Experiment 2

Torsion Test of Mild Steel Solid Shaft

Aim: To determine the yield point, breaking torque and modulus of rigidity.

Apparatus Required:

1. Torsion test specimen
2. Scale
3. Micrometer/Vernier calliper
4. Torsion-testing machine
5. Troptometer (optional)

Theory: Whenever a solid circular shaft is subjected to torsional moment, *shear stress* is developed within it as shown in Figure 1.

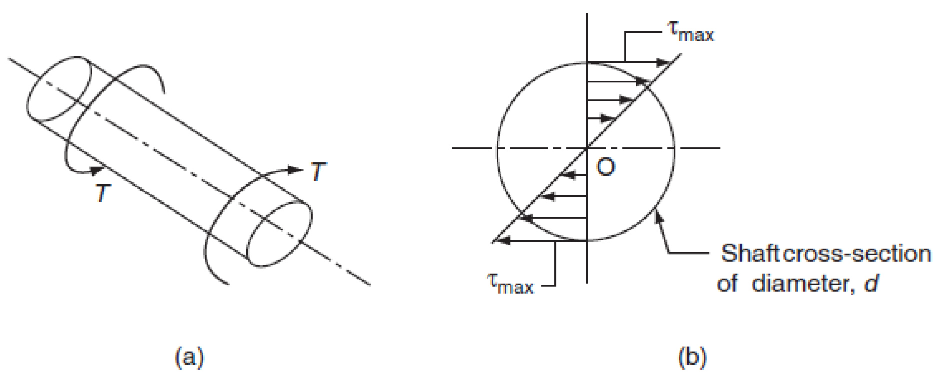

Figure 1 Solid Shaft subjected to torsion: (a) Shaft under torsion, (b) shear stress in shaft.

The shear stress is not uniformly distributed across the section, rather it is linearly distributed being 0 at the centre and maximum at the outermost radial location. Maximum shear stress is given by the equation for a solid circular shaft of diameter, *d*:

$$\tau_{\max} = \frac{16T}{\pi d^3} \tag{1}$$

If one end of the shaft is fixed, then the other free end is twisted due to the section of torque, *T* gets twisted as shown in Figure 2. A line AB scribed on the shaft before twisting assumes the position AB′ and at the center of the shaft describes

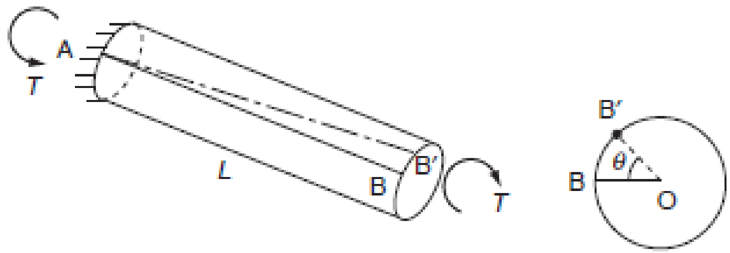

Figure 2 Twisting of shaft.

an angle ∠BOB′ = θ, which is known as the *angle of twist*. It is given by the equation:

$$\theta = \frac{TL}{GJ} = \frac{32TL}{G\pi d^4} \tag{2}$$

Here, L represents the specimen length, d is its diameter and G is the *modulus of rigidity*. It is to be remembered carefully that the above Eqs. (1) and (2) are valid so long as the stress is proportional to strain, that is, as long as torque T is within the *proportional limit*. If we apply increasingly more torque, the specimen continues to be more stressed with more twisting. Soon the maximum shear stress reaches the *yield point*. Now, further increase in torque will make the next lower shear stress to reach the yield point and the process continues till the entire cross-section reaches uniform shear stress distribution. At this point, the shaft is said to be *fully plastic* and the corresponding torque is called *plastic torque*. The following figure (Figure 3) shows the stress distributions when partial yielding has occurred and also when the total yield has taken place.

