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DEVELOPMENT OF A CNG AUTO RICKSHAW DRIVE SHAFT FROM A LOCALLY AVAILABLE MATERIAL

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Abstract-*CNG auto rickshaw is the cheapest passenger car, increasing recently in Bangladesh. These vehicles are usually seen to operate under overload condition. As a result several components fail randomly during operation. For this type of vehicles, drive shaft transmits power from engine to rear wheels directly. Therefore, it is subjected to fluctuating loads of combined bending and torsion with various degrees of stress concentration. Hence failure of the shaft is common. But it has to import from manufacturer, which makes not only its replacement costly but also time consuming due to unavailability throughout the country. In Bangladesh there is no recognized company for manufacturing the shaft locally. This paper intends to estimate the mechanical properties of the shaft material. A locally available material is properly heat treated for developing the required properties of existing one. The economy of the shaft for mass production by the local manufacturer is also estimated.*

Key words: Drive shaft, Stresses, Heat Treatment, Design Calculation and Cost Estimation.

1. INTRODUCTION

A drive shaft is a rotating member that transmits power from engine to wheels [1]. Figure 1 shows a typical drive shaft. 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. Substituting high cost conventional drive shaft by locally made shaft is an important criterion for lowering the maintenance cost of the CNG auto rickshaw. Its shaft is a single piece bar transmitting power between engine 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 of the major component fail related with it. For short single piece solid CNG auto rickshaw shaft, critical speed is not vital, but buckling force is high. Therefore ordinary material would not sustain under operating condition. Austin H. Bonnett[4] discuss the causes of shaft failures among them corrosion (29%), fatigue (25%), brittle fracture(16%) and over load (11%) are major reasons. That means, material properties is vital for shaft design and service life. In this work an attempt has made to analysis the shaft material properties by different testing machine. Later a locally found material is also tested, same as the original one. Decision is taken either the selected material is suitable for shaft. If not, heat treatment process might be the optimal resolution that can be employed for developing the shaft material. If the shaft is possible to make in Bangladesh, cost of the shaft and replacement will reduce to a greater extend.

Fig.1: Drive shaft of CNG auto rickshaw

2. METHODOLOGY

The essential mechanical properties for a drive shaft are stresses, deflection, buckling load, critical speed. 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. That meansuniform bending moment along the specimen length. Hardness was measured by Rockwell hardness tester. Standard torsion testing machine is used for estimating the torsional behavior. Depending on the test, decision is taken either collected material can be employed directly as shaft material. For this case, result is negative. Therefore properties enhancement is required. The new trend of heat treatment for shaft material is hardening or normalizing. For Mild Steel metal hardening and quenching provides longer service than conventional case hardening.

3. SHAFT DESIGN ANALYSIS

Every Shaft has two types of load[5].They are (i) Torsion due to transmitted torque. (ii) Bending from transverse loads.Deformations in any structural element depend upon the characteristics of the load, the element shape and its material properties. 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. The shaft may be designed on the basis of strength, rigidity and torsional stiffness. To minimize both deflections and stresses, the shaft length should be kept as short as possible and overhangs minimized. Light and strong materials are best suited for the shaft.Problems associated withconventional drive shaft are following-

(i) Frequent failure (ii) Importation (iii) High cost (iv) Unavailable through the country (v) Non repairable.

4. SHAFT MATERIALS

The materials used for ordinary shaft is Mild Steel. When high strength is required an alloy steel such as nickel, Nickel Chromium or Chrome-Vanadium Steel are used. In most cases ordinary material does not possesses enough strength to use as shaft material directly. Therefore heat treated alloy steel, aluminum is preferred for light duty vehicles. Modern trend of the automotive vehicles is to use composite drive shaft. But it is not yet used for auto rickshaw. Precision hardened steel is used in CNG auto rickshaw. But in case of a steel shaft, the modulus of elasticity remains constant until reaching the yield point, after which the steel shaft starts to behave elastic-plastically with different values of the secant modulus of elasticity. Once the shaft deflection reaches plastic limit, it responds in plastic fashion under a constant plastic moment.

5. 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[6].

