Compression Test

The goal of a compression test is to determine the behavior or response of a material while it experiences a compressive load by measuring fundamental variables, such as, strain, stress, and deformation. Uniaxial compression tests provide much of the same information about material properties as tension tests. By testing a material in compression, the compressive strength, yield strength, ultimate strength, elastic limit, and the elastic modulus all be determined. With the understanding of these different parameters and the values associated with a specific material it may be determined whether or not the material is suited for specific applications or if it will fail under the specified stresses.

The compression test specimen is comparatively simple in shape, and the length of the test piece should not be too great, because it is necessary to avoid buckling. The compression test specimen either a cylinder with a ratio of length to diameter $L/D < 2$ to avoid non-axial motion, or the specimen may be in the form of a cube.

Compression tests are used if in-service forces are of this type. Also, they are used when the material is brittle in tension (such as concrete, Gray cast iron), or when a material's behavior under large and permanent strains is desired, as in metal-forming applications.

Simple tensile testing usually produces sufficient data to determine the mechanical properties of ductile materials. In those materials, the yield limits under tension and compression are generally the same. Therefore, it is not necessary to perform the compression test on highly ductile materials such as mild steel or most Al-alloys. On the other hand, in some materials such as brittle and fibrous ones, the tensile strength is considerably different from compressive strength as seen in Figure 1. Therefore, it is necessary to test them under tension and compression separately.

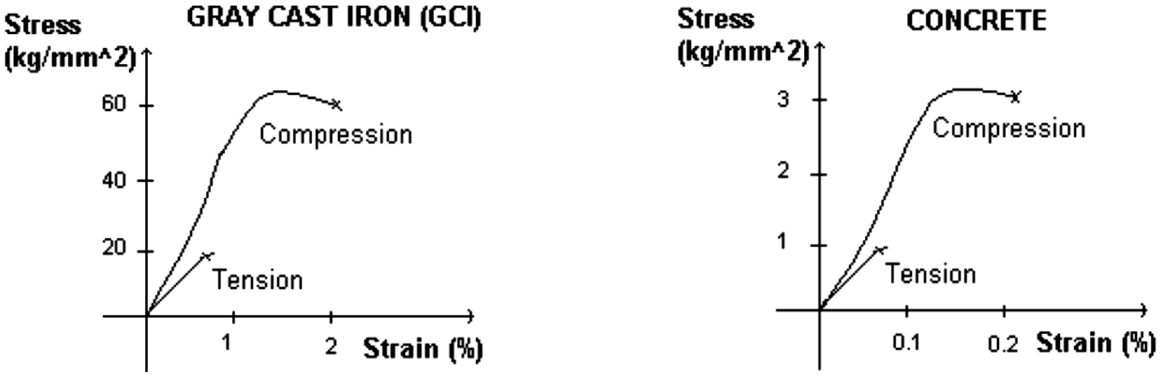

Figure 1: Compression and Tension stress-strain curves for (a) GCI and (b) Concrete

Brittle materials, such as cast iron and concrete, are often weak in tension because of the presence of submicroscopic cracks and faults. However, these materials can prove to be quite strong in compression, due to the fact that the compression test tends to increase the cross sectional areas of specimens, preventing necking to occur, and cracks tend to remain closed in compression. In compression, a single large flaw is not fatal (as it is in tension). Often, it is found that brittle materials fail at much higher compressive stresses than tensile stresses (Table 1), although ductile materials such as metals may have tensile and compressive strengths that are nearly equal.

Table 1: Comparison of the tensile, compressive, and flexural strengths of selected ceramic materials

Material	Tensile strength, MPa	Compressive strength, MPa
$A1_2O_3$	207	2586
SiC	172	689

A compression test is conducted in a manner similar to the tensile test, except that the force is compressive and the specimen contracts along the direction of the stress.

Brittle materials in compression typically have an initial linear region followed by a region in which the shortening increases at a higher rate than does the load. Thus, the compression stress – strain diagram has a shape that is similar to the shape of the tensile diagram. However, brittle materials usually reach much higher ultimate stresses in compression than in tension. Brittle materials in compression behave elastically up to certain load, and then fail suddenly by splitting or by cracking in the way as shown in Figure 2.