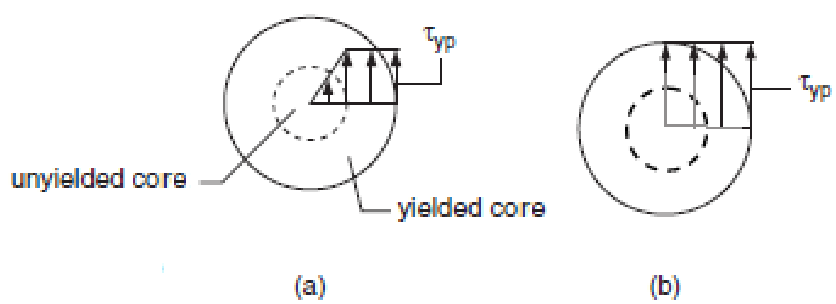

Figure 3 Shaft stresses at yielding: (a) Partial yielding, (b) complete yielding. r

If d' be the diameter of the unyielded core as shown in Figure 3(a), then the corresponding torque T can be calculated as:

$$
\begin{aligned}
T' &= \int_0^{d'/2} \frac{2\tau_{\mathrm{yp}}}{d'}\rho^2(2\pi\rho)\,\mathrm{d}\rho + \int_{d'/2}^{d/2} \tau_{\mathrm{yp}}\rho(2\pi\rho)\,\mathrm{d}\rho \\
&= \left(\frac{4\pi\tau_{\mathrm{yp}}}{d'}\right)\int_0^{d'/2} \rho^3\,\mathrm{d}\rho + (2\pi\tau_{\mathrm{yp}})\int_{d'/2}^{d/2} \rho^2\,\mathrm{d}\rho \\
&= \frac{\pi\tau_{\mathrm{yp}}d'^3}{16} + \frac{\pi\tau_{\mathrm{yp}}}{12}(d^3 - d'^3) \\
&= \frac{\pi\tau_{\mathrm{yp}}d^3}{12} - \frac{\pi\tau_{\mathrm{yp}}d'^3}{48}
\end{aligned}
$$

or

$$
T' = \frac{\pi\tau_{\mathrm{yp}}d^3}{48}\left(4 - \frac{d'^3}{d^3}\right) \quad 0 \le d' \le d \tag{3}
$$

Obviously, at the beginning of yielding, $d' = d$ and at the end of the yielding, $d' = 0$. Thus, if T_{yp} indicates the torque level when the shaft just starts to yield and if T_{plastic} indicates the torque when the shaft becomes fully plastic, then from Eq. (3), we can say

$$
T_{\mathrm{plastic}} = \frac{4}{3}T_{\mathrm{yp}} \tag{4}
$$

If we go on increasing the torque value beyond the yield point, the shear stress becomes a *non-linear function of the shaft's angle of twist*. Even then, when the torque becomes *ultimate* and the specimen is about to fracture, a linear relation is assumed between stress and strain and subsequently, a parameter known as the *modulus of rupture*, M_{T}, is calculated using the equation:

$$
M_{\mathrm{T}} = \frac{16T_{\mathrm{u}}}{\pi d^3} \tag{5}
$$

This data is used in the testing of shafts quite often.

Test Method:

1. The diameter and length d and L of the test specimen are measured. Figure 4 shows a typical torsion test specimen.

2. The test specimen is mounted in the torsion testing machine, as shown in Figure 5, such that, one end of the specimen is fixed and the other end is free. During testing, the free-end of the specimen is twisted by turning the handwheel slowly.

3. A circular Vernier scale attached to the free-end measures the angle of twist. Sometimes, a dedicated instrument, known as the *troptometer* is employed to measure the angle of twist.

4. From the torque recording unit of the machine for a given angle of twist, corresponding torque value is measured.

5. Steps 3 and 4 are repeated to get sufficient data for the linear zone and to calculate the modulus of rigidity at a later stage.