5.1 Hardening

The process of hardening consist of heating the metal to a temperature of 30-50 ºC above the upper critical point for hypo-eutectoid steels and by the same temperature above the lower critical temperature for hyper-eutectoid steels. It is held at this temperature for some time and then quenched [7]. Sometimes hardening may be incorporated by tempering. The quenching cycle involves three successive phases [8]. They are (i) Heating to temperature (T) called the austenitzing temperature. (ii) Maintaining this temperature (T) to dissolve the carbide sand to obtain a homogenous solid solution of austenite. These two phases together form the austenisation phase. (iii) Cooling by immersion in some medium (water, oil and air) sufficiently rapid to obtain the desired quenching components. The quenching media in general used are water, brine, oils, air and molten salt. Water is probably the most widely used as it simple and effective. It cools at the rate of 982°C per sec.

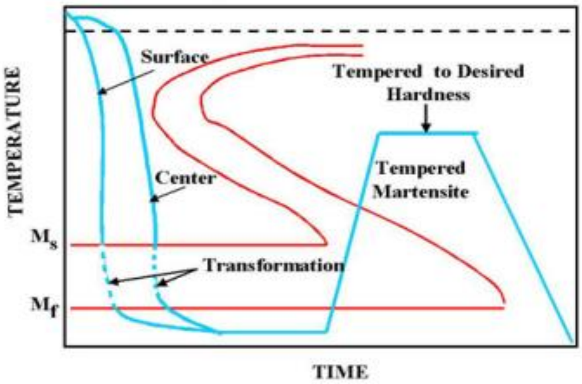


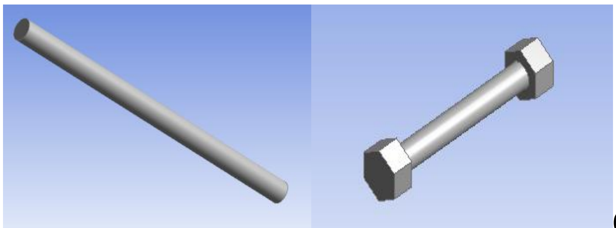
Fig.2: Conventional quenching and tempering process

It tends, however, to form bubbles on the surface of the metal being quenched an causes soft spots, so a brine solution is often used to prevent this trouble. In this case hardening and quenching involves the following criteria.

(i) Quenching medium-Water
(ii) Medium temperature-30ºC
(iii) Heating time of Mild Steel-1 hr.
(iv) Temperature-800ºC

6. PREPARATION OF TEST SPECIMENS AND TESTING

Since it is not possible to test the whole shaft performance, test specimens wereprepared by machining to the required dimensions usingLathe, Shaper and Grindingmachine. Filing was done to polish the surface to obtain theprospect result. The specimensprepared for testing are shown in Fig. 3.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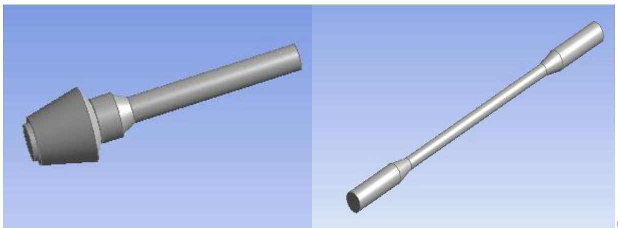
(b)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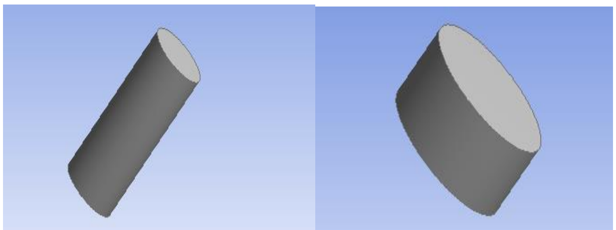
(e)(f)

Fig.3:(a) Bending, (b) Torsion, (c) Fatigue, (d) Tensile,(e) Compression and (f) Hardness test specimens

6.1 Bending Test

Smooth cylindrical specimens without notches were used for bend testing underthree-point bend arrangement.Under three point bending, strain is confined in the midspan area of the specimen which finally leads to yielding of the bar. Bend test is therefore suitable for evaluating strength of brittle materials where interpretation of tensile test result of the same material is difficult due to breaking of specimens around specimen gripping. The evaluation of the tensile result is therefore not valid since the failed areas are not included in the specimen gauge length. Under three point bending, strain is confined in the midspan 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 4 shows that, original and hardened mild steel have low bending tendency.

