DEVELOPMENT OF AN INDIGENOUS, BENCH-T0P MANUAL TORSION TESTING MACHINE

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APPROVAL PAGE

CERTIFICATION

This work has not been presented elsewhere for the award of a degree, or any other purpose.

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DEDICATION

The work of this thesis is proudly dedicated to **Engr. (Dr) Kareem Buliyamin** for just being a "medium" by Allah's Grace and for the benefits of sustainable consciousness of Materials Testing and Quality Control activities in developing countries, particularly Nigeria.

ABSTRACT

The increasing enrollment of students in higher institutions of learning in Nigeria demands higher capital expenditures, which either in some cases are not available or grossly insufficient, to provide essential machines and equipment for the training of professional engineers and technologists. Consequently, torsion test is often overlooked despite its importance in the investigation of mechanical properties for automobile, manufacturing, and bio-medical engineering products.

An indigenous bench-top manual torsion testing machine was developed to perform pure torsion test on metal rods. The machine provided information on the shear properties of the materials being tested upon which shear moduli were determined. The machine was produced predominantly by fabrication method coupled with machining and casting processes. The various materials of production included mild-steel, aluminium, cast-iron, tool-steel, and polymer.

Torsion test was conducted, using the machine so developed in this work, on Aluminium and Brass specimen with 5 mm diameter, respectively; and 5.5 mm diameter of Mild-steel. The experimental shear moduli from the test shown that Aluminum has 23,205.92 N/mm^2 (16% less than expected), while Brass has 21,498.06 N/mm^2, (43% less than expected) and Mild-steel has 15,773.10 N/mm^2 (80% less than expected).

The results suggested a re-investigation into the load measuring unit, as the applied torque load may be higher than the one being measured. However, a simple practical approach is being made to demonstrate torsion test for teaching purposes.

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LIST OF SYMBOLS/NOTATIONS

T = Torque in N-m

G = Modulus of Rigidity/Shear Modulus in N/m^2

ϕ = Shear strain in rad/rad.

τ, τ_{max} = Shear Stress and Maximum Shear Stress, in N/m^2

J = Polar Moment of Inertia, in m^4

θ = Angle of Twist in degree or radian

F = Tension Force in N/m^2

r = Radius of Circular Shaft

ε = Nominal Strain in m/m

δa, δr, δF = Elemental Change in Area, Radius and Force

Π = pi (i.e. 3.1428571)

ℓ = Length of Solid Materials in m

d (or ϕ_d) = Diameter of Solid Materials in m

t = Throat Thickness of Fillet Welds or Thickness of Parallel Sunk Key in mm

s = Size (or leg) of Fillet Weld in mm

w = Width of Parallel Sunk Key in mm

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE PROJECT

No one wants a product to fail and as such, samples of different engineering materials are subjected to a wide variety of mechanical tests. This is done to obtain various values of the material strengths being tested, at elastic load, yield load, maximum and even fracture loads. Materials testing activities provide data that are used to asses the performance characteristics of engineering products and components at actual use conditions and environments. The results of these tests are used primarily for two main purposes, namely: (i) Engineering Design – determination of strengths and component geometry and (ii) Quality Control – either by materials producer to verify the process or by the end user to confirm the material specifications

In Nigeria today, material testing is beginning to be recognized as one primer for economic drive of the modern industrial sector [SON News, 2002]. This is because many systems and structural failure with their consequent catastrophic loses; both to life and resources are caused either by one or combination of any of the following; namely, lack or inadequate knowledge of material science and negligence of material properties by the users, producers and trade merchants respectively. The recent cases of aircraft crashes of the Belleview, Sosoliso and the Chanchangi Airliners [US Africa, 2007] bear witness to the importance of testing knowledge, conformity to standards and their enforcement.

Despite the establishment of Standard Organization of Nigeria (i.e. SON) by Act No. 56 of 1971 with the authority of standards elaboration, specifications and quality assurance system of commodities and manufactured products, the material testing knowledge and applications are at low ebb in Nigeria. At present, Shear and Torsion tests are not included in the Mechanical tests available at the centre. Though, this is covered in the Memorandum of Understanding (M.O.U) recently signed between SON and the American Society for Testing and Materials (ASTM). The M.O.U covers adoption and reproduction of the ASTM standards [SON News, 2008].

Also, most research institutions and Higher Institutions of learning in the country, acutely lack facilities for torsion testing. This is on account of high cost, which ranges between N2.5 to N6.5 millions naira. This is why torsion testing has become less frequent to researchers unlike tensile and compressive testing. It is against this draw-back, that a development of a locally made Torsion tester is enviably demanded.

1.2 SIGNIFICANCE OF THE PROJECT

Torsion test, unlike other type of materials tests, does not only measure the material properties of the test sample, but also provides data for the entire component part in a system, subjected to twisting moment. This includes the measure of strength of the joints and fixture to which the component part is attached to. The project also provided an alternative, in simplicity of design, the use of first principle approach in materials testing technology and cost to acquire a material tester for torsion characteristics of metals.

1.3 STATEMENTS OF THE PROBLEM

Educational institutions in Nigeria are faced with larger capital expenditures, which are in some cases not available or grossly insufficient, to provide essential machines and equipment for the training of professional engineers and technologists. An up-dated Strength/Materials Testing laboratory is not exceptional in this predicament, despite its central role to researches in design and development of engineering products.

The problem of cost and the subsequent scarcity of material testing machines are compounded by today's increasing number of students' enrollments. Often times, students are unable to participate actively in a given experiment. One or two students actually conduct the work while others observe, or in some cases the instructor run the experiment while the students observe. This then, make the laboratory session synonymous to demonstration classes depriving a hand-on-experience. The worse of these problems is electricity power failure [Megbowon and Oyebisi, 2004; Agee, 2004] which rendered most of the conventional torsion testing machine unavailable most of the time the students are in need of them.

1.4 OBJECTIVES OF THE PROJECT

The broad objective of the project is the Development of an Indigenous, Bench-top Manual Torsion Testing Machine for teaching, research and development applications. The specific objectives of the study are to:

(i) design a bench-top, manual torsion testing machine;

(ii) fabricate the machine designed in (i); and

(iii) evaluate the performance of the machine

1.5 EXPECTED CONTRIBUTIONS OF RESEARCH TO KNOWLEDGE

The study is expected to:

(a) promote hand-on-practical experience and standards consciousness among students and professionals through economic materials testing technology, obtained from the developed machine; and

(b) establish the relationships among elastic shear modulus (G), shear strength, and the shear stress-strain behaviour in general, which is useful in determining quality and performance of materials in service.

CHAPTER TWO

LITERATURE REVIEW

2.1 MATERIAL PROPERTIES AND TESTING

Materials fail as a result of non-correlation between their properties of strength and a number of design variables like manufacturing processes, design loads, component geometry, assembling and environments. The seemly unsinkable TITANIC Ship sunk in less than three hours back in 1912. According to a recent research carried out by Tim Foecke [INSTRON, 2007 and ABC News, 2007] and his colleagues at the National Institute of Standards and Technology (NIST), in which, they simulated the ship's design with its rivets from the very same materials and manufacturing processes in the same part of England, where the TITANIC ship was produced.

Through a compression test, they were able to simulate the forces on the rivets and found out that the rivet heads broke off and opened the Titanic's hull like a zipper. This, allowed water to pour into the ship far quicker than would be expected to rescue much of the crew on board. Foecke's finding, shows that the wrought iron rivets were substandard due to poor method of quality checking, which caused them to fail prematurely. Many studies were also done locally on the corrosion and wear behavours of locally sourced steel materials under varying conditions [Osarenmwinda, 2004; Okpala and Jombo, 2004; and Aluko, 2004]. This is important in order to know how effective they are when subjected to torsion application.

The collapse of the Tacoma Narrows Bridge of November 7, 1940 [Wikipedia, 2007] due to wind induced torsion vibrations and the recent numbers of aircraft crashes in Nigeria involving Bellviews Airlines, October 23, 2005; BAS Airlines, May, 2002;

Sosoliso Airlines and the Chanchangi Airlines of the year 2006 and 2007 respectively are partly caused by equipment or material failure [USAfrica, 2007]. Considering the magnitude of these disasters, the tragedies could be greatly reduced through the initial and periodic testing of the properties of strength of their component parts. Testing of materials [John, 1983] are necessary for many reasons, namely to:

(i) determine the quality of a material;

(ii) determine such properties as strength, hardness and ductility;

(iii)check for flaws within a material or in a finished component; and

(iv) assess the likely performance of the material in a particular service condition.

2.2 MECHANICAL TESTING OF MATERIALS

Mechanical testing of materials is a process of applying loads in form of stretching, squeezing, hitting, turning and twisting to test samples or specimen in order to investigate their toughness and strength at actual use conditions (Frank, 2004). The samples of material that are tested in the laboratory are called "Test Pieces or Specimens". They are often times characterized with some specialized geometries in terms of lengths, diameters, notches (such as holes, slots and grooves). This becomes necessary to either eliminate or minimize errors creeping into test results from a number of factors (Jenkins, 2007).

The load requirements in materials testing, shown in Fig. 2.1, could involve uniformity, linearity and axiality of loads; loading rate; and loading speed. Other factors include gripping requirements and the factors affecting instrumentation such as hysterisis, repeatability, precision, accuracy and resolution.

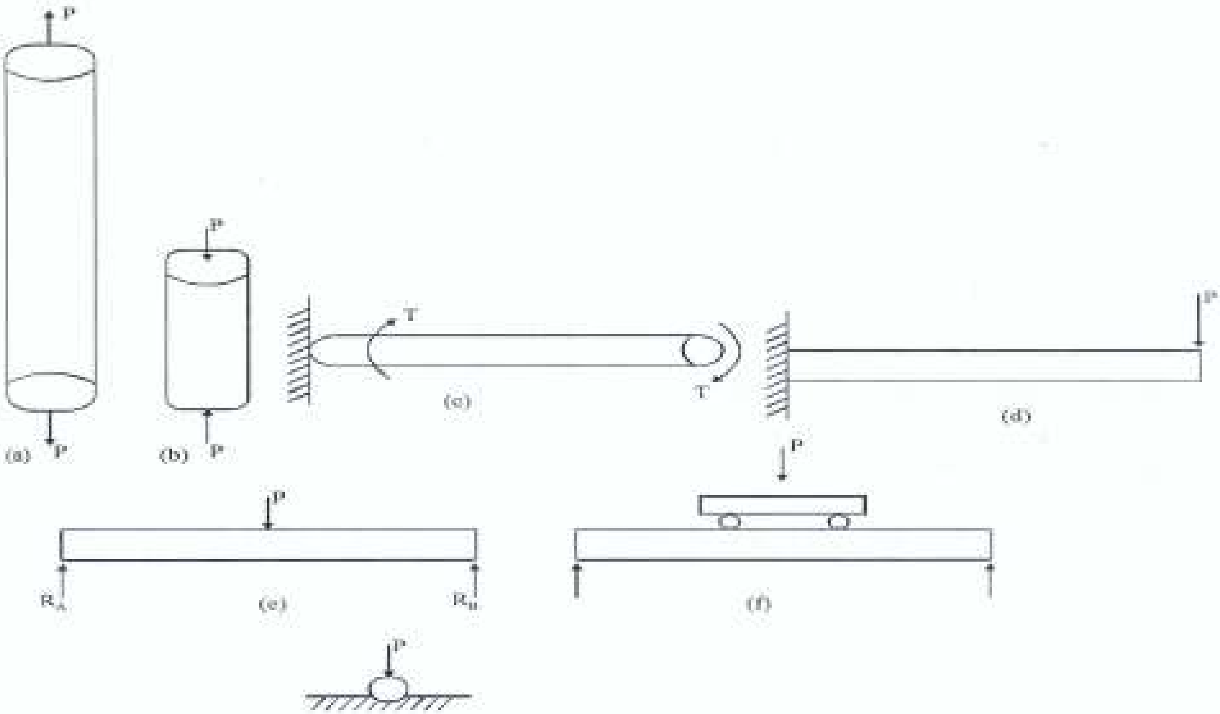


Fig. 2.1: Geometry and Loading of Some Mechanical Testing of Materials

(a) Tension (b) Compression (c) Torsion (d) Cantilever Flexure

(e) Three-point Flexure (f) Four-point Flexure (g) Hardness indentation.

Mechanical testing machines and equipment come in different forms ranging from simple hand-actuated devices to electro (or servo) mechanical and servo-hydraulic machines. The basic differences are by the method through which the load is applied. The mechanical types employ the principles of screw power while the hydraulic, often designed for high pressure, make use of hydraulic fluid energy. Mechanical testing of materials can be divided into two broad groups; namely: (i) Structural Tests and (ii) Material Characterization Tests.

2.2.1 STRUCTURAL TEST

In the structural test, the full-scale designed components or structures (e.g. bridges, vehicles, and aircrafts) are tested. The idea is to model accurately the situation arising during operation such that the experiments give information on the behaviour and likely failure modes of the structure being tested [Wiesner, 2007]. Although, this method actually represents the most realistic way of assessing mechanical behaviour, it is neither economical nor practical in many circumstances.

It is significant to note that recent researches have recognized the predictive capability of computer modeling of the actual structural configuration, working loads simulation and failure mode, in the investigation of mechanical behaviour of materials. Wide plate-testing, which involves the use of medium-scale tests, has been an alternative to actual structural test.

2.2.2 MATERIAL CHARACTERIZATION TESTS

This is a small scaled investigation of materials properties in the laboratory, with the test being conducted under control conditions of service life. The cause and effects of every predominant test parameter (e.g. load, environment) could be investigated separately unlike the structural where isolation of one for the others is impracticable.

Though, the test is comparatively cheap, simple and generally applicable, even for complex geometrical components; its results in some cases (e.g. charpy tests) rely frequently on empirical correlations with full-scale structural test. This is because the full scale testing is the most realistic way of assessing mechanical behaviour, despite its non-economical and impracticability in many instances.