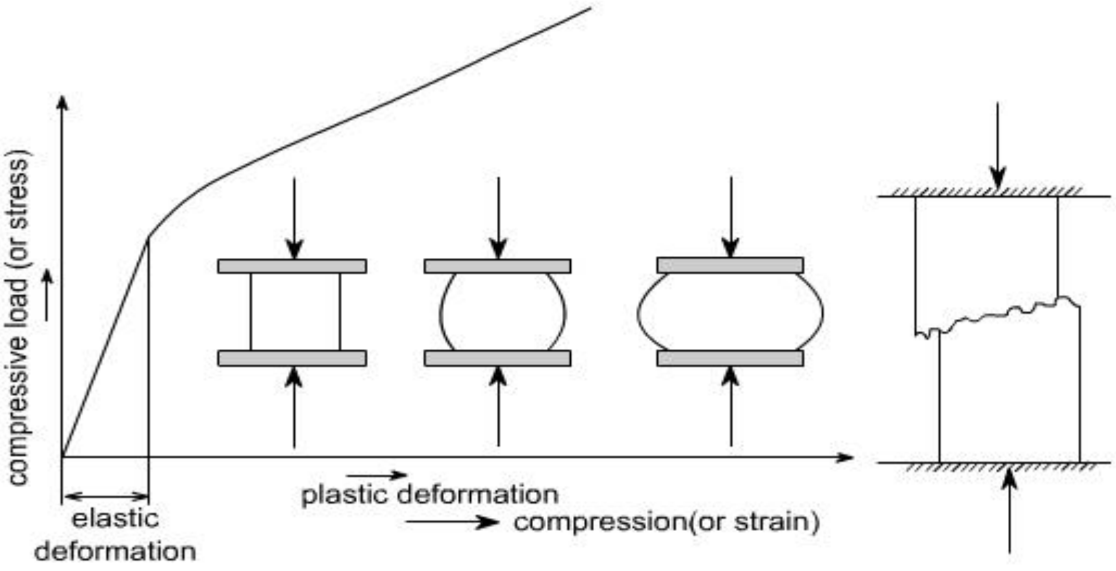

Figure 2: Compression stress-strain curve

Caution must be taken during compression testing to minimize friction between the loading platen and the specimen because friction will provide an artificial resistance to ΔA and will therefore make the material appear stiffer and stronger than it actually is. Even after plastic deformation has begun, the true stress -true strain curve from a well-run compression test of a metal should closely match that of tensile test, although the engineering curve will not because of tensile necking.

One potential advantage of compression testing is the avoidance of necking instability, so larger strains can often be imposed than are possible under tension. This can also be seen as a drawback if aspects of the necking behavior and ensuring tensile fracture are of interest. Compression testing also avoids early failure due to brittle cracking in ceramic materials.

Nonaxial Testing

In addition to axial tension and compression, engineering components may be subjected to bending, shearing and torsion. Standardized tests for evaluating material response under these load conditions are well developed. While bend testing can be used to measure Young's Modulus E much like tension or compression testing, shear and torsion tests are used to measure G, a quantity known as the shear modulus.

Shear and Torsion Testing

Shearing is defined as the application of load in opposite directions along two parallel surfaces. As displacement occurs, the parallel surfaces remain parallel to one another, but are shifted. Note that an extra pair of vertical shear forces in Figure 1 must be presented to avoid free-body rotation.

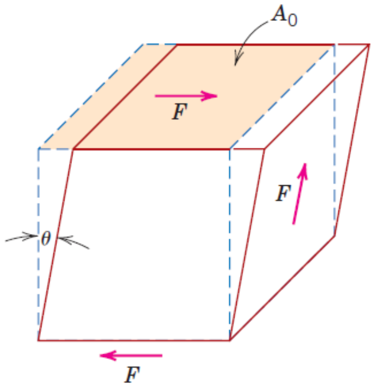

Figure 1: Pure shear loading

Hook's law is still obeyed under shear by linear elastic materials, but for an isotropic material the ***shear stress* τ** and the **shear strain γ** are related by the shear modulus G such as:

$$\tau = G\,\gamma \qquad (1)$$

The shear stress is given by

$$\tau = \frac{F}{A} \qquad (2)$$

The shear strain is defined by the ***shear angle θ***, such as:

$$\gamma = \tan\theta \qquad (3)$$

The units for shear stress and strain are the same as for their tensile counterparts.