Span length L = 168 mm

Diameter d = 18.2 mm

Bending moment $M_b = \frac{FL}{4}$ (1)

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

The original shaft material resists maximum bending load of 36500 N. After heat treatment of Mild Steel the bending load resisting capacity becomes 24175 N to 27750 N. The load vs. deflection curves is shown in Fig. 4. The summary of bending test is given in Table 1.

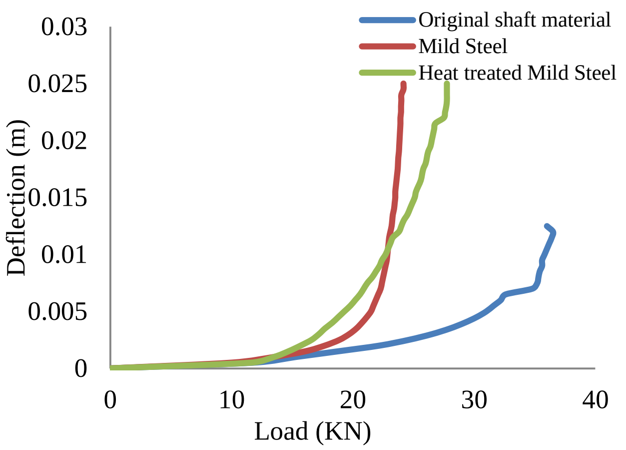

Fig.4: Deflection vs. Load curves

Table 1: Summary of Bending test

Details	Original shaft material	Mild Steel before heat treatment	Mild Steel after heat treatment
Flexure load at maximum (N)	36500	24175	27750
Bending stress at max. load (MPa)	2462	1668	1960

6.2 Torsional Test

Generally, torsion occurs when the twisting moment or torque is applied to a member as shown in Fig. 5. 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 [9].In torsion testing, the relationship between torque and degree of rotation is graphically presented and parameters such as ultimate torsional shearing strength (modulus of rupture), shear strength at proportional limit and shear modulus (modulus of rigidity) are generally investigated[10]. Moreover, fracture surfaces of specimens tested under torsion can be used to determine the characteristics of the materials whether it would fail in a brittle or a ductile manner. It can be seen from Fig.6 that higher torsional force is required at the higher degrees of rotation. For both original shaft material and heat treated Mild Steel, the torsional stress up to proportional limit is very close to each other as shown in Fig. 7. Equation (1) and Eq. (4) is used to calculate the torsional deformation and stress tabulated in Table 2.

Diameter d = 4.1 mm

Polar moment of inertia = 2.37E-11 m^4

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

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

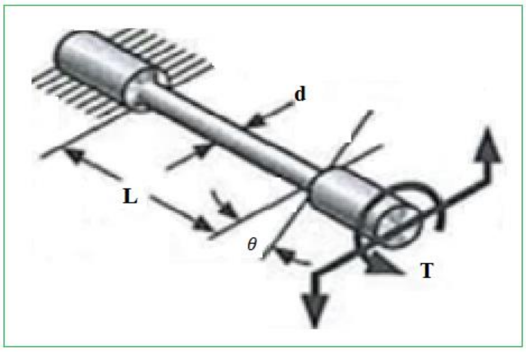

Fig.5: Torsion of a specimen [7]