The variances in the small scaled-tests are due to inherent uncertainties, which according to Fearnehough (1973) may include:

(i) small-scale specimens do not have the same constraints as the structure due to differences in dimensions and stress state; this can cause, for instance, general yielding of small-scale specimens at stresses when structural behaviour is still elastic;

(ii) The loading and strain rates in small-scale tests cannot always simulate structural conditions; and

(iii) The combination of small-scale specimen compliance and testing machine stiffness is not normally representative of the structure.

Nonetheless, there are number of material characterization tests aimed at different properties of material and failure modes as shown in Table 2.1. The tests are carefully guided by standard specifications, formulated by standardizing agencies and organizations such as ASTM, ANSI, BSI, ISO, SAE, ASM, DIN, JIS, and SON.

Table 2.1: Type of Mechanical Tests of Materials

Strength Properties	Fracture Properties	Corrosion Properties	Fatigue Properties	Temperature Properties
* Tensile Tests * Compression Tests * Torsion Tests * Bending Tests	Charpy Tests Drop-weight (Pellini) Test Fracture Mechanics Tests e.g. Static fracture initiation test Dynamic Initiation tests Crack arrest tests	Stress corrosion tests Hydrogen Embrittlement Test	Fatigue Endurance Tests Fatigue Crack growth Tests	Creep Tests Creep Crack growth test Strength, fracture and fatigue test at elevated temperature (i.e. above 30% of the metal melting temperature. Low cycle fatigue (LCF) test.

Source: Wiesner, (2007).

2.3 TORSION TEST MEASURANDS

2.3.1 TORSION TEST

Torsion test is the type of test performs on components that are subjected to twisting or torsion forces during their operation. The test is intended to investigate the torsion properties in shear such as the elastic shear strength, stiffness, ductility, energy absorption and maximum load capacity. The test has found increasing use in the automobile, aerospace and bio-medical engineering industries. Other components tested in torsion include: bolts, nut, switches, wire, bar shafts, fasteners and joints or fixtures to which a component is attached.

Torsion test is performed by holding the two ends of a test-piece (that had already being provided with correct geometries) in between two gripping jaws. One of the jaws is fixed, while the torsion moment is transmitted to the test-piece through the other jaw, which is rotated by mechanical screw drive. This could be achieved either manually, using hand wheel or by electro-mechanical drive. When required, a higher torsion load is applied by employing a closed-loop hydraulic servo system.

The applied torque, T, is measured using either a spring gauge or strain gauge dynamometer. The relative turns/twists of the specimen in the grips is measured by a troptometer. A troptometer device is made up of calibrated compass and pointer, which are clamped on the specimen within its gauge length. The troptometer, of this type most essentially is capable of measuring strain up to and slightly above the elastic limit. The angular deformation and strain in the plastic range is obtained by counting complete revolution(s) of the graduated compass.

Torsion test involves the incremental measurement of the applied twisting force, called torque T (in N-m) and the corresponding angle of twist,θ, (in radians). The test orientation could either be torque control or angular speed control. Torque control experiments apply a uniformly increasing torque to the specimen and the amount of strain is measured as an angle through which the specimen has turned. Angular speed control turns the specimen at a specific speed while the torque is measured. The shear modulus, G, of any test sample can then be obtained by plotting the graph of torque, T, (in N-m) against the angle of twist (in radians) using the relations:

2.3.2 TORQUE AND TORQUE MEASUREMENT

Torque [Redmon, 2006] is defined as a twisting effort applied to an object that tends to make the object turn about its own axis of rotation. It is simply a turning or rotational force which is different from the term force that acts in a straight line. The magnitude of a torque is equal to the product of the magnitude of the applied force, F, and the distance between the object's axes of rotation.

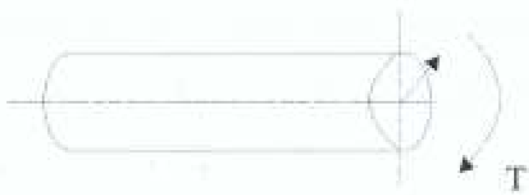


Fig 2.2: Rotational Force

$$T = Fr \qquad (2.1)$$

where

T = Torque in N – m

F = Force in N

r = Radius of the bar in m

Torque can be measured either by sensing the actual shaft deflection caused by twisting force, or by detecting the effects of this deflection. These are known as "In-line and Reaction Torque" measurements respectively.

In-line torque measurement involves the placing or coupling of a torque sensor (usually made of strain gauge) in between torque carrying components or shafts. As the torque sensor is placed as close as possible to the torque of interest, the method is good in preventing errors from parasitic torques (e.g. bearing effect), extraneous loads, and components that have large rotational inertias that would dampen any dynamic torques.

A reaction torque detector, on the other hand, operates on the Newton's third law, which states that: "to every action, there is equal, opposite and collinear reaction". The torque sensor is mounted on any restraining element/member connected to the twisting/rotating shaft.

The torque that is transferred by the rotating shaft to the restraining member and resisted is being measured by the sensors as reaction torque. The main draw-back in this method, is that, the output reading may carry along some amount of extraneous errors due to sensitivity of sensors to unwanted loads (such as weight of supports, bearing, connector, chuck and housing).

In material testing, two types of dynamometer commonly in use are the spring balance dynamometer and the elastic deflection transducers. The spring balance consisting of a closely wound helical spring, either used directly to measure load on a small specimen or used in conjunction with a multiple-lever or hydraulic transmission system [Harmer *et al*, 1964]. The spring balance is incapable of measuring fluctuating induced torsion load like in internal combustion engine.

2.3.3 STRAIN AND TORSIONAL STRAIN MEASUREMENT

There are different devices used in measuring the strain and angle of twist in torsion test. They are commonly called **Torsiometer** or **Troptometer**. Torsiometer is defined as an instrument for determining the torque on a shaft and hence the horse power of an engine, especially of a marine engine of high power, by measuring the amount of twist of a given length of the shaft [Webster's Dictionary, 2000 Supplementary].

As earlier described in section 2.3.1, a mechanical troptometer consists of two collars attached to the specimen at specified distance of gauge length. The relative angular displacement of the collars is taken by three different methods.

One is by a vernier scale attached to one collar which moves around a graduated circle attached to the other. In another type, mirrors are attached to the collars, and observation are made with telescopes and scales, while the third type consists of long radial arms attached to the collars, the arms being arranged to move around graduated arcs as the specimen twists [Harmer *et el,* 1964].

The electronic troptometers, build on strain gauge technology, provide for more precision and reliable measurement of strain in modern material testing machines. It is worth noting that apart from the high cost of strain gauge elements, the accessories and the read-out equipment (i.e. strain indicator), the technology is not yet prevalent in Nigeria.

2.4 THEORY OF TORSION

When a shaft is subjected to a turning/twisting moment, other wisely called Torque, T (i.e. $T = Fr$) in a plane perpendicular to the longitudinal axis of the member, it will undergo some angular displacement. Shear stresses are developed on a cross-sectional plane as a result of the applied torque. These shear stresses vary linearly, together with the angle of twist,θ, from zero at the center for a circular specimen to a maximum at the circumference/perimeter. They act in a direction tangential to the radius on all transverse sections.

The basic torsion equation is derived based on the following assumptions [Khurmi and Gupta, 2005; Benham and Warnock, 1980; and Bhavikatti 2004] that:

(i) the material is uniform, homogenous and isotropic;

(ii) the angle of twist along the shaft is uniform;

(iii) the cross-sectional area remains plane throughout;

(iv) all diameters of the normal cross-section which were straight before the twist remain so with their value unchanged after the twist; and

(v) the maximum shear stress does not exceed the elastic limit.

2.4.1 ANGLE OF TWIST AND SHEAR STRAIN

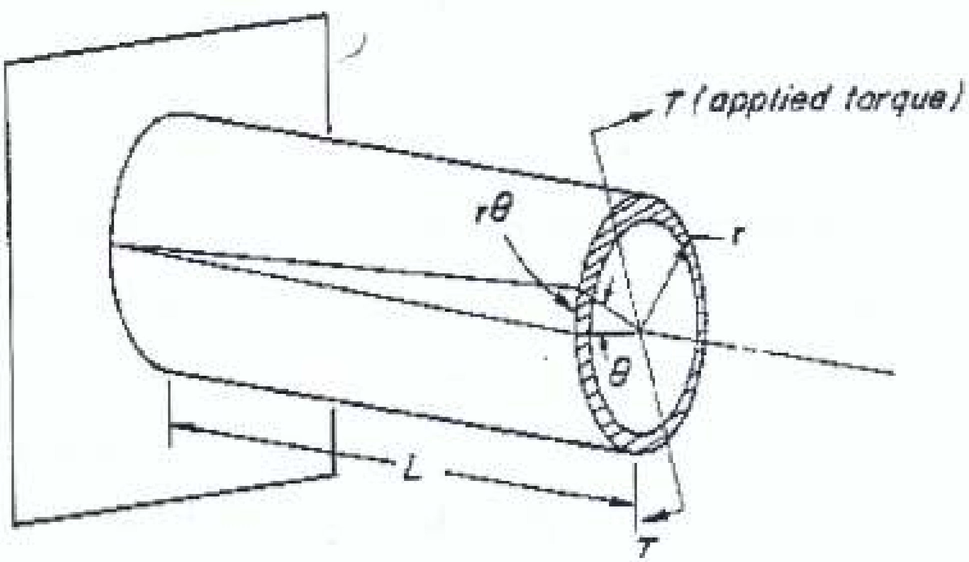


Fig. 2.3: Torsion of Circular Bar [Source: Jenkins (2007)]

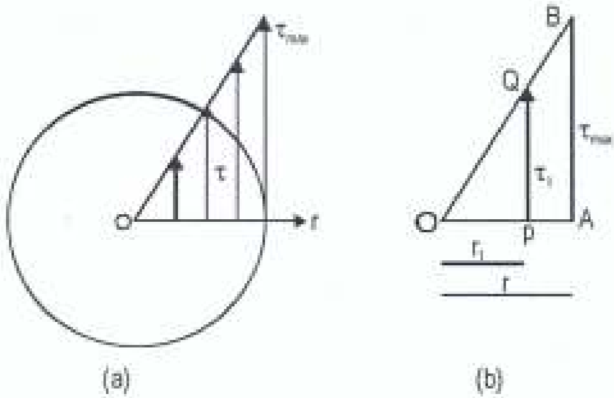


Fig. 2.4: Elastic Shear Stress Variation in Solid Circular Homogeneous Bar

Considering Fig 2.3 shear strain, ϕ = deformation per unit length

$$\phi = \frac{r\theta}{\ell} \tag{2.2}$$

But the shear modulus, G is given as:

$$G = \frac{\tau}{\phi} \tag{2.3}$$

Substituting for shear strain, ϕ, in equation 2.3

$$\frac{\tau}{r} = \frac{G\theta}{L} \tag{2.4}$$

The equation 2.4 is an expression for shear stress and the angle of twist, valid for both the solid and hollow circular test samples in torsion test, within the elastic deformation. It is a useful relation to obtain Shear Modulus, G with reference to the geometry of the test sample.

2.4.2 TORSIONAL AND SHEAR STRENGTH

Since shear stress varies linearly from zero at center to maximum at the perimeter, as shown in Fig. 2.4 (a and bc), then the Torsional Strength is determined thus [Khurmi and Gupta, 2005; Benham and Warnock, 1980; and Bhavikatti 2004]:

Using similar triangles OAB and OPQ in Fig. 2.4b:

$$\frac{\tau}{\tau_{max}} = \frac{r_1}{r}$$

$$\tau = \frac{r_1}{r}\tau_{max} \qquad (2.5)$$

Considering an elemental area δa at distance r_1, from the center with shear stress, τ. Then the shear force is

$$\delta F = \tau \delta a \qquad (2.6)$$

The resisting torsional moment by the element,

$$\delta T = \delta F * r_1 \qquad (2.7)$$

$$\delta T = \tau \delta a r_1 \qquad (2.8)$$

$$But\ \tau = \frac{r_1}{r}\ \tau_{max} \qquad \text{and} \qquad \delta a = 2\prod r_1\, \delta r$$

$$\delta T = \left(\frac{r_1}{r}\tau_{max}\right)(2\Pi r_1 \delta r)(r_1)$$

$$T = \frac{\tau_{max}}{r}\int_0^r 2\pi\, r_1^3 \delta r \qquad (2.9)$$

But $J = 2\Pi\int_0^r r_1^3 \delta r$ which is the Polar Moment of Inertia of the whole section.

Then;

$$T = \frac{\tau_{max}}{r} J$$

$$\frac{T}{J} = \frac{\tau_{max}}{r} \qquad (2.10)$$

Combining equations 2.4 and 2.10 together,

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l} \tag{2.11}$$

This is called the Elastic Torsion Equation and is valid for circular bars that are solid or hollow, homogenous and elastic.

For solid circular bar, the maximum torsional strength by integration of equation 2.9 is given as;

$$T = \frac{2\Pi\tau}{r}\left[\frac{r^4}{4}\right] \tag{2.12}$$

$$T = \frac{\pi\tau\, r^3}{2} \tag{2.13}$$

And the maximum elastic shear stress is

$$\tau_{max} = \frac{2T}{\pi r^3} \tag{2.14}$$

2.4.3 ELASTIC PLASTIC SHEAR STRESS

When the metal starts to deform plastically, the shear stress distribution is no longer linear as earlier discussed but is as shown in Fig. 2.5.

