Design and Performance Evaluation of a Low-Cost Torsion Testing Machine

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ABSTRACT :*A low-cost torsion testing machine capable of determining the shear properties of materials according to American Society for Testing and Materials (ASTM) specifications was developed. The machine provided an economical means of performing the standard ASTM torsion experiment on low carbon steel (mild steel) in the materials laboratory of Mechanical Engineering Department of University of Port Harcourt. It also provided opportunity for the students to study different specimen under torsion. After the fabrication of the machine, it was tested with two different specimens made of brass and stainless steel of 6mm diameter and 154mm long each to ensure that the equipment met the design standard. The tests were conducted to determine the average shear modulus (G) of the materials. In comparison, the average shear modulus of brass specimen obtained with the machine produced in this work is about 4.1% lower than the value obtained with the torsion testing machine at the Mechanics and Material Laboratory of Institute of Management and Technology (IMT) Enugu and 6.5% lower than that of the published value, while the average shear modulus of stainless steel obtained with the machine produced in this work is about 2.2% lower than the value obtained with the torsion testing machine at the Mechanics and Material Laboratory of IMT and 8.16% lower than the published value.*

Keywords:*Low-Cost, Shear Modulus, Torsion Testing Machine,Torsional Strength*

Nomenclature

d is diameter of cross section.

G is modulus of rigidity

J is polar moment of inertia (mm^4)

L is length of material (mm)

N is speed of the shaft

P is power transmitted (watts),

r is radius of material (mm)

S_s is shear stress (MPa) or (N/mm^2)

S_{su} is modulus of rupture (MPa) or (N/mm^2)

S_{sy} istorsional yield stress (MPa) or (N/mm^2)

T isTorque acting on the cross section (Nmm)

T_y is the corresponding torque at yield point

T_u is the corresponding torque at the maximum point

ε_s is shear strain (rad)

θ is angle of twist (rad)

$\tau_{\max}$ = maximum shear stress in shaft

I. Introduction

In engineering practice, the machine parts are subjected to various loads which may arise from energy transmission, weight of machine, frictional resistances, inertia of reciprocating parts, and change of temperature or lack of balance of moving parts [1].

The different loads acting on a machine part produce various types of stresses such as tensile stress, compressive stress, shear stress, etc. The response of materials to stress and strain in shear can be extremely important in the design, analysis and manufacture of a wide variety of products and components which are loaded primarily in shear or torsion. Knowledge of rigidity of materials in shear is important because it then enables safe design of components of machines which are subjected to shear forces. The data for determining the characteristics of materials is obtained using the torsion testing machine. The standard for the experimental tests are based on the American Society for Testing and Materials [2]. The torque-twisted diagram is constructed from these data, and elementary mechanics theory is used to construct the shear stress-shear strain diagram.

Unfortunately, many engineering and engineering technology programs do not include torsion test in the test of mechanical properties of materials, often due to insufficient funding required to purchase a torsion testing machine which typically costs between $10,000 and $25,000 depending on capacity and instrumentation [3]. A survey to determine the basis of characterisation of engineering materials in respect to mechanical properties indicated that even Standard Organization of Nigeria (SON), Scientific Equipment Development Institute (SEDI) and several universities do not included shear stress/strain values. This is because the facilities for carrying out such test are inexistent. The implication is that most designs are done based on test book values which in most cases may not consonance with the material available on hand.

This work design and performance evaluation of a low-cost torsion testing machinehas been carried out to fill the missing gap in Nigeria so that mechanical properties of local materials in shear can be determined. In addition students will be availed with equipment to carry out experimental procedures which hitherto had been lacking.

II. Design Considerations and Production

Machine Description

Figure1is an isometric drawing showing the features of the low-cost torsion testing machine. The machine consists of the following parts as described in table 1.