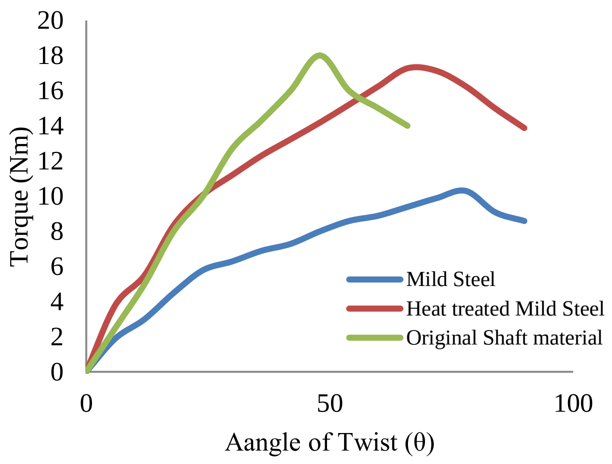

Fig.6: Relationship between Torque and Angle of twist

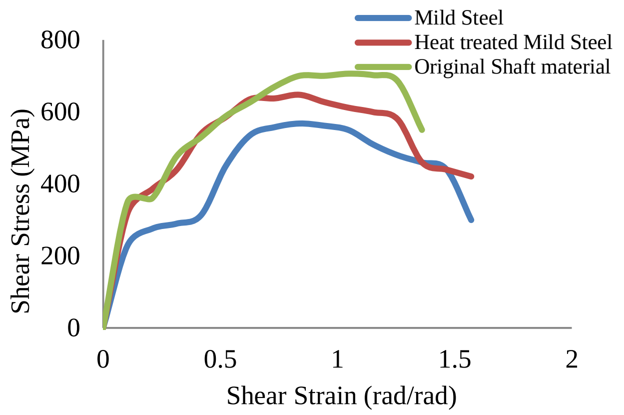

Fig.7: Shear stress vs. Shear strain curves

Table 2: Summary of torsion test

Details	Original shaft material	Mild Steel before heat treatment	Mild Steel after heat treatment
Maximum torque (Nm)	17.28	13.88	15
Shear stress at max. torque (MPa)	694	580	620
Shear strain at max. Torque (rad/rad)	0.0102	0.01137	0.0098
Modulus of Rigidity (GPa)	68	51	63

6.3 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]. Figure 8 shows the cyclic stress in this test method.Applied stresses wereflexural (bending) in nature.

Table 3: Summary of cyclic Fatigue test

Details	Original shaft material	Mild Steel	Heat treatment Mild Steel
Number of cycles	8.1e5	4.48e5	7.7e5

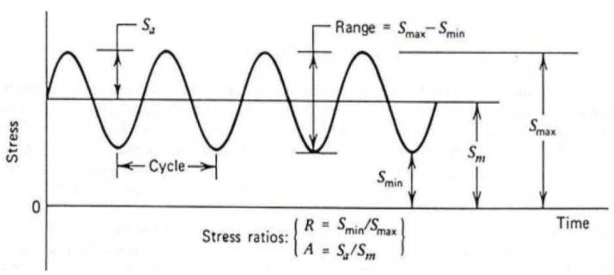

Fig.8: Cyclic stress in constant amplitude fatigue test method

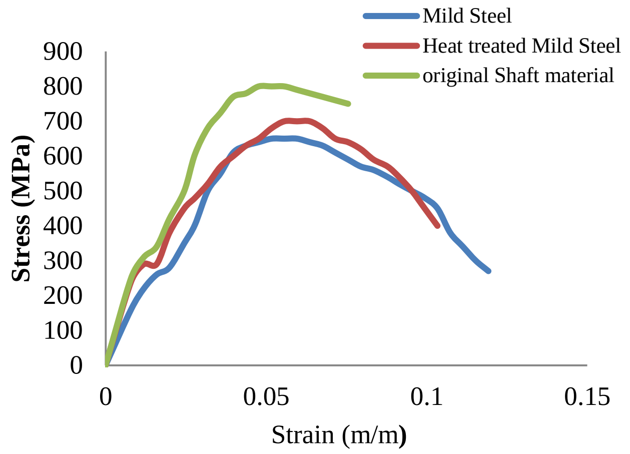

Fig.9: Stress vs. Strain curves

6.4 Tensile Test

Tensile testing [13, 14] 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. These properties can be used for design and analysis of engineering structures, and for developing new materials that better suit a specified use. Figure 9 shows the tensile stress vs. strain curves. After heat treatment the proportional limit of the Mild Steel reaches 265MPa, near to the existing shaft material. The test results are calculated by Eq. (5), Eq. (6) and Eq. (7).