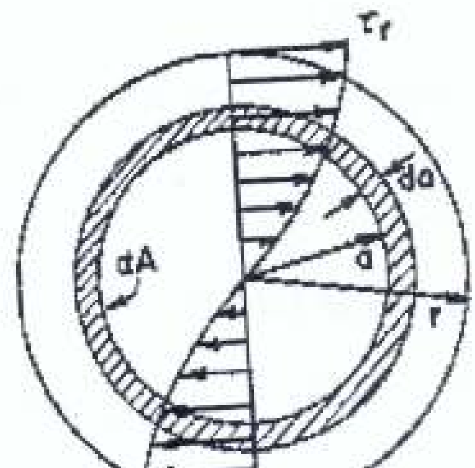


Fig. 2.5: Elastic Plastic Stress Deformation [Source: Jenkins (2007)]

The relationship between torque, T and shear stress, τ is no longer the same as determined in the elastic deformation range and so, the general torsion equation ceased to be valid. To evaluate their relationship in the plastic deformation range, let us recall equation 2.8

$$\delta T = \tau \delta a r_1$$

$$\delta T = 2\pi\tau\, r_1^2 \delta r$$

The total torque resisted across the section is then

$$T = 2\pi \int_0^r \tau\, r_1^2 \delta r \qquad (2.15)$$

But the shear strain $\phi = \dfrac{r_1\theta}{\ell}$ at any radius r_1 is still valid, and substituting this in equation 2.15

$$T = 2\pi \int_0^r \frac{\tau\, \phi^2 L^2}{\theta^2} \times \frac{L}{\theta} \delta r \qquad (2.16)$$

The shear stress, τ, at any radius r_1 is a function of shear strain ϕ only, that is;

$$\tau = f(\phi) \qquad (2.17)$$

The torque, T, is written in terms of shear strain, ϕ only as

$$T\theta^3 = 2\pi L^3 \int_0^{\phi r} f(\phi_1)\, \phi_1^2\, d\phi \qquad (2.18)$$

Differentiating both sides of the equation with respect to angle of twist (θ)

$$\frac{d}{d\theta}\left(T\theta^3\right) = 2\pi L^3 f(\phi_1)\, \phi_1^2\, \frac{d\phi_1}{d\theta} \qquad (2.19)$$

Since $\phi_i = \dfrac{r_1\theta}{L}$

$$\frac{d\phi}{d\theta} = \frac{r}{L} \qquad (2.20)$$

And substituting these quantities in equation for $\frac{d}{d\theta}\left(T\theta^3\right)$ and working out the

derivative $3T\theta^2 + \frac{dt}{d\theta}\theta^3 = 2\pi\tau r^3\theta^2 \qquad (2.21)$

And

$$3T + \theta\frac{dt}{d\theta} = 2\pi\tau\, r^3 \qquad (2.22)$$

Resolving for the shear stress, then;

$$\tau = \frac{1}{2\pi\, r^3}\left(\theta\frac{dt}{d\theta} + 3T\right) \qquad (2.23)$$

The equation 2.23 provided the opportunity of obtaining values of shear stress, τ, at various positions of angle of twist, θ in the plastic deformation range. A graphical analogous of this relation is shown in Fig. 2.6.

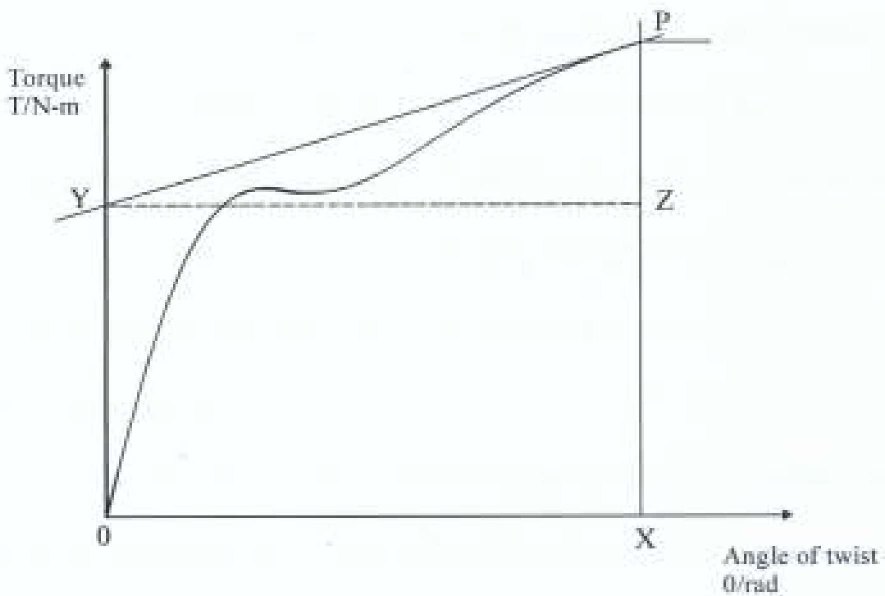


Fig. 2.6: A Typical Torque-Twist Curve

If the plastic shear stress at P is to be determined, then a tangent is drawn at the point P to intercept the Torque ordinate at Y. Then by geometry:

$\theta = YZ$

$$\frac{dt}{d\theta} = \frac{PZ}{YZ}, \text{ and}$$

$T = XP$

Therefore,

$$\tau = \frac{1}{2\pi r^3}\left(\theta \frac{dt}{d\theta} + 3T\right)$$

$$\tau = \frac{1}{2\pi r^3}\left(ZY\frac{PZ}{YZ} + 3XP\right)$$

$$\tau = \frac{PZ + 3XP}{2\pi r^3} \qquad (2.24)$$

2.5 EXISTING DESIGN OF THE CONVENTIONAL TORSION TESTING MACHINES

Material testing machines are mostly available in two categories, either hydraulically or electromechanically. This classification is based on the method in which the testing load is applied. The hydraulic types make use of either a single or double acting piston to apply load. On the other hand, the screw operated machines are often driven by a variable speed electric motor to apply load on the specimen.

In general, Torsion Testing Machines usually come as robust and floor mounting laboratory testers with high investment cost. The simplicity of design cum reduction in size and cost has remained serious challenges to the construction of these machines despite considerable improvement in their performance, efficiency and design. The Fig.2.7 shows an Avery 6609 CGG Reverse Torsion Testing machine while Fig.2.8 is a Riehle Torsion Testing machine.

Fig. 2.7: Avery 6609 CGG Reverse Torsion Testing Machine

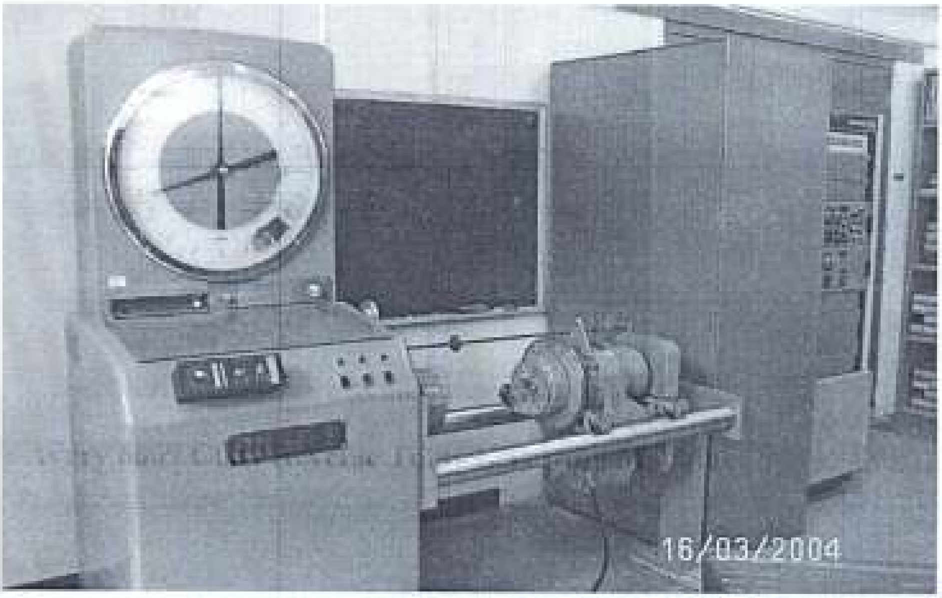


Fig. 2.8: Riehle Torsion Testing Machine

In these machines, torque load is applied to the specimen by a straining mechanism comprising of enclosed oil bath worm gearing coupled to a four-speed motor driven gearbox. The straining mechanism is mounted on a saddle which slides on anti-friction rollers along machined ways of the bed.

2.6 LOAD WEIGHING METHODS ON MATERIALS TESTING MACHINES

A number of methods are available for measuring applied loads on materials testing machines. These include (a) lever weighing system (b) pendulum weighing system (c) spring balance weighing system (d) bourdon-tube weighing system and (e) electronic weighing system.

2.6.1 Lever Weighing System

This is one of the oldest methods used in testing machine in which known loads, on a lever beam or system of levers supported on knife edges, balance the unknown load. In the Avery machine mentioned above, torque load on the specimen is detected by a balanced torque arm to the compound lever system of the load indicating unit as shown in Fig. 2.9.

2.6.2 Pendulum Weighing System

The method in which a pendulum weight suspended on a platform, swing out to balance the deflection of the platform under the effect of an externally applied load. This then actuate the movement of a rack and pinion driven pointer connected to it. The displacement of the pointer is used to indicate the unknown load on a calibrated scale. A manually Riehle torsion testing machine that make use of pendulum system is shown in Fig. 2.10. Torque load is applied by rotating the hand wheel in a clockwise direction which tends to rotate the specimen. The rotation is partially restrained by the pendulum, but the measurement of the applied torque is a function of the height to which the pendulum is raised.

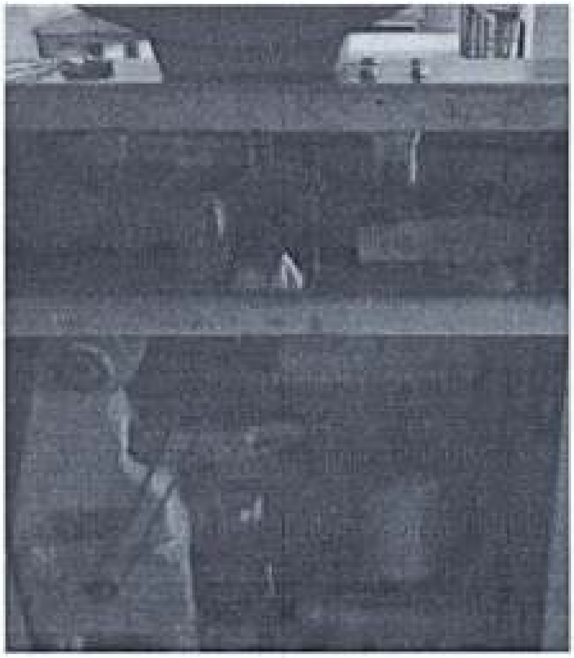


Fig. 2.9: Torque Measuring Unit of Avery 6609 CGG Torsion Testing Machine

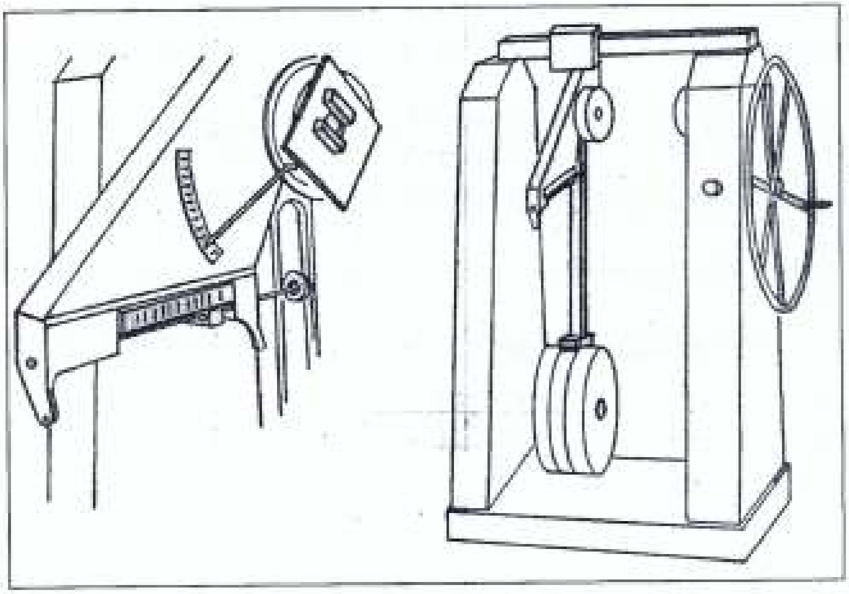


Fig. 2.10: Riehle Pendulum Torsion Testing Machine

2.6.3 Spring Balance Weighing System

A calibrated spring balance either stretches out or compresses to balance a load applied on it. When this happens, the displacement of a pointer attached to the spring balance is used to indicate the weight of the unknown load paced on the spring.

2.6.4 Bourdon Tube Weighing System

This is a very sensitive method used in the measurement of unknown load in fluids. It is widely used as pressure gauges in hydraulic and pneumatic systems. The tube consists of calibrated elastic springs which deformed out to actuate rack and pinion driven pointer, when fluid flows into the device.

2.6.5 Electronics Weighing System

In recent times, the electrical resistance strain gauge has been in use for experimental investigation of stress and strain relations. In some testing machines, the forces transmitted are determined by an elastically strained block of metal, to which strain gauges are attached, which is in series with the specimen. The strain gauge block of metal is called load cell. The operation of the resistance strain gauge is based on the principle that the electrical resistance of metallic wires changes when subjected to a mechanical deformation. The resistivity of the metallic conductors changes with a change in length and area.

CHAPTER THREE

DESIGN SPECIFICATIONS, MATERIALS SELECTIONS AND FABRICATION

3.1 DESIGN SPECIFICATIONS

The specifications for the machine are discussed under design considerations and design calculations respectively.

3.1.1 Design Considerations

3.1.1.1 Machine Speed

The loading rate at which the test sample is being turned is required to be very slow in torsion test. This is to ensure steady increase in static loading and to ease the measurement of the required variables [Harmer, *et al*, 1964]. This requirement is met as the machine is manually driven.

3.1.1.2 Weight

The machine is a bench-size type, unlike the usually conventional floor-mounted types. Therefore, the design is limited to the production of basic component parts. It is therefore portable.

3.1.1.3 Availability and Standardization of Parts

To facilitate reproduction and replacements, a numbers of parts are bought-out such as the bearings, Jacob chucks, bolts and nuts and spring balance. Other parts were machined in the workshop at minimum efforts and cost.