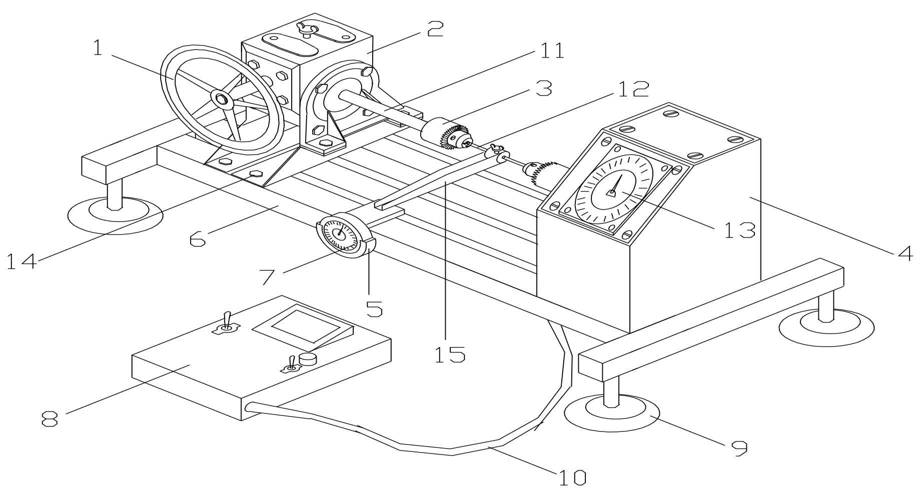


Figure1: Isometric View of the Torsion Testing Machine

Table 1: Parts of the Torsion Testing Machine

S/No	Parts
1	Hand Wheel
2	Gear Box
3	Jacobs' Chuck
4	Housing or Torquemeter
5	Torsiometer Support
6	Base
7	Torsiometer
8	Digital Meter
9	Detachable Feet
10	Cable
11	Input Shaft
12	Test Specimen
13	Torquemeter
14	Screw
15	Deflector Arm

Design Considerations

Factors considered in the design of this machine include the force to generate the required amount of torque to produce twist on the specimen and the determination of the angle of the twist of the specimen, bearing selection, material of construction, and specimens to test.

Torque

In this work, steel which has the tensile strength ranging from 290MPa to 870Mpa was used as the basis of the design of the machine [4].

According to American Society of Mechanical Engineers (ASME), code for the design of transmission shaft, the maximum permissible shear stress for shaft purchased under definite physical specification the permissible shear stress, τ , may be taken as, 30% of the elastic limit in tensionbut not more than 18% of the ultimate tensile strength (S_{ut}) [1]. This implies that; $\tau = 0.18S_{ut}$. (1)

Substitution of the upper range value of the tensile strength of steel in equation (1) gives τ = 156.6 MPa.

According to Hibbeler[5], the maximum shear stress is related to the applied torque as in equation (2).

$$\tau_{max} = \frac{Tr}{J}. \tag{2}$$

where

$$J = \frac{\pi d^4}{32}. \tag{3}$$

For the purpose of experimental test, a specimen of 6mm diameter and maximum length of 350mm was used. Substitution of diameter, d, into equation (3) gave the value of J as $127.24mm$. Also substitution of the values of r, J and τ into equation (2) gave the value of T as $6.6Nm$.

To increase the amount of torque generated, a worm drive reduction gearbox of 30mm worm and 540mm worm gear was used. This achieved a velocity ratio of 18:1, which resulted in the rotational speed n of 0.6 r.p.m.

According to Khurmi and Gupta [1], the power transmitted in watts by the shaft and torque is related as shown in equation (4)

$$P = \frac{2\pi NT}{60}. \tag{4}$$

Substitution of established value of T as $6.6Nm$ and N as 18 in equation (2) gave the value of P as 12.44w. Making T the subject of equation (4) and substitution of the values of P and ngave the driving torque as 200Nm. This torque was well above the 6.6Nm established earlier.

