
Length	35	cm	Number of nodes: 54980
Weight	0.71	kg	Number of Elements: 3200

Finite Element Analysis (FEA)

It is a method for numerical solution of field problems. FEA cuts a structure into several elements (pieces of the structure). Then it reconnects elements as nodes as if nodes were pins or drops of glue that hold elements together. This process results in a set of simultaneous algebraic equations. The model and meshed body of the FEA analysis is shown in Fig. 6. The features of the model are given in Table 2. FEA can handle very complex geometry, wide variety of engineering problems with multifaceted restraints [14]. It can handle both CAD and Solid Work model. Once a comprehensive model is developed, application of FEA can analyze the said design with details and thus saves time and investment reducing the requirement of making expensive prototypes. However, it is an approximate analysis method. Use of improper boundary condition is catastrophic. Therefore its analysis is little complicate, but magnificent. FEM/FEA needs computer programs and facilities. It gives solution only at nodal points. Again the FEM has some inherent errors. Figure 7 shows the FEA working steps.

Loading and boundary conditions

Maximum load condition for a drive shaft occurs during initial rotation of the wheel. The edge connected with the wheel drum behaves as a fixed body offering hindrance to the engine torque. Hence significant boundary conditions that may apply for analysis are (i) weight (ii) rotational velocity/moment (iii) fixed support etc. [15]. During operation several factor affect the drive shaft leading to early breakdown. But for analysis it is not feasible to consider the minor terms. Thus some assumption is under consideration for standard analysis of a drive shaft. They are the followings-

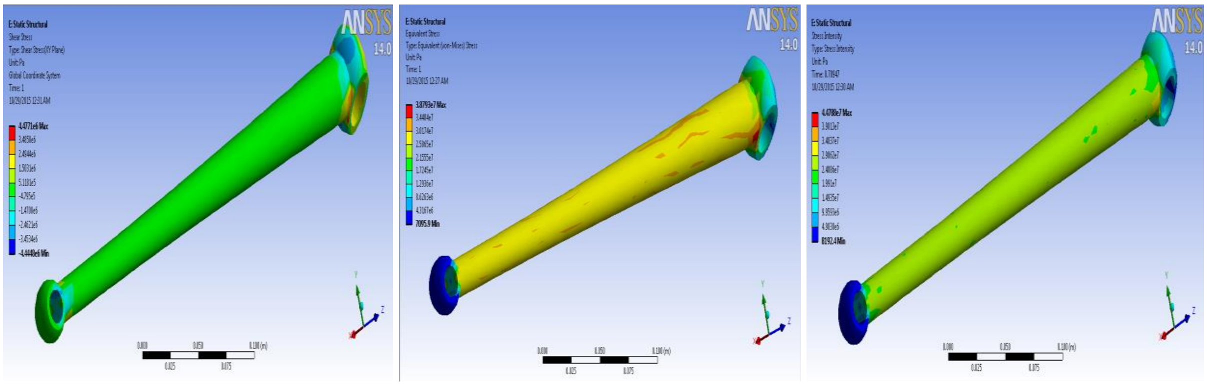
a. The shaft rotates at a constant speed about its longitudinal axis.
b. The shaft is a solid cylinder of uniform circular cross sectional area.
c. The shaft is fastened with perfect balancing.
d. All damping effects are avoided.
e. The stress-strain relationship for material follows conventional law.
f. Any fluid interactions and change of temperature are neglected.

Static Structure analysis

Static structural analysis is mainly concerned with finding out the behavior of a physical structure when subjected to force. If a load is applied sufficiently slowly, the inertia forces (Newton's second law of motion) can be ignored and the analysis can be simplified as static analysis [16]. The basic parameters relating static analysis are deformations, internal forces, stresses, support reactions, accelerations, and stability. For drive shaft torque is applied on one edge where other end assumes fixed as shown in Fig. 6(a). The governing equation involve are Eq. 9, Eq. 10. The results are depicted in Fig. 8, Fig. 9, and Fig. 10.