3.1.1.4 Simplicity of Design

From the stand point of budget, weight, capacity and maintainability, the design is simplified into six major parts namely; (1) Base Plate (2) Input Rotation

Assembly (3) Fixed End Assembly (4) Strain Indicator Assembly (5) Torque Load Assembly and (6) the Test Sample(s).

3.1.1.5 Measuring Units

The radial turns of angle scale records the angular deformation while the spring balance was used to measure the load.

3.1.1.6 Cost

It has been practically difficult to commit huge sum of money, as high as N2.5 – N6.5 million to a machine/equipment in a single laboratory, all over our Higher Institutions in Nigeria. Against this back-drop, this manual torsion machine was designed at an average cost of about seventy-nine thousand naira

3.1.1.7 Service Conditions

The simplicity of design has actually facilitated maintenance cost and maximizes the period/year of service use. With minimum number of hand tools, the entire machine was assembled.

3.1.2 Design Calculations

3.1.2.1 Twist Moment on the Rotating Shaft (T)

$$T = F * L \qquad (3.1)$$

Where,

F = applied force (in Newtons, N) at the lever arm knob. It is read from the calibrated spring balance attached to the rotating barrel.

L = the effective length (in metres, m) of the lever arm.

T = 500 x 0.3 = 150 N m

3.1.2.2 Diameter of the Rotating Shaft (d)

The minimum allowable diameter of the rotating shaft was found to be 26.30 mm, using the expression:

$$d^3 = \frac{16T}{\pi \tau_k} \qquad (3.2)$$

Where, T = maximum torque of the machine in N mm

d = diameter of the Shaft in mm

τ_k = the maximum permissible shear stress for shaft with allowance for keyways. It is given as 42 MN/m^2 (Khurmi and Gupta, 2005).

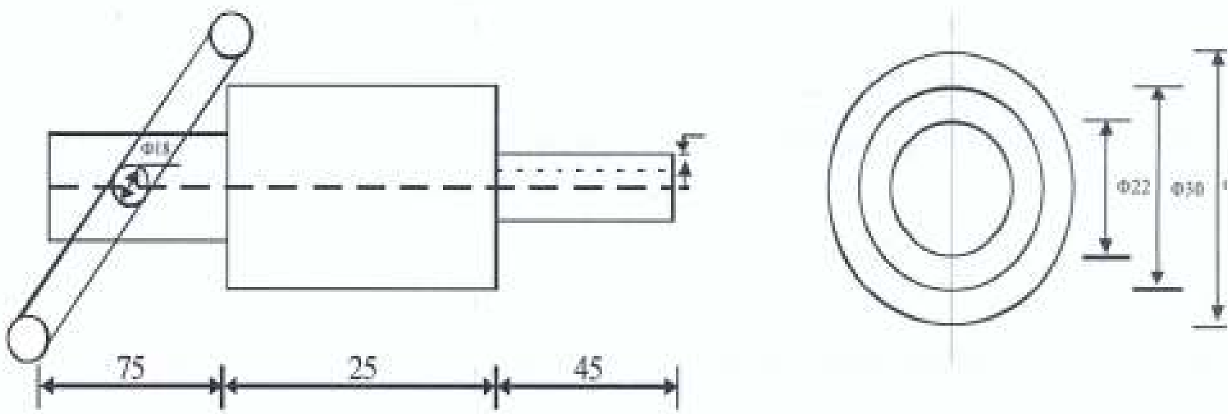


Fig. 3.1: Rotating Shaft and the Lever-arm

$$d^3 = \frac{16 \times 150 \times 10^3}{\pi \times 42} = 18{,}189.13635\ \text{mm}^3$$

d = 26.30 mm

Then, the shaft diameter was varied between 22 to 32 mm to compensate for stress concentrations at the keyway side and the blank hole side of the lever-arm.

3.1.2.3 Strength of the Parallel Sunk Square Key on the Rotating Shaft

The shearing and crushing stresses in the torque transmitting key between the barrel shaft and the barrel were computed as 43.29 N/mm^2 and 86.58 N/mm^2 respectively. Khurmi and Gupta (2005) gave the expressions as:

Shear Stress, $$\tau = \frac{2T}{\ell wd} \quad (3.3)$$

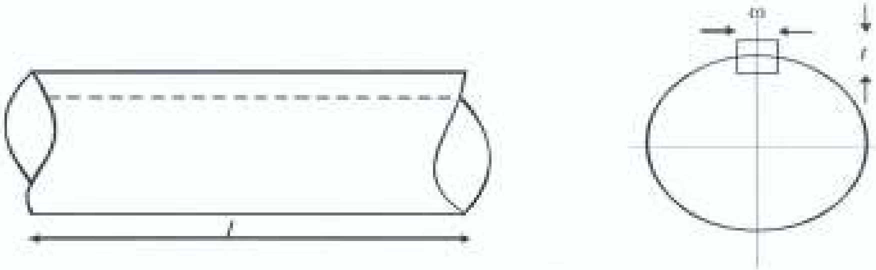


Fig. 3.2: Key and Keyway Design between the Rotating Shaft and the Barrel

$$\tau = \frac{2 \times 150 \times 10^3}{45 \times 7 \times 22} = 43.29 \text{ N/mm}^2$$

Similarly, the crushing stress is given as [Khurmi and Gupta (2005)]:

Crushing Stress, $$\sigma_c = \frac{4T}{\ell td} \quad (3.4)$$

$$\sigma_c = \frac{4 \times 150 \times 10^3}{45 \times 7 \times 22} = 86.58 \text{ N/mm}^2$$

Where, Length of the key, ℓ = 45 mm

Width of the key, w = 7 mm

Thickness of the key, = 7 mm and

Diameter of the shaft portion carrying the key d = 22 mm.

3.1.2.4 Strength of the Fillet Welds at the Rotating Chuck and the Fixed Chuck of the Machine

Torque strength of circular fillet weld under torsion is expressed by Khurmi and Gupta (2005) and Hall *et el* (2003) as:

$$\textbf{Grip Torque, } T = \frac{\tau_{fw} \pi \, \mathrm{sd}^2}{2.83} \qquad (3.5)$$

$$T = \frac{98 \times \pi \times 10 \times 12^2}{2.83} = 156.66 \, \mathrm{kN/mm^2}$$

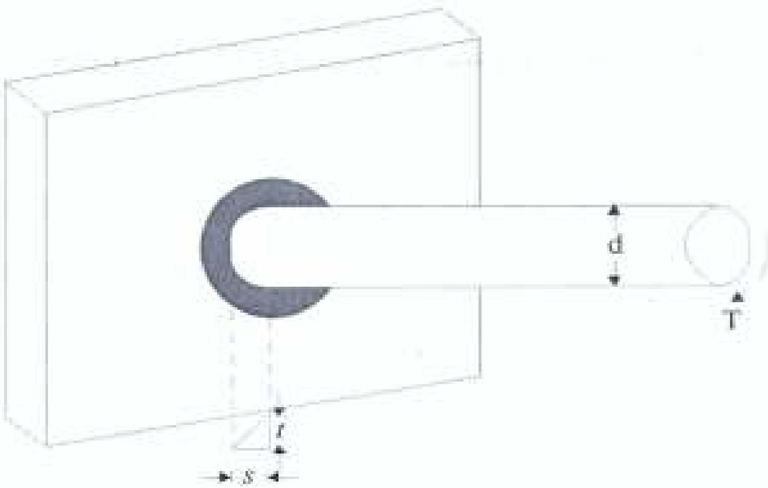


Fig. 3.3: Circular Fillet Weld Subjected to Torsion Load

Where, Size (or leg) of the weld, s = 10 mm and s = $\frac{t}{Sin\, 45^0}$

Throat thickness of the weld, t in mm

Diameter of the stud carrying chuck, d = 12 mm and

Allowable shear stress (τ_{fw}) for circular fillet weld that is made with mild steel coated electrode, when the joint is subjected to steady load. This is given as 98 N/mm^2 [Sadhu, (2003); Khurmi and Gupta (2005)].

3.1.2.5 Base Plate Design for Moment of Resistance and Bending Stress

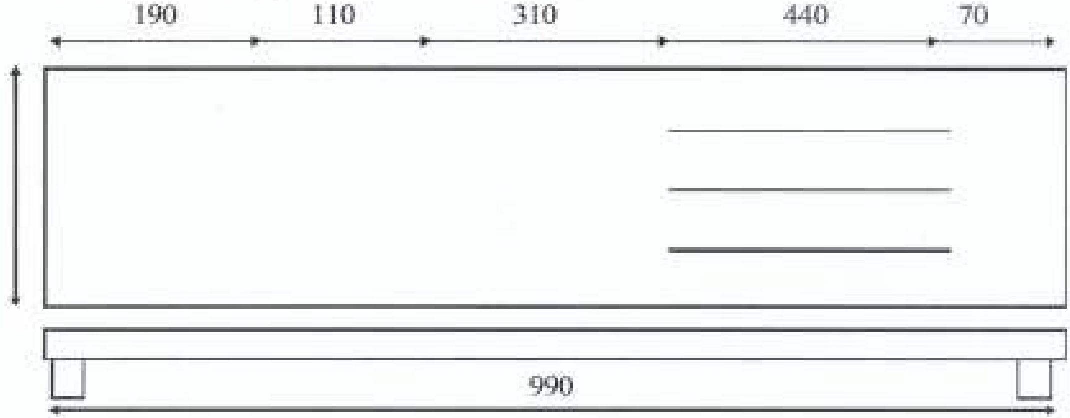


Fig. 3.4 Base Plate with Reinforcement

The base plate is considered to be a simply support beam with the bearing block annotated as a point or concentrated load of 105 N determined from a weighing balance. The fixed end assembly is found to weigh 7.68 kg (7.68 kg x 10 m/s^2 = 76.8 N) and it is annotated as a uniformly distributed load, as it has provision to slides in three slots, milled in the base plate as shown above. Then, the free-body diagram of this type of mechanical system is given thus:

The equivalent point load between sections D and E is

W = 76.8 x 0.370 = 28.42 N

Determining the reactions at the supports

$$+\uparrow \sum M_A = 0$$

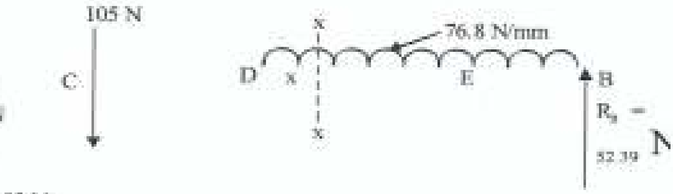
$$-(105 \times 0.295) - (28.42 \times 0.735) + (R_B \times 0.99) = 0$$

$$R_B = \frac{51.8637}{0.99} = 52.39 \text{ N}$$

$$+\uparrow \sum F_y = 0$$

$$R_A - 105 - 28.42 + R_B = 0$$

$$R_A = 133.42 - 52.39 = 81.03 \text{ N}$$



Shear Forces (F)

$F_A = +R_A = 81.03\text{N}$

$F_C = 81.03 - 105 = -23.97$ N

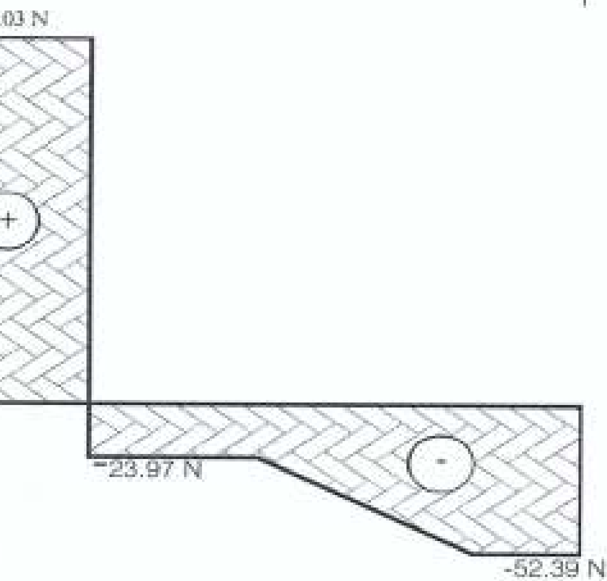
$F_x = -23.97 - 76.8x$

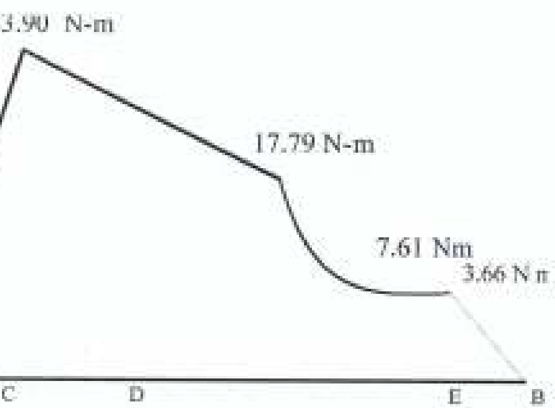
At the mid-span of the UDL portion DE,

$= -23.97 - 76.8\ (0.185) = -38.18$ N

$F_E = -23.97 - 76.8(0.370) = -52.39$ N

$F_B = -52.39$ N





Bending Moments (M)

When x = 0 $\qquad$ $M_A = 0$

When x = 0.295 m

$M_c = (81.03 \times 0.295) = 23.90$ N m

$M_c = 23.90$ N m

When x = 0.550 m

$M_D = (81.03 \times 0.550) - (105 \times 0.255)$

$M_D = 17.79$ N m

In the uniformly distributed portion DE

When x = 0.92 m

$$M_x = (81.03 \times 0.92) - (105 \times 0.625) - \frac{76.8x^2}{2}$$

$M_x = 74.55 - 65.63 - 38.4x^2$

$M_x = 8.92 - 38.4x^2$ N m

The value of M_x depends upon the instantaneous distance from D to E.

When x is mid-span of the UDL, i.e.