Dimension d = 8 mm
Original length $L = 120$ mm

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

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

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

Table 4: Summary of Tensile test

Details	Original shaft material	Mild Steel before heat treatment	Mild Steel after heat treatment
Ultimate tensile stress(MPa)	790	650	700
Tensile yield stress (MPa)	280	210	265
Elongation (%)	7.75	11.25	9.5
Elastic modulus(GPa)	193	176	188

6.5 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 test sample is generally placed in between two plates that distribute the applied load across the entire surface area of two opposite faces of the test sample and then the plates are pushed together by a universal test machine causing the sample to flatten. The result obtain is similar as tensile test. Compressive force inCNG auto rickshaw shaft is negligible. Thus compressive ultimate stress is calculatedby Eq. (8) shown in Table 5.

Specimen dimension d = 18.23 mm
Original length $L = 140$ mm

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

Table 5: Summary of Compression test

Details	Original shaft material	Mild Steel before heat treatment	Mild Steel after heat treatment
Compressive ultimate stress (MPa)	774	627	720

6.6 Hardness Test

The hardness test isthe most valuable and most widely used mechanical test for evaluating the properties of metals as well as certain othermaterials. The hardness of a material usually is considered resistance to permanent indentation. In general, an indenter is pressed into the surface of the metal to be tested under a specific load for a definite time interval, and a measurement is made of the size or depth of the indentation. Principally, the importance of hardness testing has to do with the relationship between hardness and other properties of material. The hardness test is preferred because it is simple, easy, and relatively nondestructive. Hardness is not a fundamental property of a material. Hardness values are arbitrary, and there are no absolute standards of hardness [15]. Original shaft material has equal hardness in the surface and middle plane. Results obtained given in Table 6.
Major load-150 Kg
Minor load-10 Kg
Indenter-Diamond cone (1/16th inch)

Table 6: Summary of Hardness test

Details	Original shaft material	Mild Steel before heat treatment	Mild Steel after heat treatment
Rockwell hardness	44	34	41

7. DESIGN CALCULATION

Usually shaft subjected to combined bending and twisting moment. According to maximum shear stress theory [16] for ductile material, the maximum shear stressin the shaft is calculated by Eq. (9).

$$f_s\ (max) = ½\sqrt{(f_b)^2+4(f_s)^2} \quad (9)$$

So we get

$$\pi/16\times f_s\ (max)\times d^3 = \sqrt{M^2+T^2} \quad (10)$$

Again, for reverse bending load Endurance fatigue limit is given by Eq. (11).

$$f_e=0.5f_u \quad (11)$$

But the fatigue limit will be greatly reduced with test piece dimensions, surface smoothness, and fillet radius. The resultant fatigue limits are given by Eq. (12).

$$f_{e\ red} = f_e/k_f\times k\times k_{sur} \quad (12)$$

Where,
k_f = Notch factor =1+$q(k_t$-1)
$f_{e\ red}$=Reduce fatigue limit,
k = dimension factor,
k_{sur} = surface factor.
q = notch sensitivity,
K_t = form or stress concentration factor.

For designing shaft of CNG auto-rickshaw, we assume the load applied per wheel be 1170 N (120 kg). We have the distance from neutral axis to the outer most fiber is 0.056 m, the shaft transmitted 15 KW at 4000 rpm. From bending and torsion test of CNG auto-rickshaw shaft the corresponding stress are 2462MPaand 694 MPa respectively. So bending moment on the shaft,

$$M = F\times y = 120 \times 9.8 = 1170 \text{ N}$$

Andtwisting torque,

$$T = \frac{63000P}{2\pi N} = 317 \text{ N-m}$$

(i) Shaft of CNG auto rickshaw: For originals shaft material,

$$f_s\ (max)\text{=1414 MPa}$$

From equation (10), diameter of the shaft, d = 16.34 mm

Again,
Ultimate strength, f_u=790 MN/m^2
D = 13 mm, d =7.0 mm, r =2 mm.
D/d = 13/7.0 =1.85, r/d = 2.0/7.0 = 0.29.
So we get k_{sur} = 0.81, k_t = 1.299, q = 0.9.
Let the dimension factor k = 0.95
So the notch factor,