There is no change in the area over which the force is imposed during pure shear loading, so there is no distinction made between engineering and true stresses.

Many cases of shear loading can be found in real components. As an example, shear loading in the rivets holding two overlapping plates together when the plates are pulled or pushed in opposite directions. In bonded lap joints, the shear load is borne by the adhesive layer holding two parts of the joint together. Shear test is shown in Figure 2

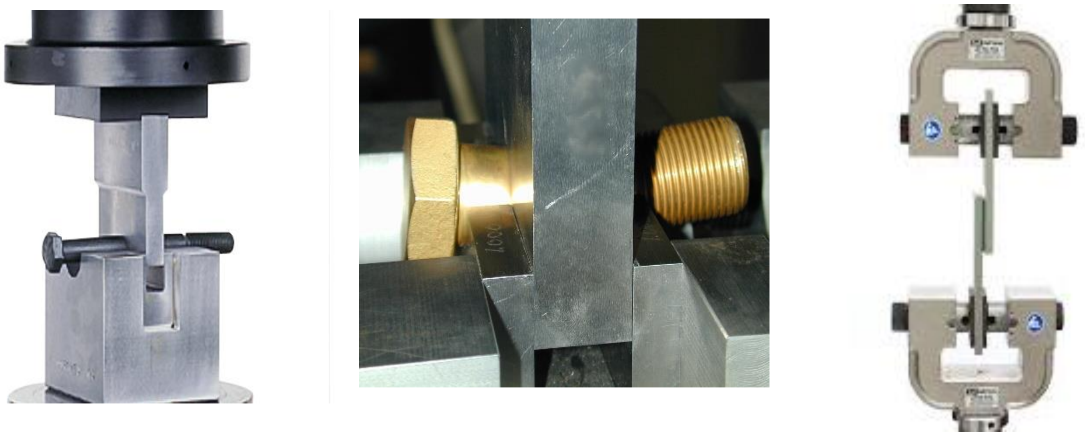

Figure 2: Shear test

Torsion loading is the application of a torque force such that a member is twisted about its axis. Many products and components are subjected to torsional forces during their operation. It is common in rotating shafts. By testing these products in torsion, manufacturers are able to simulate real life service conditions, check product quality, verify designs, and ensure proper manufacturing techniques. This test is generally carried out on cylindrical or tubular specimen with a reduced mid-section, Figure 3. A typical torsion test specimen is mounted between the two heads of a machine, shown in Figure 4, and is twisted.

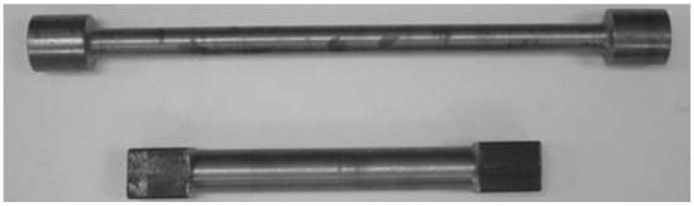

Figure 3: Torsion test specimens

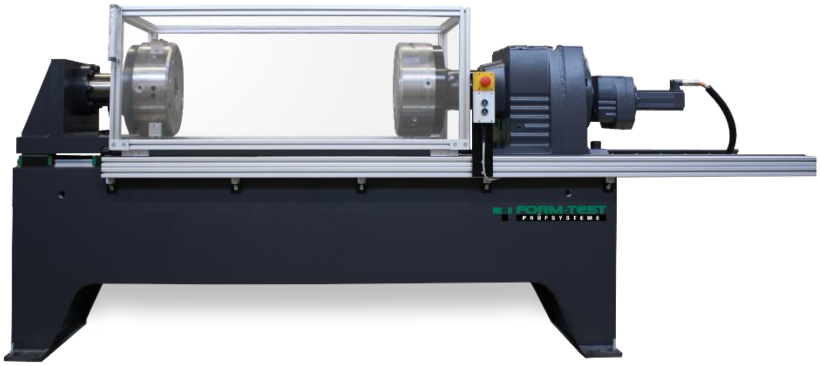

Figure 4: Torsion test Machine

Torque vs angle of twist is obtained from torsional test. In fact, the "torque versus angle" diagram looks very similar to a "stress versus strain" curve that might be generated by a tensile test, Figure 5.