X = 0.185 m

$M_x = 8.92 - 38.4\ (0.185)^2$

$M_x = 7.61$ N-m

When x is the full-span of the UDL, i.e.

x = 0.370 m

$M_E = 8.92 - 38.4\ (0.37)^2$

$M_E = 3.66$ N-m

The maximum bending moment occurs at point C due to the weight of the bearing block.

The maximum safe load the base plate beam can carry is therefore determined thus:

Recall,

$$M = \sigma_B \frac{I}{y} = \sigma_B Z,$$

where:

M = Bending moment in N-m

σ_B = Bending stress in N/m^2

I = Moment of inertia of the section in m^4

y = Distance of the centroidal axis from the extreme fibre, in m

Z = Section modules of the section in m^4

From the cross-section of the base-plate, the width, b, is 300 mm and the depth, d, is 6.0 mm. Also, the effective area covered by the bearing block on the base-plate is 150 mm x 50 mm.

$$M_{MAX} = \sigma_B Z = \sigma_B \left[\frac{bd^2}{6}\right]$$

$$\sigma_B = \frac{6M_{MAX}}{bd^2} = \frac{6 \times 23.90}{0.3 \times (0.006)^2}$$

$$\sigma_B = 13.28 \times 10^6 \text{ N/m}^2$$

The safe load carrying capacity (P in Newton) of the base-plate due to the bearing block is:

$$P = \sigma_B A$$

$$P = 13.28 \times 10^6 \times [0.15 \times 0.05]$$

$$P = 99.6 \text{ kN}$$

From the standpoint of safe compressive load on the base plate which is about 100 kN, it is very clear that the weight of bearing block, which is just 105 N, can be carried safely on the base plate.

3.2 MATERIALS SELECTIONS

A number of materials used in the machine are mild-steel, aluminium, cast-iron, rubber, of which mild-steel was predominant as shown in Table 3.1.

Table 3.1 Factors Affecting Materials Selection of a Bench-top Torsion Machine

Materials	Sub-component Parts of the Machine	Factors Affecting Selection
Mild-steel	Bearing Block, Fixed Chuck Assembly, Barrel Shaft, Barrel, Base-plate, Threaded hanger, Specimen	Availability, Relatively cheap, Good Machinability, Good Mechanical properties, Weldability, Moderate weight, Fair surface coating,
Aluminium	Protractor, Protractor face plate, Pointer rod, Specimen	Light weight, aesthetic factor, corrosion resistance, Torsion test
Cast-iron	Lock-screw wheel	Castability, Light weight
Harden Tool Steel	Bolts , nuts, Inverted L-post	Hardness, Toughness, Corrosion resistance, Forgeability
Rubber	Protractor face plate support	Lightness, aesthetic factor, Zero reading adjustment.
Spring Steel	Helical Coil Spring Balance	High resilience, shock and Fatigue Resistance
Brass	Specimen, Pointer	Aesthetic factor, Torsion test

3.3 METHODS OF FABRICATION

3.3.1 Construction of the Base Plate

Materials Used: Mild steel (6.0 mm thickness)

Tools/Machines Used: Hacksaw, Acetylene flame, Vertical Milling, Drilling and Welding machines.

Procedure: The base plate was cut with acetylene flame and milled to 300 mm x 990 mm x 6 mm dimension. Three parallel uniform slots were milled for the fixed-end assembly at one end, using vertical milling machine. The slots dimensions are 15 mm x 379 mm with 15 mm equidistance from one another. Three $\phi 24$ mm holes were drilled using sensitive drilling machine for mounting of the bearing block and the L-post. The base plate was reinforced with material of the gauge using dimension10 mm x 950 mm x 6 mm.

3.3.2 Construction of the Bearing Block

Materials Used: Mild steel Block with 50 mm thickness

Tools/Machines Used: Acetylene flame, drilling, shaping machines and Lathe engine.

Procedure: The Block (150 mm x 195 mm x 50 mm) was cut out of the parent material using acetylene flame. $\phi 95$ mm hole was bored to a depth of 40 mm while the remaining was bored to $\phi 30$ mm. At the top edge, a 3 mm depth slot was milled transversely to accommodate pointer rod. Two $\phi 24$ mm blind holes were drilled and tapped at the bottom edge of the block for fastening it to the Base plate, using M24 bolts and nuts.

3.3.3 Construction of the Fixed end Assembly

Materials Used: Mild steel Block with 25 mm thickness

Tools/Machines Used: Acetylene flame, drilling and shaping machines, lathe engine.

Procedure: The part comprises of two blocks, namely fixed chuck block and the locking screw block. The blocks were cut to sizes 135 mm x 130 mm x 25 mm and 135 mm x 155 mm x 25 mm respectively using acetylene flame and shaping machine. The blocks were step milled at the bottom to provide legs that can slide in the slots already prepared on the base plate. A ϕ20 mm open hole was drilled at the longitudinal axis of the locking screw block to house the locking screw that locks the assembly at any desired position.

3.3.4 Construction of the Input Rotation Assembly

Materials Used: Mild-steel rods.

Tools/Machines Used: Drilling, milling machines and lathe.

Procedure: The parts required are the Barrel and the rotating Shaft.

The Barrel – A 55 mm x ϕ59 mm rod was bored to ϕ23 mm through a depth of 45 mm at one end and provided with 4 mm depth keyway over the same section. At the same axis, the other end of the barrel was drilled and tapped to ϕ10 mm to house the rotating chuck stud. The external circumference of the barrel was grooved to act as a pulley for winding of the tension wire that pulls on the graduated spring balance.

The Rotating Shaft – The shaft was step turned to varying cross-sections, such as ϕ32 mm x 75 mm, ϕ31 mm x 25 mm and ϕ22 mm x 45 mm respectively. The first section was drilled to ϕ18 mm to house the lever-arm.

3.3.5 Construction of the Inverted L- post

Materials Used: Harden Tool steel rod (ϕ19 mm)

Tool/Machines Used: Drilling, Grinding machines and Lathe.

Procedure: One end of the rod was red heated at distance 200 mm and horizontally bent using hammer and anvil. The tip of the bent section was drilled using griding machine. Over the same section, a ϕ7.5 mm hole was drilled at 45 mm distance to accommodate the threaded hanger. The other end section was threaded over 70 mm length for standing and tighting the post on the base plate using M24 nuts.

3.4 DESIGN LAYOUT AND GENERAL DESCRIPTION OF THE MACHINE

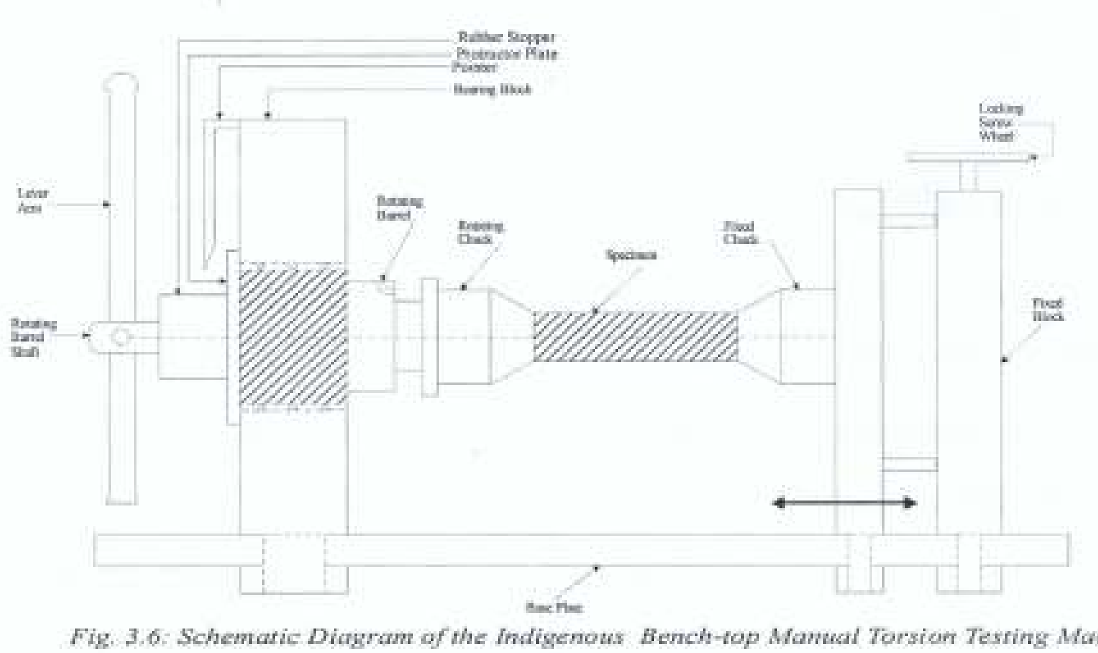


Fig. 3.6: Schematic Diagram of the Indigenous Bench-top Manual Torsion Testing Machine

The general design layout in a typical experimental set-up of the Torsion Testing machine is shown in Fig 3.6. The torsion moment was communicated on to the specimen through the rotating chuck mounted in the bearing block via the barrel and the rotating shaft, which is rotated by the lever arm. The specimen was made to experience twisting moment by the action of the fixed chuck, which held it firmly in position to resist turning moment. This counter-moment developed at the fixed chuck and the fixed end assembly is equal in magnitude to the one initiated at the rotating end of the specimen. The fixed chuck assembly was designed to slide side-ways along the base plate. This is to accommodate variation in length of test samples in accordance with their different diameters or cross-sectional area. The assembly could be locked at desired position, before the test began; making use of the screw-wheel and nut after the test sample has been properly clamped.

A protractor plate or graduated angle scale was mounted on the rotating shaft and turns with the test sample. The relative angular turns (i.e. the angle of twist, θ) of the test sample are read off from the protractor making use of a fixed pointer. The pointer was placed parallel to the axis of the test sample. It is held in position by the slot provided on top of the Bearing Block.

The spring dynamometer concept was used for the measurement of the applied torque on the specimen. A graduated spring scale was carefully and perpendicularly connected to the specimen. With the aid of a tension wire, the spring measures the tension load in the wire as the specimen is being twisted. The applied torque, T, is determined from the product of the tension load, F, in the wire and the effective length ℓ of the lever arm (i.e. $T = F\,\ell$ in Newton metres N-m).

3.5 ASSEMBLY OF THE TORSION TESTING MACHINE

3.5.1 Assembly of the Straining/Rotating End

The base plate is the bed upon which all the sub-assemblies were mounted by making use of the hole and slot profiles already provided on it. The barrel shaft was slotted and fastened with 7 mm Allen- key, into the assembly of the barrel and rotating chuck, which had earlier been welded together. The whole of this unit was then inserted into the bearing block from its front view shown in Fig. 3.7. The protractor plate was mounted on the protruding end of the barrel shaft at the back view of the bearing block. This was held in position and firmly by the rubber stopper. The lever arm was inserted into the barrel shaft and a plastic knob was screwed to one of its end to prevent slippage while in operation. The straining-end is shown in Fig.3.8.

3.5.2 Assembly of the Fixed-end Unit

The unit is made up of four major parts, namely; fixed chuck, fixed-chuck block, locking-screw block and the locking screw provided with a casted wheel. The first three parts had earlier been welded together to make a sub-unit. This was mounted on to the three milled slots on the base-plate. The locking screw was then inserted into the locking-screw block. The whole unit, as shown in Fig. 3.9, could be locked in any desired position in the slots with a square-nut.

3.5.3 Assembly of the Load Indicating Unit

The inverted L-post was mounted near the straining-end on the base-plate and lock in position with two M24 nuts. The calibrated spring balance was attached to the threaded hanger, while the hanger was suspended in a hole drilled on the L- section of the inverted post and held in position with a knurled-nut. When the test is to be conducted, the tension wire is attached to the spring balance and the rotating barrel, while the protractor pointer is placed in the slot milled on the bearing block. The general set-up of the machine with a specimen in between the two chucks is shown in Fig.3.10.