Angle of Twist

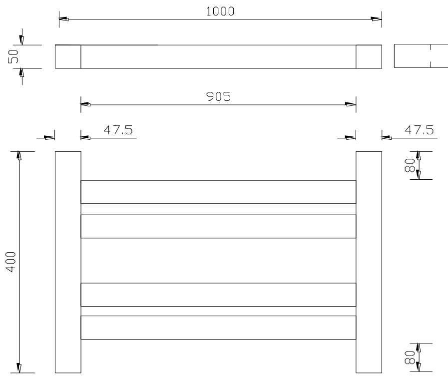
The next design parameter considered for this machine was the angle twist. According Shigley and Mischke [4], the angle of twist,θ, can be calculated for a linear elastic material according to equation (5).

$$\theta = \frac{TL}{JG}. \tag{5}$$

The corresponding angles of twist that resulted from the applied torque were measured with a torsiometer. Their average corresponding angles of twist and the applied torque was used to calculate the shear modulus of material in the elastic range using equation (5).

Production

In producing this machine, consideration was given to keeping the production costs low by adopting steps that minimised scrapping of any part produced. Design specifications were strictly adhered to and production methods were properly reviewed to avoid repetitive works on the component which could be accomplished in a process.Themachinebase was produced using 70mm*70mm mild steel angle iron and the drawing is as shown in figure 2.Four detachable cast aluminium stands were produced and figure 3 shows the drawing of the cast aluminium stands. These stands were joined to the machine base with screws.
Housing for the torquemeter was produced from a mild steel plate and the drawing is shown in figure 4.The housing served as an enclosure for the two balls and cam attached to the torsion shaft.The torsion shaft and a cam fixed on it were produced and the drawing is as shown in figure 5.The torsion shaft-cam arrangement was placed inside the housing and the torquemeter arm attached to the cam. One end of the torsion shaft was passed through one side of the housing and a hexagonal drive chuck attached to it for holding the specimen. A gearbox platform to support the gearbox was also produced and the drawing is shown in figure 6.A gearbox shaft that connected the handwheel with the gearbox was produced. A keyway was made in the side of the shaft where the handwheel is fixed. Figure 7, is the drawing of the gearbox shaft with the keyway.A support for torsiometer was produced and the drawingis shown in figure 8. The support was attached to the base of the machine with locking screws as shown in figure 1.Figure9, is the drawing of deflection arm that was produced. The deflection arm was attached to the specimen and was made to touch the tip of the torsiometer as shown in figure1.