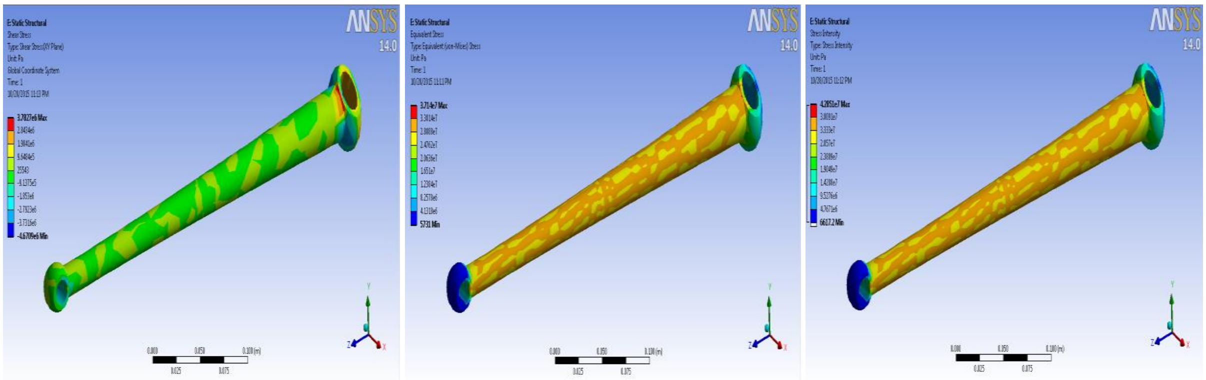
$$\text{Shear stress} \quad \sigma = \frac{16M_t}{\pi d^3} \tag{9}$$

$$\text{Equivalent stress} \quad \sigma_{eq} = \sqrt{\sigma_{bmax}{}^2 + 3\tau_{max}{}^2} \tag{10}$$



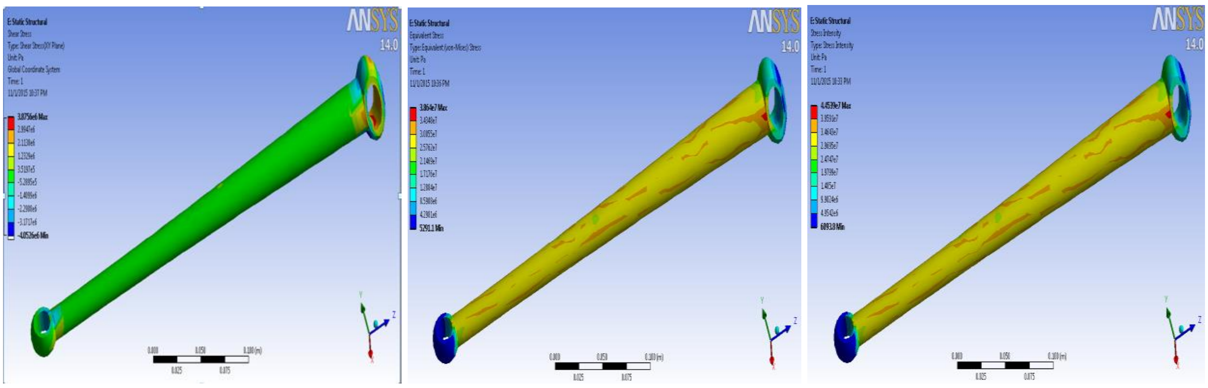
a. b. c.

Fig. 8. For Mild Steel without heat treatment (a) Shear stress (b) Equivalent stress, (c) Stress intensity



a. b. c.

Fig. 9. For original shaft material (a) Shear stress, (b) Equivalent stress, (c) Stress intensity



a. b. c.

Fig. 10. For heat treated Mild Steel (a) Shear stress, (b) Equivalent stress, (c) Stress intensity

3. Results and Discussion

Every Shaft executes two types of load. They are torsion due to transmitted torque and bending from transverse loads. With laterally loaded shafts, the flexural deformations are based on the applied moment and the flexural stiffness of the shaft at the cross section. In addition, the flexural stiffness (EI) of the shaft is a function of the Young's modulus (E), moment of inertia (I) of the shaft cross section and the properties of the surrounding fluid. Thus shaft material varies according to the level of the applied stresses. CNG auto rickshaw is a light weighted vehicle. Therefore, Mild steel can be used for as shaft material. To minimize both deflections and stresses, the shaft length should be kept as short as possible and overhangs usually minimized. Being light and strong Mild Steel is best suited for the CNG shaft. The results of FEA are given in Table 3 to clarify the statement.