Fig. 3.7: The Bearing Block

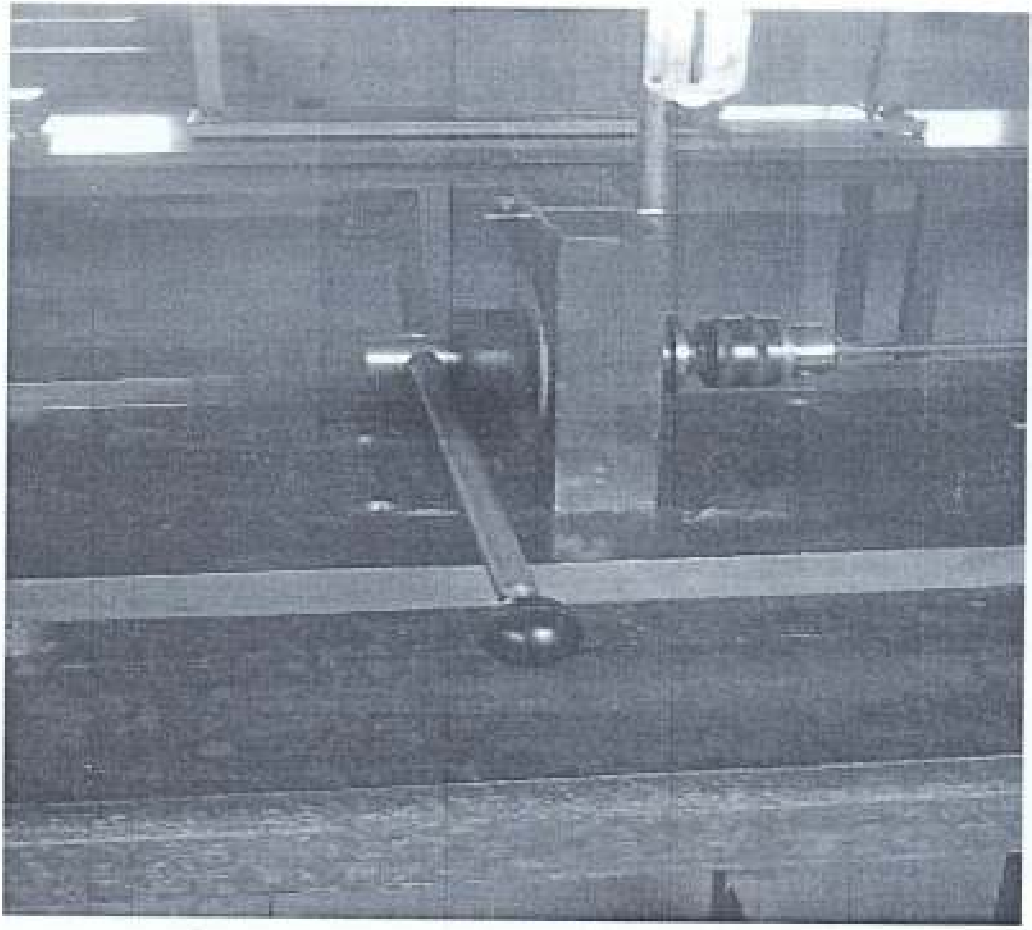


Fig. 3.8: Straining-end Assembly

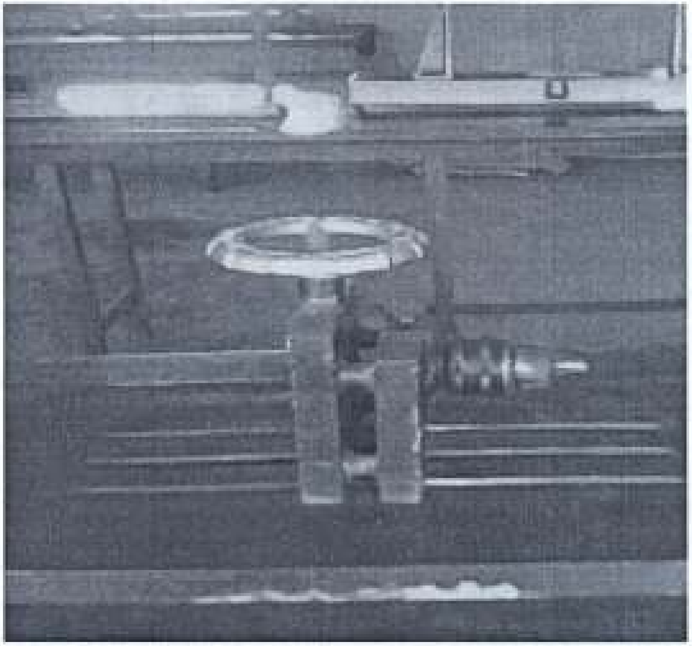


Fig. 3.9: Fixed-end Assembly

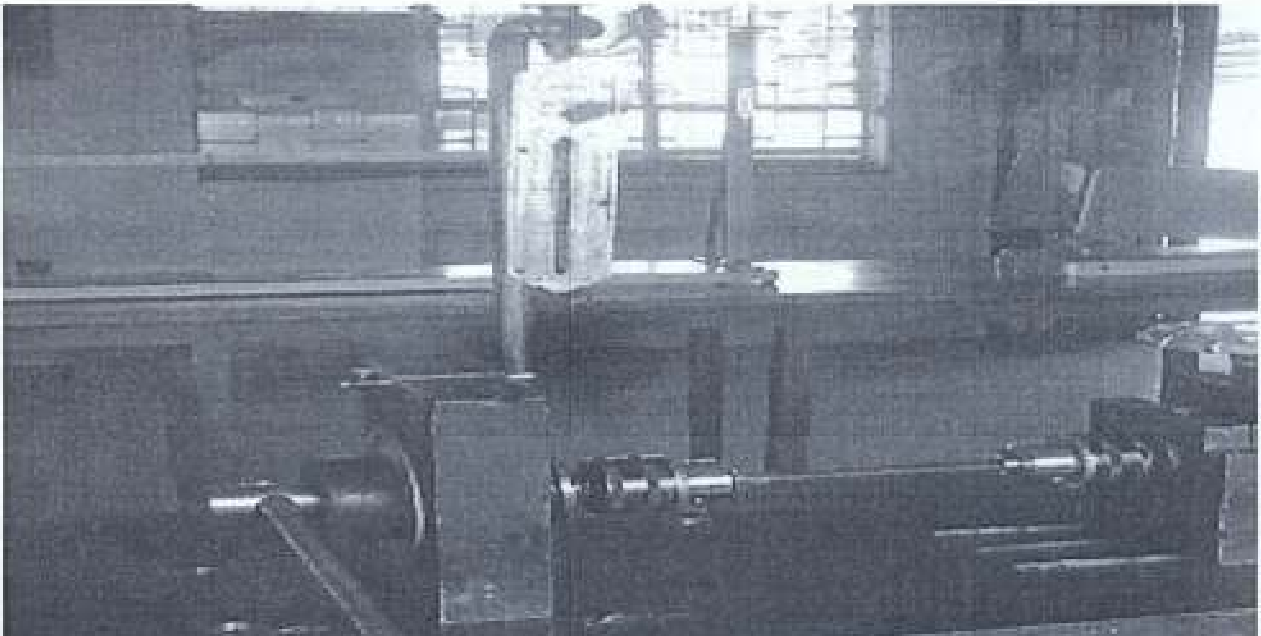


Fig. 3.10: An Indigenous Bench-Top Manual Torsion Testing Machine

3.6 COST ESTIMATION OF THE TORSION TESTING MACHINE

Table 3.2 Materials Cost for the Indigenous Bench-top Manual Torsion Testing Machine

ITEMS NO	*DESCRIPTION OF PARTS*	*MATERIALS*	*NO OFF*	*RATE #*	*TOTAL COST #*
1	Bearing Block	Mild steel	1	6,500:00	6,500:00
2	Spring Balance Scale	Standard	1	10,000:00	10,000:00
3	Jacob Jaw Chuck	Standard	2	1,800:00	3,600:00
4	Bearings	Alloy Steel	2	2,500:00	5,000:00
5	Inverted L - Post	Tool-steel	1	2,500:00	2,500:00
6	Rotating Shaft	Mild-steel	1	1,500:00	1,500:00
7	Angle Scale $0^0 - 360^0$	Standard	1	1,750:00	1,750:00
8	Rotating Barrel Shaft	Mild steel	1	750:00	750:00
9	Face Plate	Aluminum	1	500:00	500:00
10	Base Plate	Mild steel	1	15,500:00	15,500:00
11	Threaded Hanger	Mild steel	1	750:00	750:00
12	Rubber Stopper	Rubber	1	500:00	500:00
13	Fixed End Block	Mild steel	1	2,500:00	2,500:00
14	Locking Screw Block	Mild steel	1	3,250:00	3,250:00
15	Locking Screw	Mild steel	1	750:00	750:00
16	Locking Screw Wheel	Cast iron	1	2,000:00	2,000:00
17	Bolts & Nuts M12 x1.5	Mild steel	2	60:00	120:00
18	M24 x 2.0 Nuts	Mild steel	3	30:00	90:00
19	Surface Coating	Varieties	-	2,500:00	2,500:00
20	Tension wire	Alloy steel	-	500:00	500:00
TOTAL					***60,560:00***

Table 3.3 Labour Cost for Fabrication of the Indigenous Bench-top Manual Torsion Testing Machine

TEMS NO	*DESCRIPTION OF PARTS*	❖ *MAN-HOUR CHARGING RATE (₦)*	*TIME OF WORK (HOURS)*	*AMOUNT ₦*
	Base Plate	₦ 70,000.00 x 1/30 Day x 1/8 Hour	5 ½	1,604.17
	Bearing Block	₦ 70,000.00 x 1/30 Day x 1/8 Hour	2	583.33
	Rotating Shaft	₦ 70,000.00 x 1/30 Day x 1/8 Hour	2	583.33
	Rotating Barrel Shaft	₦ 70,000.00 x 1/30 Day x 1/8 Hour	2½	729.17
	Lever-arm	₦ 70,000.00 x 1/30 Day x 1/8 Hour	2	583.33
	Face Plate & Angle Scale	₦ 70,000.00 x 1/30 Day x 1/8 Hour	1	291.67
	Fixed End Block	₦ 70,000.00 x 1/30 Day x 1/8 Hour	2	583.33
	Locking Screw Block	₦ 70,000.00 x 1/30 Day x 1/8 Hour	2½	729.17
	Locking Screw & Lock-Nut	₦ 70,000.00 x 1/30 Day x 1/8 Hour	2½	729.17
0	Locking Screw Wheel	₦ 70,000.00 x 1/30 Day x 1/8 Hour	3	875.00
1	Inverted L - Post	₦ 70,000.00 x 1/30 Day x 1/8 Hour	1	291.67
2	Threaded Hanger	₦ 70,000.00 x 1/30 Day x 1/8 Hour	1½	437.50
3	Assembly of Parts and Finishing work	₦ 70,000.00 x 1/30 Day x 1/8 Hour	5	1,458.33
	TOTAL		*32½*	*9,479.17*

❖ Average wage rate in the locality of research for junior skilled machinist and fabricator was found to be ₦291.67 hour job.

a) Material Cost = **₦ 60,560:00**
b) Labour Cost = **₦ 9,479.17**
c) Miscellaneous Cost: 5% of each respective cost of the materials and labour = **₦ 3,501.96**

Total Cost of Production (a + b + c), = #73,541.13

CHAPTER FOUR

MACHINE TESTING AND EVALUATION

The torsion machine in this work was used to generate pure shear stress in the torsional loaded specimen. From the test, the shear elastic modulus (G), shear proportional stress τ_p, shear stress versus shear strain curve was obtained. Apart from the basic objectives of a typical torsion test, the machine performance was also evaluated.

4.1 SPECIFICATIONS OF TORSION SPECIMEN

Specifications for structural specimen were used in conducting torsion test on the machine. So, the specimens were not given serious geometrical configurations. A sample each of 5.0 mm diameter of Aluminium and Brass and 5.5 mm diameter of Mild-steel were tested over a gauge length of 60 mm and 66 mm, while the total length were 90 mm and 99 mm, respectively.

4.2 METHOD OF TESTING

A micrometer and metre-rule were used to measure the diameter and length of the specimens respectively. The average diameter for each specimen is then obtained which are used to compute their polar moment of inertias. A straight line mark was drawn along the longitudinal axis of each specimen using indelible marker. The machine load indicator was assembled with the spring balance connected to the rotating barrel perpendicularly. The specimen was inserted into the machine chucks and locked.

The spring balance and the graduated angle scale were adjusted to read zero by relieving the threaded hanger and turning the rubber stopper carrying the angle scale. Then, the test was started by turning the lever-arm anti-clock wisely. At 10 N intervals, the simultaneous readings of the load and the angle of twist were recorded from the spring balance and the angle scale respectively.

4.3 TEST RESULTS

Test results were determined using the following classical torsion expressions:

Torque load $T = Fr$ (4.1)

Polar Moment of Inertia, $J = \frac{\pi d^4}{32}$ (4.2)

Shear Strain $\phi = \frac{r\theta}{\ell}$ (4.3)

Shear Stress $\tau = \frac{Tr}{J}$ (4.4)

Shear Modulus $G = \frac{\tau}{\phi}$ (4.5)

Table 4.1 Test Results of 5.0 mm Diameter Aluminium

N	Force Load P / N	Angle of Twist θ^{o}	Angle of Twist θ / rad	Torque Load T / N-mm	Shear Strain ϕ	Shear Stress τ N/mm²	Angle of Twist θ / rad	Torque Load T / N-mm	Shear Strain ϕ	Shear Stress τ N/mm²
0	0	0	0	0	0	0	0	0	0	
1	10	17	0.2967	3000	0.0124	122.23	0.2967	3000	0.0124	122.2
2	20	27	0.4712	6000	0.0196	244.2	0.4712	6000	0.0196	244
3	30	31	0.541	9000	0.0226	366.3	0.541	9000	0.0226	366
4	40	38.5	0.6719	12000	0.028	488.4	0.6719	12000	0.028	488
5	50	46	0.8028	15000	0.0335	610.5	0.8028	15000	0.0335	610
6	60	52.5	0.9162	18000	0.0382	732.6	0.9162	18000	0.0382	732
7	70	59	1.0297	21000	0.0429	854.7	1.0297	21000	0.0429	854
8	80	62.5	1.0908	24000	0.0455	976.8	1.0908	24000	0.0455	976
9	95	71.5	1.2478	28500	0.052	1159.95	1.2478	28500	0.052	1159.9
0	100	73	1.274	30000	0.0531	1221	**SLOPES**	**23764.37**		**23205.9**
1	114	80	1.3962	34200	0.0582	1391.94				
2	120	86	1.5009	36000	0.0626	1465.2				
3	130	90	1.5707	39000	0.0655	1587.3				
4	155	106	1.8499	46500	0.0771	1892.55				
5	170	117	2.0419	51000	0.0851	2075.7				
6	180	126	2.199	54000	0.0917	2197.8				
7	200	141.5	2.4695	60000	0.103	2442				
8	210	149	2.6003	63000	0.1084	2564.1				
9	220	155	2.7051	66000	0.1128	2686.2				
20	230	163.5	2.8534	69000	0.119	2808.3				
21	250	182	3.1763	75000	0.1325	3052.5				
22	274	199	3.4729	82200	0.1448	3345.54				
23	300	222	3.8743	90000	0.1616	3663				
24	330	243	4.2408	99000	0.1768	4029.3				
25	362	271	4.7295	108600	0.1972	4420.02				
26	390	293	5.1134	117000	0.2132	4761.9				
27	420	316	5.5148	126000	0.23	5128.2				
28	440	330	5.7592	132000	0.2402	5372.4				