6. Application of angle of twist in steps like 90°, 180°, 270°, …. are continued to be applied at the free-end of the specimen by the torque application unit and the corresponding torque are read-off. After some time of the continued application of twisting, the specimen breaks off and the breaking or ultimate torque is measured.

7. Broken pieces of the specimen are collected and the fractured surface is examined carefully.

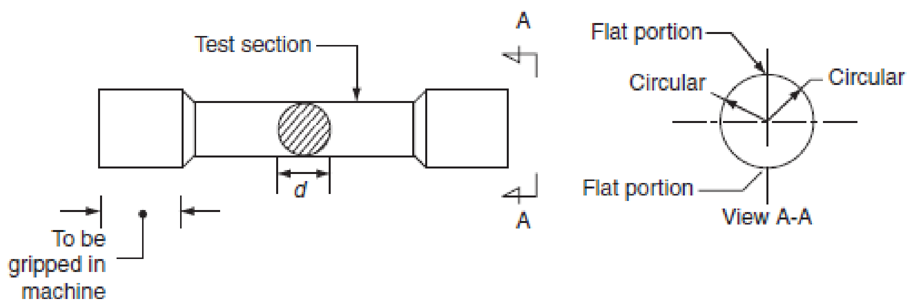

Figure 4 A typical torsion specimen.

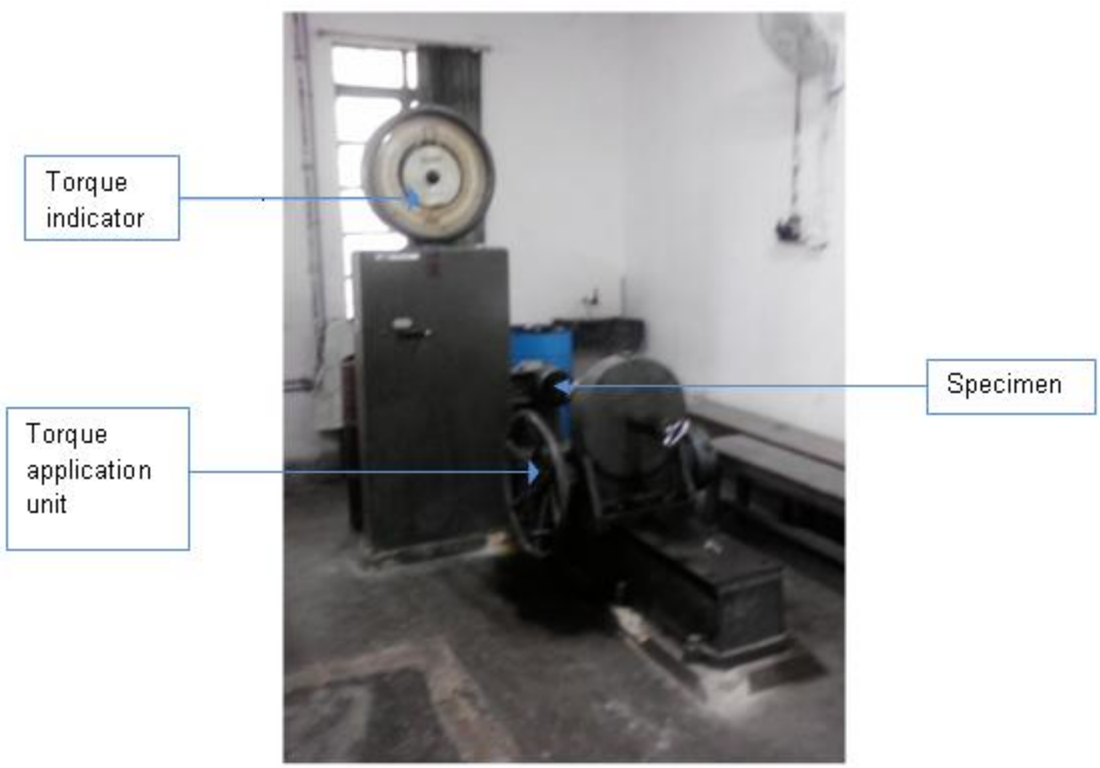

Figure 5 Torsion testing machine.