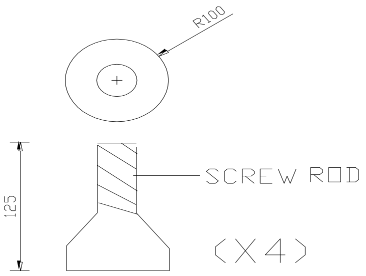


Figure2: BaseFigure 3: Detachable Aluminium Feet

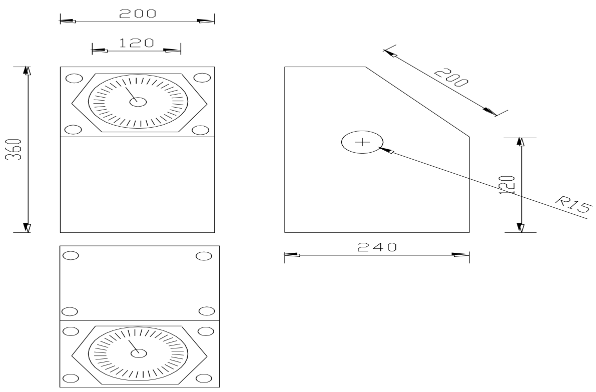


Figure 4: Housing for Torquemeter

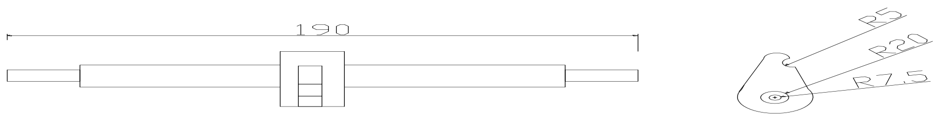


Figure5: Torsion Shaft and Cam

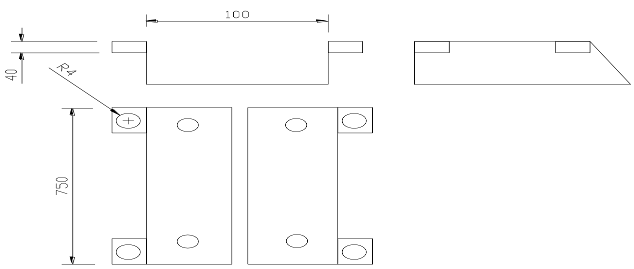


Figure 6: Gearbox Platform

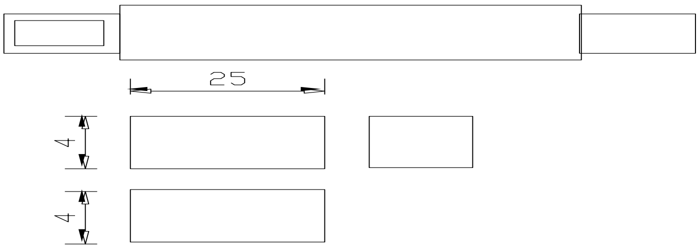


Figure 7: Gearbox Shaft with keyway

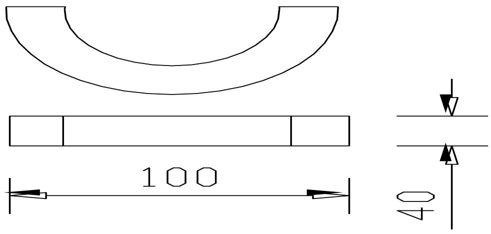


Figure8: Torsiometer Support.

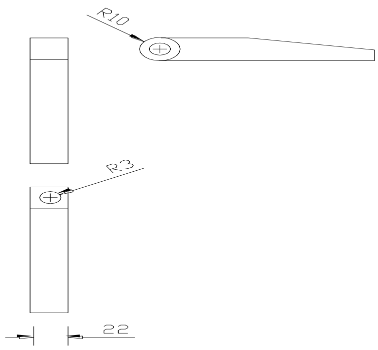


Figure9: Deflection Arm

The cost of developing this machine was one hundred and fifty eight thousand, eight hundred and eighty eight naira. The torquemeter, gearbox, torsiometer, machining and fabrication cost amounted to about 63.9% of the total cost. The Jacobs'chucks, ball bearings, mild steel plates and shafts, bolts and nuts, hand wheel, cast aluminium stand and mild steel angle iron accounted for the remainder of the total cost. Table 2 show the detail of the production cost.

Table 2: Cost of Production of the Torsion Testing Machine

S/No	Description of Material	Quantity	Rate(Naira)	Price(Naira)
1	Torsiometer	1	12,000	12,000
2	Speed reduction gearbox	1	25,000	25,000
3	Torquemeter	1	20,500	20,500
4	M25 * 100mm Bolt and nut	20	250	5,000
5	Ball bearing	2	2,500	5,000
6	Handwheel	1	2,200	2,200
7	16 mm Jacobs'chuk	2	2,400	4,800
8	75 mm Mild steel shaft	1	16,500	16,500
9	Mild steel angle iron		8,000	8,000
10	Cast aluminium Stand	4	720	2,880
11	Mild steel plate		4,500	4,500

12	Machining cost			21,000
13	Fabrication cost			23,000
14	Transportation			4,200
15	Brass specimen			1,800
16	Stainless steel			2,500
	Total			158,880

Plate 1 shows the photograph of the low-cost torsion testing machine produced in this work.