GAUGE	*DIAMETER:*	*5.0 mm*
GAUGE	*LENGTH:*	*60 mm*
TOTAL	*LENGTH:*	*90 mm*
POLAR	*MOMENT J*	*61.36 mm⁴*

Table 4.2 Test Results of 5.0 mm Diameter Brass

S/N	*Force Load* *P / N*	*Angle of Twist* θ^0	*Angle of Twist* θ / *rad*	*Torque Load* *T / N-mm*	*Shear Strain* ϕ	*Shear Stress* τ *N/mm²*	*Angle of Twist* θ / *rad*	*Torque Load* *T / N-mm*	*Shear Strain* ϕ	*Shear Stress* τ *N/mm²*
0	0	0	0	0	0	0	0	0	0	
1	10	23	0.401	3000	0.0167	122.1	0.401	3000	0.0167	122.
2	22	38	0.663	6600	0.0276	268.62	0.663	6600	0.0276	268.6
3	30	43	0.75	9000	0.0313	336.3	0.75	9000	0.0313	336.
4	40	49.5	0.864	12000	0.036	488.4	0.864	12000	0.036	488.
5	50	56	0.977	15000	0.0398	610.5	0.977	15000	0.0398	610.
6	60	63	1.099	18000	0.0458	732.6	1.099	18000	0.0458	732.
7	70	66	1.152	21000	0.048	854.7	1.152	21000	0.048	854.
8	85	75	1.309	25500	0.0546	1037.9	1.309	25500	0.0546	1037.
9	110	90	1.571	33000	0.0655	1343.1	1.571	33000	0.0655	1343.
10	130	100	1.745	39000	0.0728	1587.3	**Slopes**	**21935.47**		**21498.0**
11	140	105	1.832	42000	0.0764	1709.4				
12	150	110	1.92	45000	0.0801	1831.5				
13	165	120	2.094	49500	0.0873	2014.7				
14	180	132	2.304	54000	0.0961	2197.8				
15	198	145	2.531	59000	0.1055	2401.3				
16	225	170	2.967	67500	0.1237	2747.3				
17	245	191	3.333	73500	0.139	2991.5				
18	275	210	3.665	82500	0.1528	3357.8				
19	295	227.5	3.97	88500	0.1655	3602				
20	333	257.5	4.494	99900	0.1874	4065.9				
21	385	297	5.183	115500	0.2161	4700.9				
22	415	323.5	5.646	124500	0.2354	5067.2				
23	440	339.5	5.925	132000	0.2471	5372.4				
24	445	343	5.986	133500	0.2496	5433.5				

GAUGE	*DIAMETER:*	*5.0 mm*
GAUGE	*LENGTH:*	*60 mm*
TOTAL	*LENGTH:*	*90 mm*
POLAR	*MOMENT J*	*61.36 mm⁴*

Table 4.3 **Test Results of 5.5 mm Diameter Mild Steel**

S/N	*Force Load* *P / N*	*Angle of Twist* θ^o	*Angle of Twist* θ / *rad*	*Torque Load* *T / N-mm*	*Shear Strain* ϕ	*Shear Stress* τ *N/mm²*
0	0	0	0	0	0	0
1	10	26	0.455	3000	0.019	91.8
2	20	31	0.5425	6000	0.0226	183.6
3	30	41.8	0.7315	9000	0.0305	275.4
4	40	48.5	0.8488	12000	0.0354	367.2
5	50	57	0.9975	15000	0.0416	459
6	60	61.5	1.0763	18000	0.044955	550.8
7	70	66	1.155	21000	0.0482	642.6
8	105	85	1.4875	31500	0.062	963.9
9	130	99	1.7325	39000	0.0722	1193.4
10	158	116	2.03	47400	0.0847	1450.44
11	180	134	2.345	54000	0.0978	1652.4
12	200	148	2.59	60000	0.108	1836.0
13	235	174	3.045	70500	0.127	2157.3
14	265	199	3.4825	79500	0.1452	2432.7
15	285	211	3.6925	85500	0.154	2616.3
16	305	226	3.955	91500	0.1649	2799.9
17	325	244	4.27	97500	0.1781	2983.5
18	355	271	4.7425	106500	0.1978	3258.9
19	395	298	5.215	118500	0.2175	3626.1
20	433	328	5.74	129900	0.2394	3974.94
21	465	355	6.2125	139500	0.2591	4268.7
22	480	366	6.405	144000	0.2671	4406.4

Angle of Twist θ / *rad*	*Torque Load* *T / N-mm*	*Shear Strain* ϕ	*Shea Stres* τ *N/m*
0	0	0	
0.455	3000	0.019	9
0.5425	6000	0.0226	18
0.7315	9000	0.0305	27
0.8488	12000	0.0354	36
0.9975	15000	0.0416	4
1.0763	18000	0.044955	55
1.155	21000	0.0482	64
1.4875	31500	0.062	96
Slopes	**21500.94**		**1577**

GAUGE DIAMETER: 5.5 mm

GAUGE LENGTH: 66 mm

TOTAL LENGTH: 99 mm

POLAR MOMENT J 89.84 mm⁴

4.4 EVALUATION

The torsion test was conducted on the three materials; namely Aluminium, Brass and Mild-steel. The experimental results were given by Tables 4.1 to 4.3 and using MS-Excel software (2007 Version), the experimental slopes (i.e. Shear Moduli, G) of the three metals were determined in the elastic range.

Aluminium specimen has a shear modulus of 23, 205.92 N/mm^2, Brass has 21,498.06 N/mm^2 and Mild-steel has 15,773.10 N/mm^2 respectively. Data from literature show that only experimental value, G, of Aluminium is reasonably correct, as it has the least percentage error of 0.16 (Table 4.4). The percentage deviations of Brass and Mild-steel are 0.43 and 0.80 respectively.

Table 4.4 Comparison of Experimental Shear Modulus with Standard Values

Materials	Shear Modulus from Experiment G N/mm^2	Standard Shear Modulus G N/mm^2	Experimental Deviations from Standard 1 - performance
Aluminium	23, 205.92	27,580	0.16
Brass	21,498.06	38,000	0.43
Mild-steel	15,773.10	80,000	0.80

Source: Ryder (2002).

The various curves showing the relationship involving shear stress versus shear strain; torque load versus angle of twist and the elastic shear stresses of the three materials were shown in Figs 4.1 to 4.9. The curves of Mild-steel and Aluminium specimen show some better linearity thus exhibit good ductility properties.

The physical examination of the three deformed specimen shows that angular twist of materials in pure torsion is partly dependent on their length. The turns are greater at the extreme fibres and at the regions closer to the chuck.