Table 3. Summary of the FEA result

Test items	Shear stress (MPa)	Equivalent stress (MPa)	Stress intensity (MPa)
Original Shaft material	280	790	44
Ordinary Mild Steel	210	650	34
Heat treated Mild Steel	265	700	41

4. Conclusions

The prospect of Mild Steel for the purpose drive shaft is studied. It is the most cheapest and available locally found material. The drive shaft has been analyzed using ANSYS (FEA) taking the material properties drive from the testing. It provides distribution of torsional shear stress, equivalent stress, and stress intensity over the shaft. From the test results, it is clear that the mechanical properties of the original drive shaft are high. Therefore ordinary materials are not apposite for drive shaft. They would not sustain under operating conditions. A properly heat treated material will dissolve this problem. From the above test result it is also observed that, simple hardening process enhanced Mild Steel properties adequately. Heat treated Mild Steel has sufficient strength and hardness. It can resist high torque and has low bending tendency. Thus it is suitable for drive shaft purpose with reliability. It can be easily developed with minimum effort and cost. If the shaft is developed locally, cost of manufacturing will be reduced significantly.

5. References

[1] Bhirud Pankaj Prakash, and Bimlesh Kumar Sinha, "Analysis of drive shaft", *Proc. of Annual International Conference IRAJ*, Pune, India, pp. 71-76, Jan. 19, 2014.

[2] Sumit P.Raut, Laukik P.Raut, "A Review of Various Techniques Used for Shaft Failure Analysis", *International Journal of Engineering Research and General Science*, Vol. 2, Issue 2, Feb.-Mar. 2014.

[3] Robert L. Norton, Machine Design- An Integrated Approach, *Prentice-Hall*, 2000.

[4] Austin h. Bonnett, "Cause, analysis and prevention of motor shaft failures", *IEEE*, 1998.

[5] Miss Priya Dongare, and Prof. Dr. Suhas Deshmukh, "Static and Modal Analysis of Composite Drive Shaft and Development of Regression Equations", *International Journal of Engineering Research and Technology*, Vol. 1, Issue 10, Dec. 2012.

[6] Sandeep Gujaran, Shivaji Gholap, "Fatigue Analysis of Drive Shaft", *International journal of research in aeronautical and mechanical engineering*, Vol.2, Issue.10, Oct. 2014.

[7] Information on: http://www.testresources.net/applications/by-test- type/torsion-test. (05.09.2015)

[8] Czichos, Horst, Springer Handbook of Materials Measurement Methods, *Berlin: Springer*, 2006.

[9] Davis, Joseph R. (2004). Tensile testing (2nd ed). ASM International. ISBN978-0-87170-806-9.

[10] A. J. Fenner, Mechanical Testing of Materials, *Philosophical Library*, Inc. ASTM D-671.

[11] Abass Adeyinka Azeez, "Fatigue failure and testing method", *Bachelor's Thesis*, Hamk University of Applied Sciences, 2013.

[12] Prof. Olivier de Weck, and Dr. Il Yong Kim, Engineering Design and Rapid Prototyping, *MIT*, 16.810 (16.682), Jan. 12, 2004.

[13] Sidney H. Avner, Introduction to physical metallurgy, *Tata McGraw-Hill Publishing Company Limited*, 1997.

[14] Arun Ravi, "Design, Comparison and Analysis of a Composite Drive Shaft for an Automobile", *International Review of Applied Engineering Research*. Vol. 4, No. 1, pp. 21-28, 2014.

[15] P. Jayanaidu, M. Hibbatullah, and Prof. P. Baskar, "Analysis of a Drive Shaft for Automobile Applications", *Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, Vol. 10, Issue 2, pp. 43-46, Nov. - Dec. 2013.

[16] Information on: https://en.wikipedia.org/wiki/Structural_dynamics.