$$k_f= 1+q(k_t-1) =1+0.9(1.299-1) = 1.27$$

Fatigue limit

$$f_e = 0.5f_u= 0.5\times790 \text{ MN/m}^2 = 395 \text{ MN/m}^2$$

Using Eq. (12) the reduced fatigue life,

$$f_{e\ red} = (f_e/k_f)\times k\times k_{sur}= (395/1.27)\times0.95\times0.81$$

$$f_{e\ red} = 239 \text{ MN/m}^2$$

(ii) Heat Treated Mild Steel: For heat treated Mild Steel

$$f_s\ (max)\text{=1160 MPa}$$

From equation (10), diameter of the shaft, d = 17.50 mm

Ultimate strength,f_u=700 MN/m^2

D = 13 mm, d =7.52mm, r =2.2mm

D/d = 13/7.52 =1.728, r/d = 2.2/7.52 = 0.29

So we get k_{sur} = 0.80, k_t = 1.29, q = 0.9

Let the dimension factor, k = 0.95

So notch factor,

$$k_f = 1+q(k_t-1) = 1+0.9(1.29-1) = 1.261$$

Fatigue limit,

$$f_e = 0.5f_u = 0.5\times700 \text{ MN/m}^2 = 350 \text{ MN/m}^2$$

So using Eq. (12) the reduced fatigue life,

$$f_{e\,red} = f_e/k_f\times k\times k_{sur} = (350/1.261)\times0.95\times0.80$$

$$f_{e\,red} = 211 \text{ MN/m}^2$$

8. COST COMPARISON FOR SELECTED MATERIAL

A standard drive shaft of "Bajaj 3W RE-4Strokes" under consideration for estimating the production cost per item. It is 36.5 cm long, weighting 0.7 Kg having maximum diameter of 1.82 cm. If 40 cm long and 2.54 cm diameter Mild Steel is machined to shape a shaft, approximate weight is about 1.2 Kg. The subsequent cost of production is listed in Table 7.

Table 7: Cost of a single drive shaft production

Cost / Material	Total Cost (BDT)	Machining cost (BDT)	Harden--ing Cost (BDT)	Total cost (BDT)
Shaft of CNG auto-rickshaw	-	-	-	800
Ordinary Mild Steel	75	200	-	275
Heat treated Mild Steel	75	200	150	425

9. CONCLUSIONS

The most cheapest and available locally found material is Mild Steel. It is developed though simple hardening process. The subsequent enhancement of mechanical properties is at desired level.The mechanical properties of the original drive shaft are high. Therefore ordinary material is not appositeas drive shaft directly. From the above test result it is observed that, simple hardening process enhanced Mild Steel properties satisfactorily.Heat treated Mild Steel has sufficient strength and hardness. It can resist high torque and has low bending tendency. Thus heat treated Mild Steel is suitable for drive shaft purpose with reliability. Cost of single hardened Mild Steel shaft item is about 425 BDT. This cost excludes other industrial expenses.However, adaption of mass production will reduce the cost.

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11. NOMENCLATURE

Symbol	Meaning	Unit
A	Area	(m^2)
d	Diameter	(mm)
E	Young's modulus	(GPa)
F	Force	(N)
G	Modulus of Rigidity	(GPa)
J	Polar Moment of Inertia	(m^4)
L	Length	(mm)
P	Power	(KW)
f_b	Bending stress	(MPa)
f_e	Endurance stress	(MPa)
f_s	Torsional stress	(MPa)
M_b	Bending moment	(N-m)
M_t	Moment in torsion	(N-m)
σ_c	Compressive stress	(MPa)
σ_t	Tensile stress	(MPa)

θ	Angular deformation	(°)
δ	Linear deformation	(m)
ϵ	strain	Dimension less