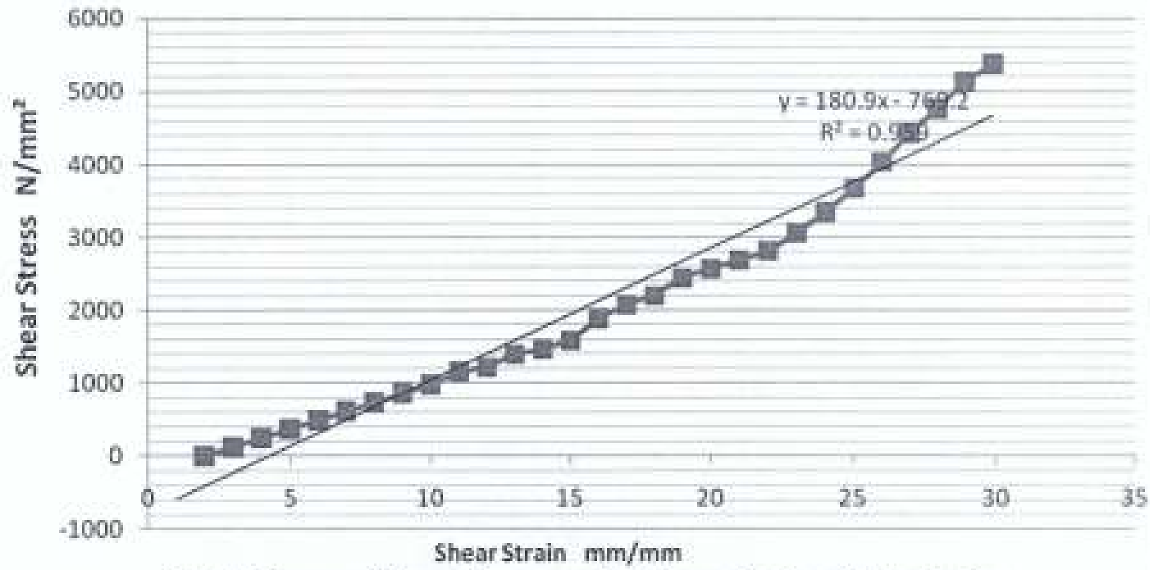


Fig. 4.1 Curve of Shear Stress against Shear Strain of Aluminium

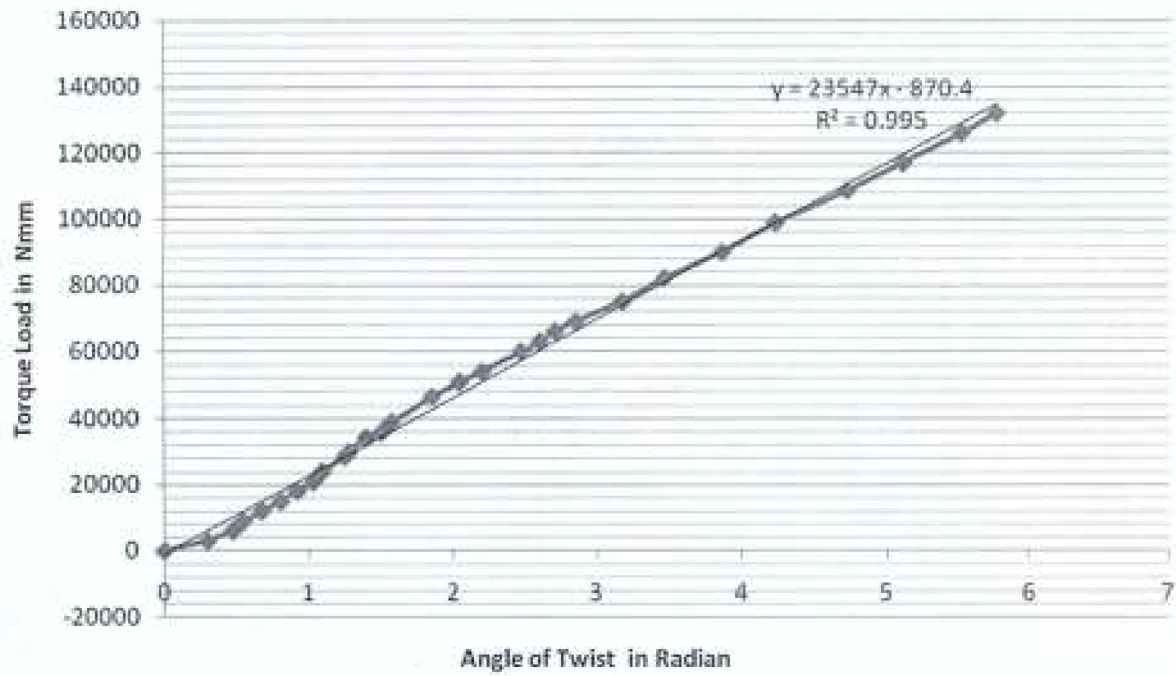


Fig 4.2 Curve of Torque Load against Angle of Twist of Aluminium

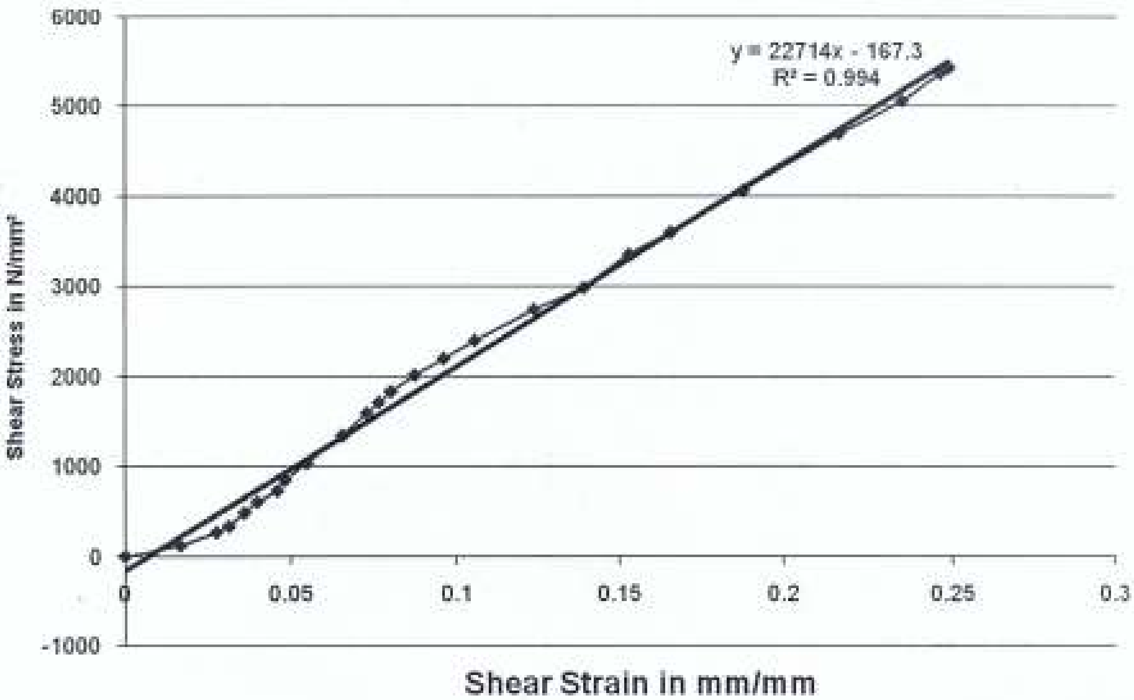


Fig. 4.3 Curve of Shear Stress against Shear Strain of 5.0 mm Diameter Brass

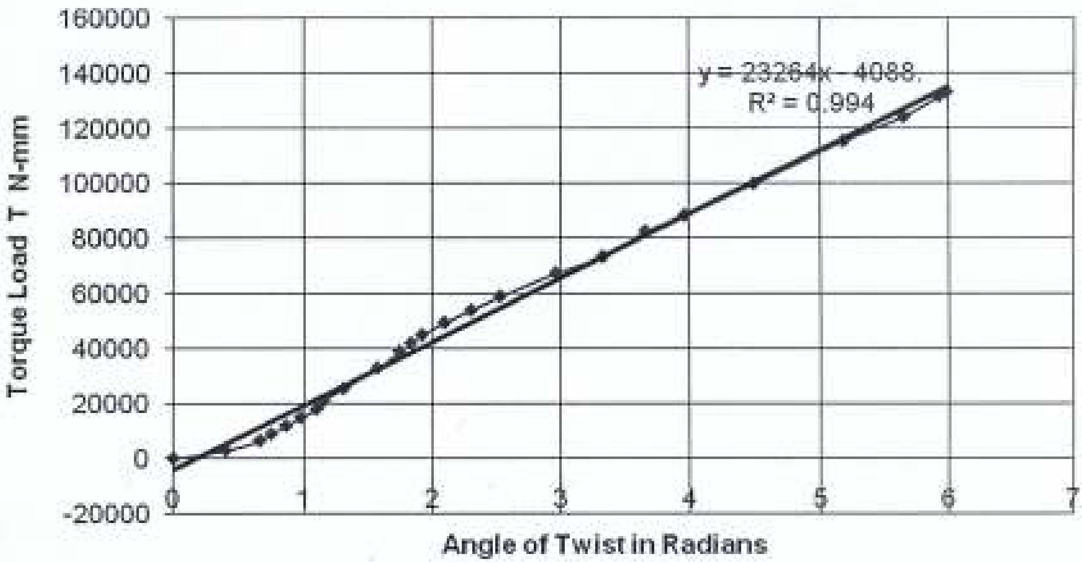


Fig. 4.4 Curve of Torque Load Against Angle of Twist of 5.0 mm Diameter Brass

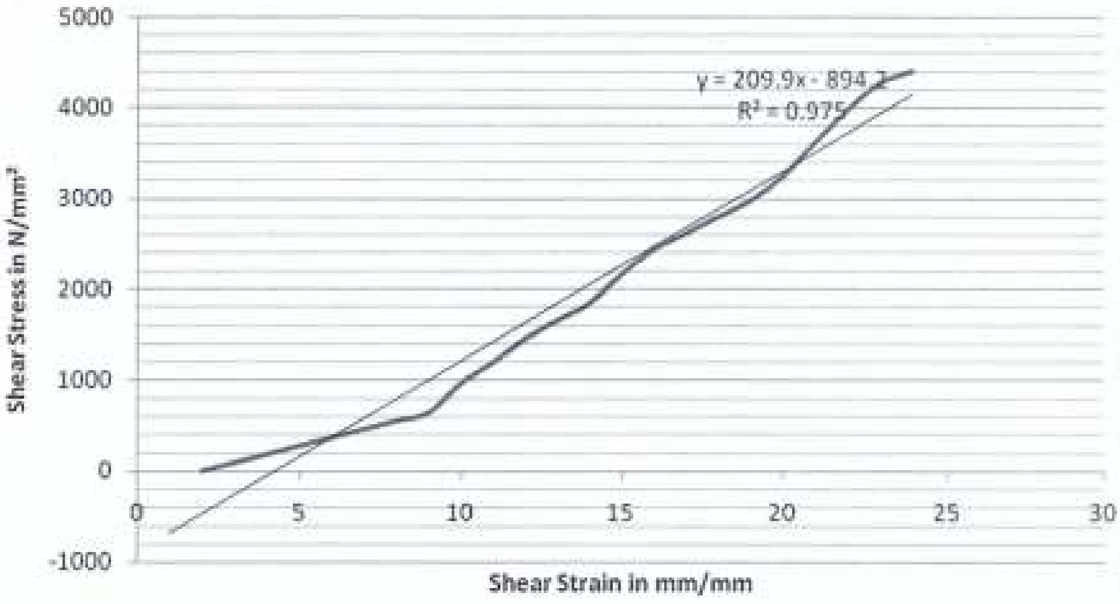


Fig. 4.5 Curve of Shear Stress against Shear Strain of Mild-steel

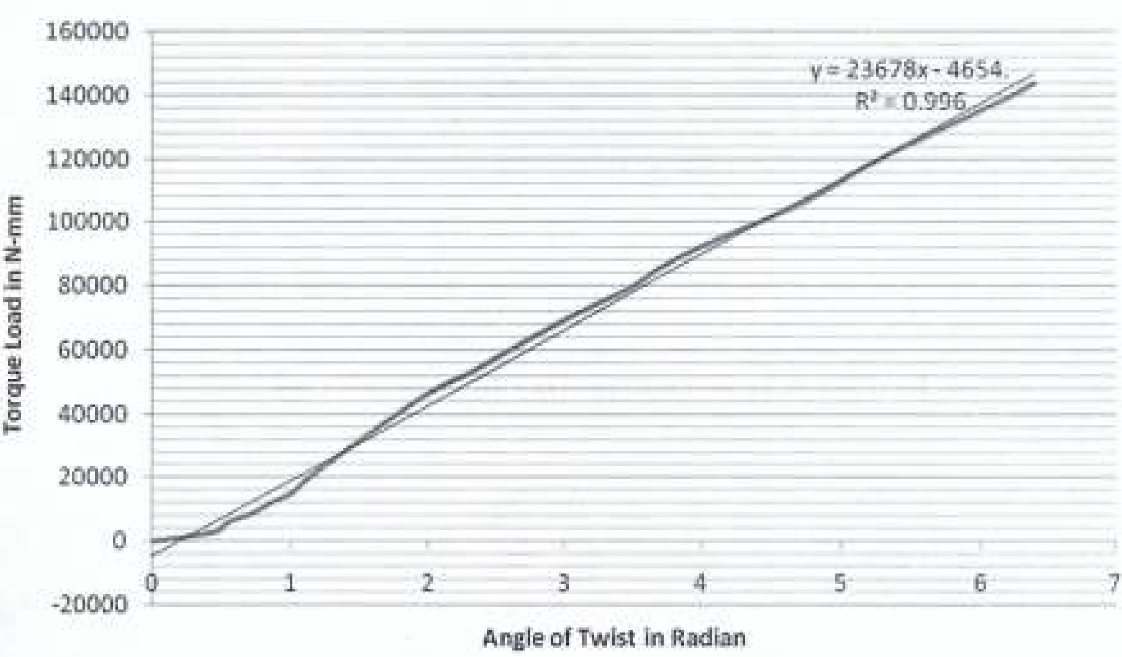


Fig.4.6 Curve of Torque Load against Angle of Twist of Mild-steel

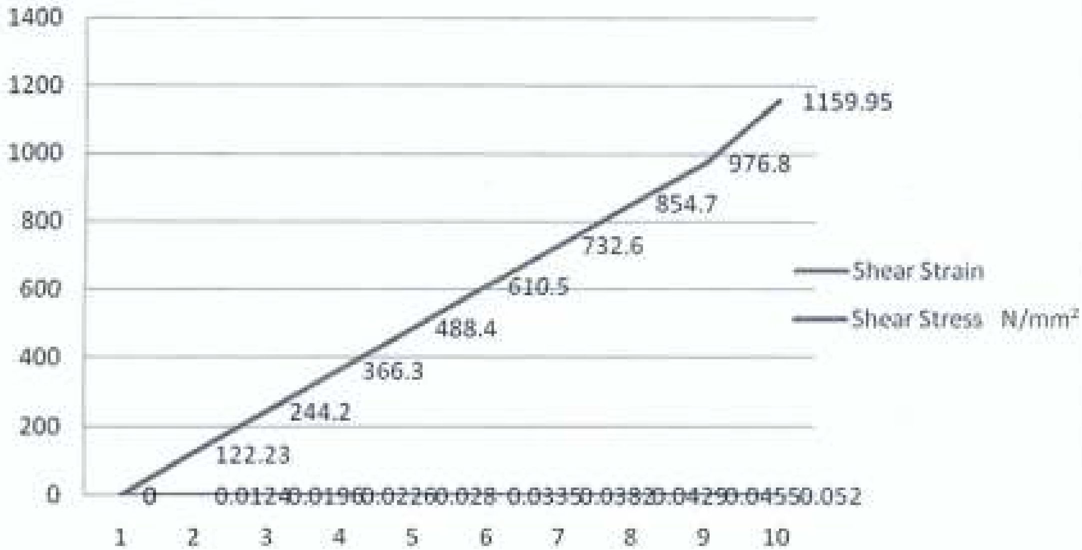


Fig. 4.7 Curve of Elastic Shear Stress of Aluminium

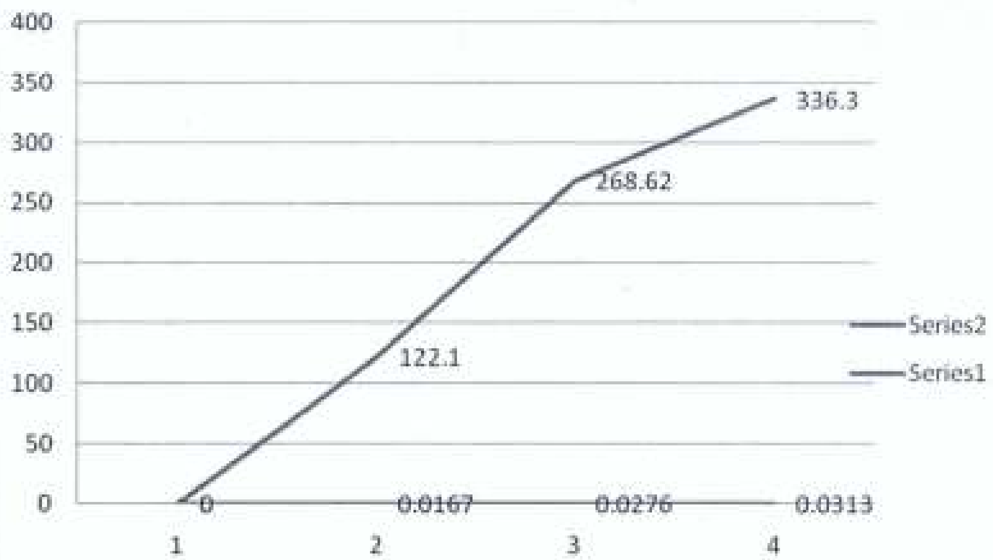


Fig. 4.8 Curve of Elastic Shear Stress of Brass

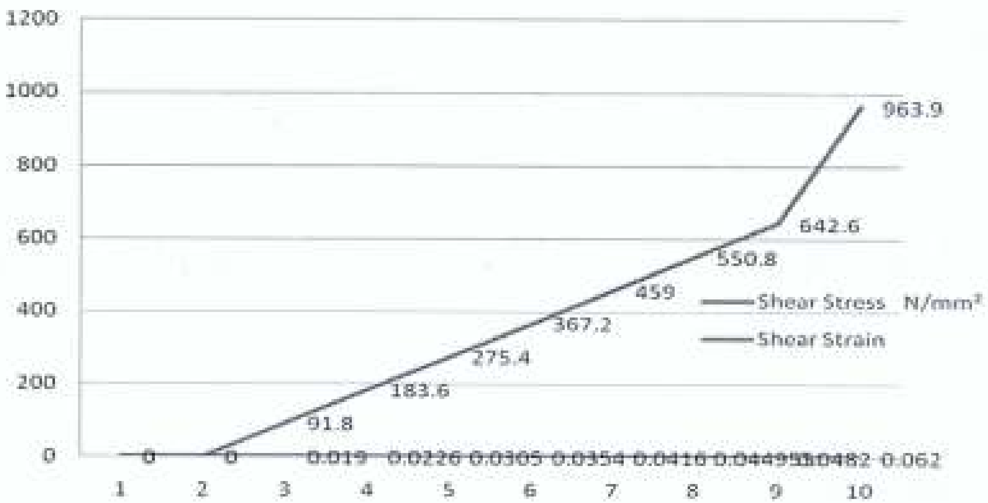


Fig. 4.9 Curve of Elastic Shear Stress of Mild-steel

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

A manually operated bench-top torsion testing machine of 150 N-m torque load capacity was developed. The machine was designed to perform pure torsion test on metal rods of diameters ranging from 5.0 mm to 5.5 mm or less. Based on these, two Jacob chucks of capacity 1.5 mm – 10.0 mm were selected to provide gripping force for specimens. A calibrated spring balance was used to measure the applied load on the system, while the principle of moment determined the twisting forces (i.e. torque loads), obtained by multiplying the length of the lever-arm measured from the fulcrum by the spring force. The machine elements such as the base-plate, the straining/rotating unit, the fixed-end unit, the strain indicator and the load indicator unit were designed based on the maximum torque load capacity obtained.

Mild-steel material was used in fabricating the machine components such as bearing block, fixed-end blocks, base-plate, barrel, barrel-shaft, and the lever-arm. Aluminium plate was used in producing the angle scale of the strain indicator unit while the locking screw-wheel of the fixed-end unit was made from cast-iron. The machine was entirely produced from machining and fabrication processes.

The test, based on ASTM 143 -63 Standards, was conducted on the machine with a sample each of aluminium, brass and mild-steel specimens. The diameter (mm), gauge length (mm) and total length (mm) of the three specimens were ϕ 5 x 60 x 90, ϕ 5 x 60 x 90 and ϕ 5.5 x 66 x 99 respectively. The experimental shear moduli obtained from the test shown that Aluminum has 23,205.92 N/mm^2 (16% less than expected), Brass has

21,498.06 N/mm^2, (43% less than expected) and Mild-steel has 15,773.10 N/mm^2 (80% less than expected).

5.2 RECOMMENDATIONS

Since torque exist in two forms- static and dynamic form. They are therefore measured in two ways, namely; in-line torque measurement and reaction torque measurement. The existing conventional material torsion testing machines employed reaction method, while the design of this thesis was based on the in-line method in order to simplify design, minimize cost and optimize laboratory space. The results obtained from the tests, however, suggest a re-investigation into the load measuring unit, as the applied torque load may be higher than the one being measured. Also, future research efforts could be based on the use of electrical strain gauges.

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