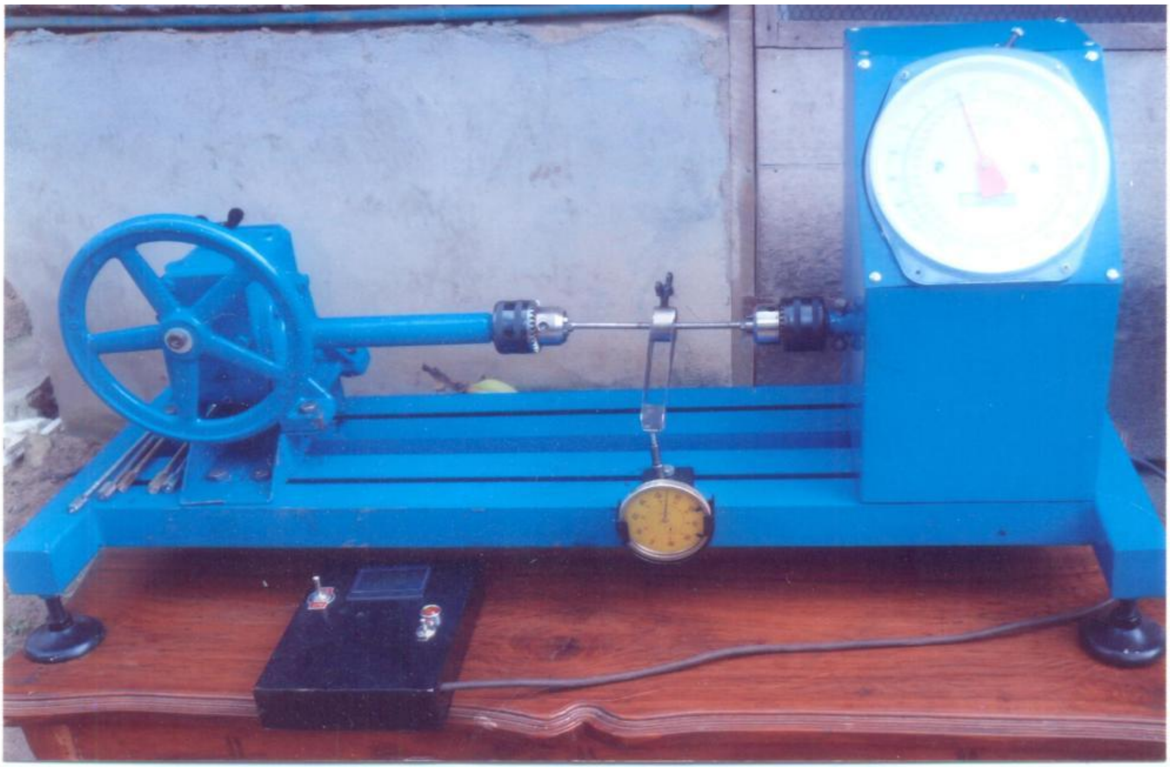


Plate1: Photograph of Low-cost Torsion Testing Machine

III. Performance Evaluation

In order to quantify the performance of the machine developed in this work, six samples of each of brassandstainless steel were produced. Three samples of each of brass and stainless steel were tested using the machine produced in this work while the three remaining samples of each of the specimens were used to conduct a similar test on a torsion testing machine at Mechanics and Material Laboratory of the Institute of Management and Technology (IMT) Enugu. The average shear modulus of the specimens were measured and recorded in table 3.

Table 3: The Average Shear Modulus of the Specimens

Specimen	**The Average Shear Modulus(GPa)**		
	Values obtained with the machine produced in this work	Values obtained at IMT	Published Values
Brass	37.4	39.0	40.0
Stainless Steel	70.9	72.5	77.2

From table 3, the average shear modulus of brass specimen obtained with the machine produced in this work is about 4.1% lower than the value obtained with the torsion testing machine at the Mechanics and Material Laboratory of IMT and 6.5% lower than that of the published value, while the average shear modulus of stainless steel obtained with the machine produced in this work is about 2.2% lower than the value obtained with the torsion testing machine at the Mechanics and Material Laboratory ofIMT and 8.16% lower than the published value.

The slight disparity was due to inability to read small fractions from the analogue meters. It could also to attributed to the inherit fabrication errors like poor machining of the components parts of the machine.

However, the machine was considered accurate enough to allow comparison between experimental results, results obtained from existing torsion testing machine and published values.

Furthermore, the machine was used to conduct torsion test on two different samples of low carbon steel. Sample A was gotten from a scrap mild steel in the Engineering Workshop of the University of Port Harcourt, while Sample B was gotten from newly purchased mild steel.