(*Photo Courtesy*: Applied Mechanics Laboratory, Mechanical Engineering Department, Jadavpur University, Kolkata)

Observed Data: The following table is prepared:

Sl. No.	*Angle of Twist (θ)*	*Torque from Scale*

The above results are plotted to show the variation between the torque *T* and the angle of twist θ. A typical plot is shown in Figure 6.

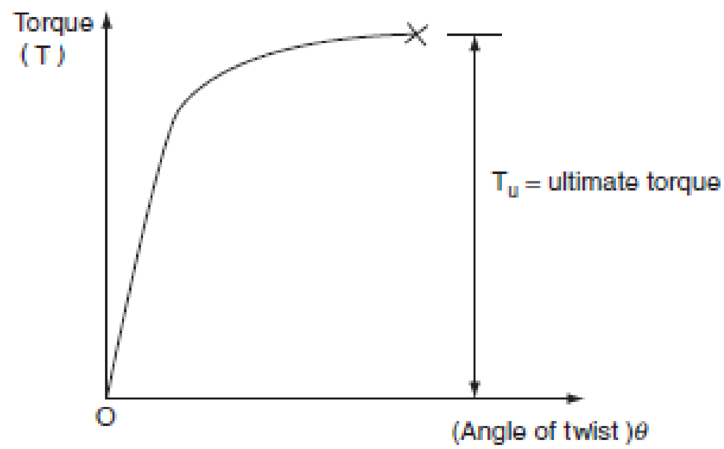

Figure 6 *T* vs. θ diagram.

Results: The following table is prepared for the linear zone.

Shear Stress $\tau = \dfrac{16T}{\pi d^3}$	*Shear Strain* $\gamma = \dfrac{d\theta}{2L}$	*Modulus of Rigidity* $G = \tau/\gamma$	*Average Modulus of Rigidity*

Fractured surface: A ductile specimen has failure surface as shown in Figure 7(a).

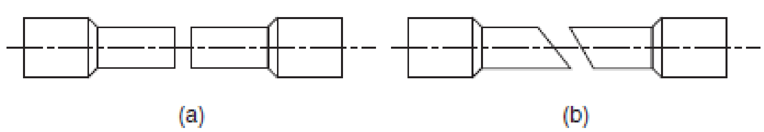

Figure 7 Fractures of torsion specimen.

Figure 7(b) shows the nature of a brittle specimen (e.g., cast iron)

Comparison between Tension and Torsion Test

Tension test and Torsion test are the two fundamental tests to determine two important elastic constants namely, *E* and *G*, that is, *modulus of elasticity* and *modulus of rigidity*, respectively. If a ductile specimen like mild steel is used for both tests, we get certain characteristics of the tests, which are:

1. In tensile testing for perfect centric tensile load, stress distribution across the section is uniform. However, in case of torsional test, stress is non-uniformly distributed across the section. This is true for other types of specimen also.

2. In tension test, there is elongation of the specimen and its cross-section is subjected to *necking*. But in case of torsion, the specimen does undergoes neither any elongation nor any necking.

3. Due to (2), the breaking load is lower than the maximum or ultimate load. However, in case of torsion, no such lowering of torque value occurs.

4. In case of tension test, *cup-and-cone* shape is obtained at failure, while, in torsion failure, no such shape is obtained and the specimen fails transversely [refer Figure 7(a)]. It is to be noted that reverse nature of failure surface will be obtained if a brittle specimen is used for both the tests.

5. It is to be kept in mind that torsion test is not as popular and well-accepted as the tensile testing is.

6. Better prediction of ductility can be obtained through torsion test in comparison to a tensile test.