Four test specimens were machined out from each of the samples according to ASTM standard. These specimens were used to conduct test experiments on the machine. The test values from both samples and their corresponding calculated values were used to plot torque-angle of twist graph. The calculations were made using equations (6)to(10), [6].

$$S_s = \frac{Tr}{J}. \quad (6)$$

$$S_{sy} = \frac{T_y r}{J}. \quad (7)$$

$$S_{su} = \frac{T_u r}{J}. \quad (8)$$

$$\varepsilon_s = \frac{r\theta}{L}. \quad (9)$$

$$G = \frac{TL}{J\theta}. \quad (10)$$

IV. Results and Discussion

The test values obtained from the specimens and their corresponding calculated values were used to plot torque-twist graph for each of the specimens. The graphs are as shown in figures 10 and 11, while the comparison of the two graphs is as shown in figure 12.

The Modulus of Rigidity (Shear Modulus) G, of each specimen was determined by taking the slope of the initial linear portion of the torque-twist graph. Table 4 shows the values of the modulus of rigidity of both samples. Figure 12 and table4 showed that there was about 6.6MPa reduction in the modulus of rigidity of sample A from that of sample B. This is about 8.6% lower than the modulus of rigidity of B.

Table 4: Modulus of Rigidity of Samples A and B.

Sample	**Modulus of rigidity**
A	70.2
B	76.8

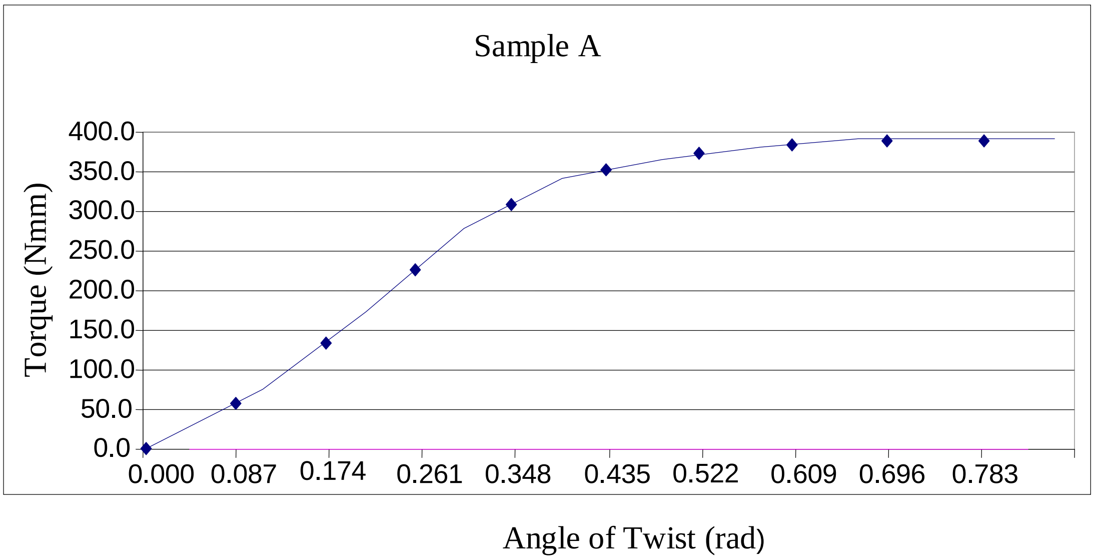


Figure 10: Torque- Angle of Twist Diagram for Sample A

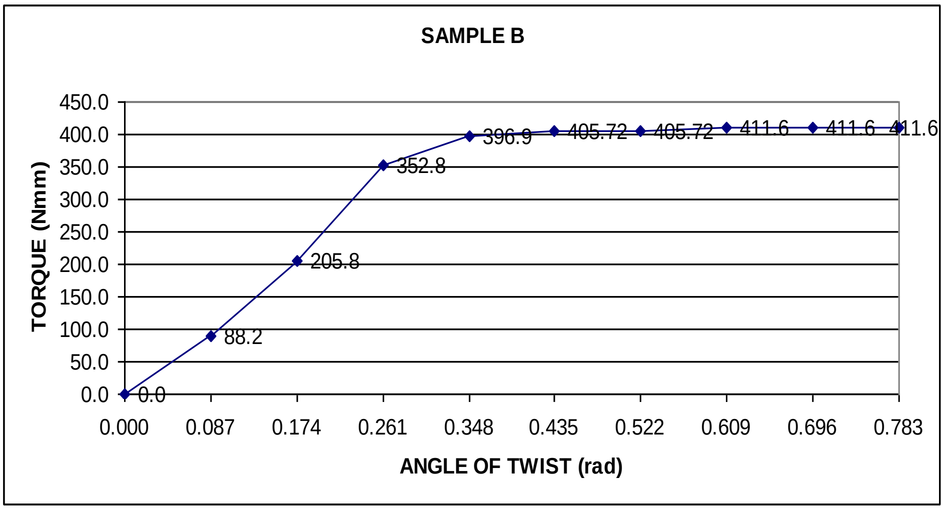


Figure11: Torque- Angle of Twist Diagram for Sample B

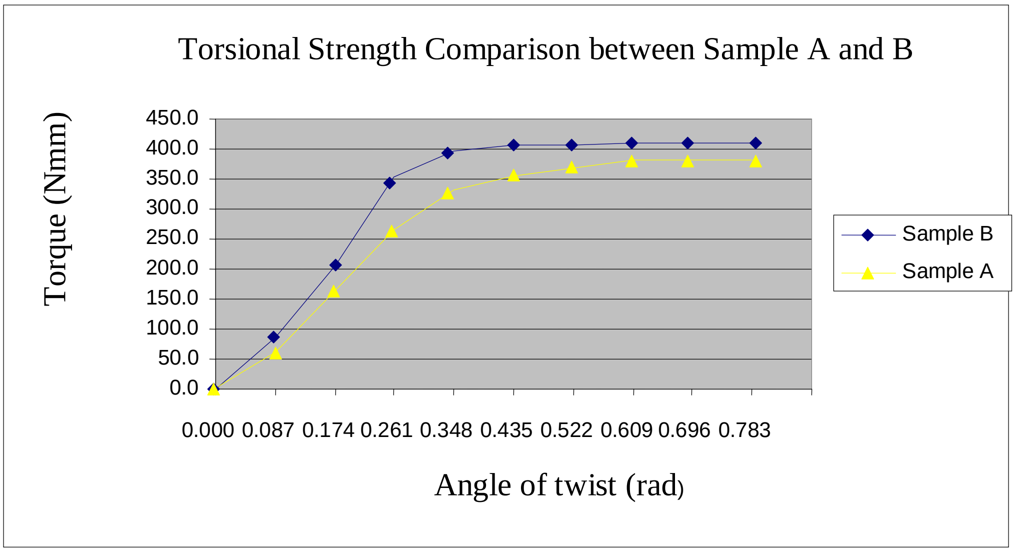


Figure12: Torsional Strength Comparison between Sample A and B

V. Conclusion

Comparing the range of cost to purchase a torsion testing machine which is between $10,000 and $25,000 depending on capacity and instrumentation [3], and the cost of producing this machine which was one hundred and fifty eight thousand, eight hundred and eighty-eight naira(about $1,059 then); the torsion testing machine developed in this work has proved to be a valuable and cost effective tool for torsion testing experiments in the Materials Laboratory of Mechanical Engineering Department of University of Port Harcourt.
Through the performance evaluation of the machine using two different specimens made of brass and stainless steel, the machine has also been considered accurate enough to allow comparison between experimental results, results obtained from existing torsion testing machine and published values.
The torsional strength analysis of two different samples of low carbon steel showed that there was 8.6% reduction in modulus of rigidity of sample A (scrap mild steel) from sample B (newly purchased mild steel).
It is expected that this practical method of designing affordable yet accurate test equipment will continue to expand the ability of students in developing new test equipment and improving on the existing ones using local and available materials. This will increase the mechanical testing capabilities at the Mechanical Engineering Department of University of Port Harcourt.

Acknowledgement

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