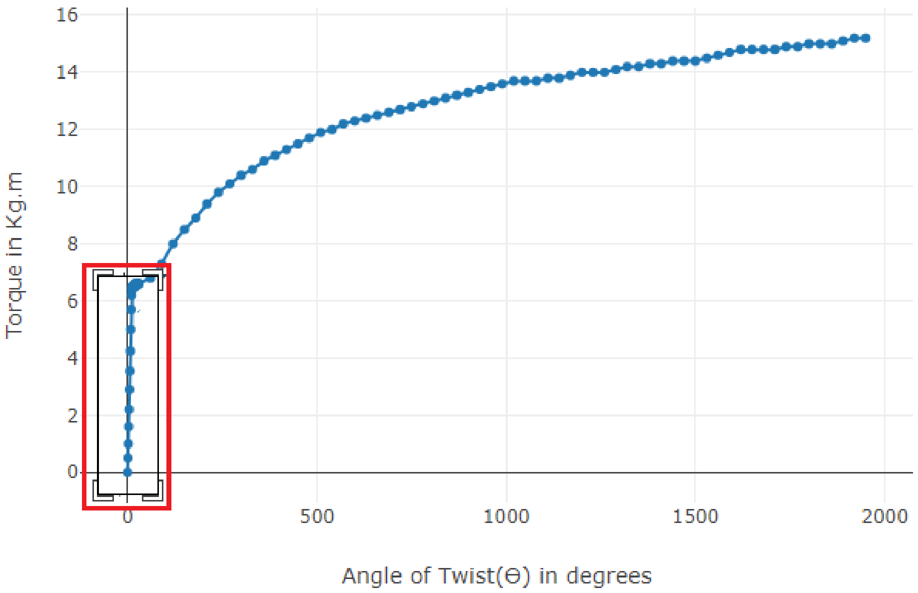

Figure 5: Torque vs angle of twist diagram of mild steel

Torsion loading results in shear stresses and strains that are calculated in essentially the same manner as for pure shear, except that they are defined in terms of the ***torque T***, ***the distance from the shaft axis r***, and ***the rotational twist angle*** Φ (in radians). The shear stress varies from zero along the axis to its maximum value at the outside surface of the shaft in the form

$$\tau = \frac{T\,r}{J} \qquad (4)$$

Where J is the polar moment of inertia. The polar moment of inertia for a circular solid shaft is

$$J = \frac{\pi D^4}{32} \qquad (5)$$

And for a circular hollow shaft

$$J = \frac{\pi (D^4 - d^4)}{32}$$

Where D and d are the outer and Inner shaft diameters, respectively. The twist angle Φ varies with position along the length of the shaft, ranging from zero at the fixed end to a maximum at the end to which the twisting moment is applied, Figure 6.

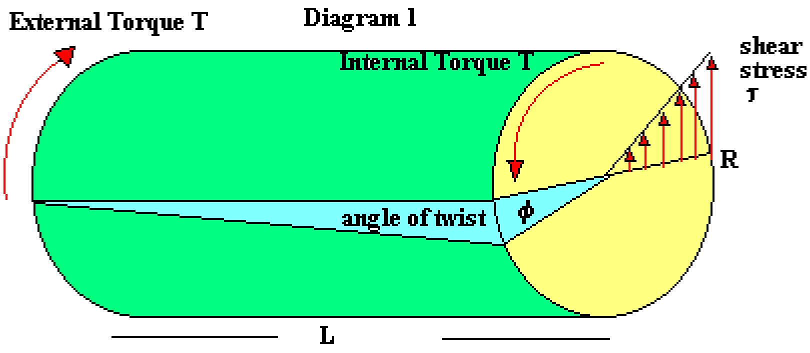

Figure 6: Torsion member

Bend Testing

Although bend testing is an option for metals and polymers, flexural test methods are most frequently used to determine the elastic behavior and strength characteristics of ceramic and glass compound. This arises from the fact that ceramics and glasses usually display essentially plastic deformation and, as such, the mechanical response of these materials is very sensitive to the presence of complex sample shapes that introduce stress concentrations. Stress concentrations can cause premature failure, thereby limiting the usefulness of the standard tensile bar in this case. By contrast, bend bars have a smooth configuration, are easy to machine and test, and require simple load fixtures. The three and four-point methods represent two common loading configurations, Figure 7.

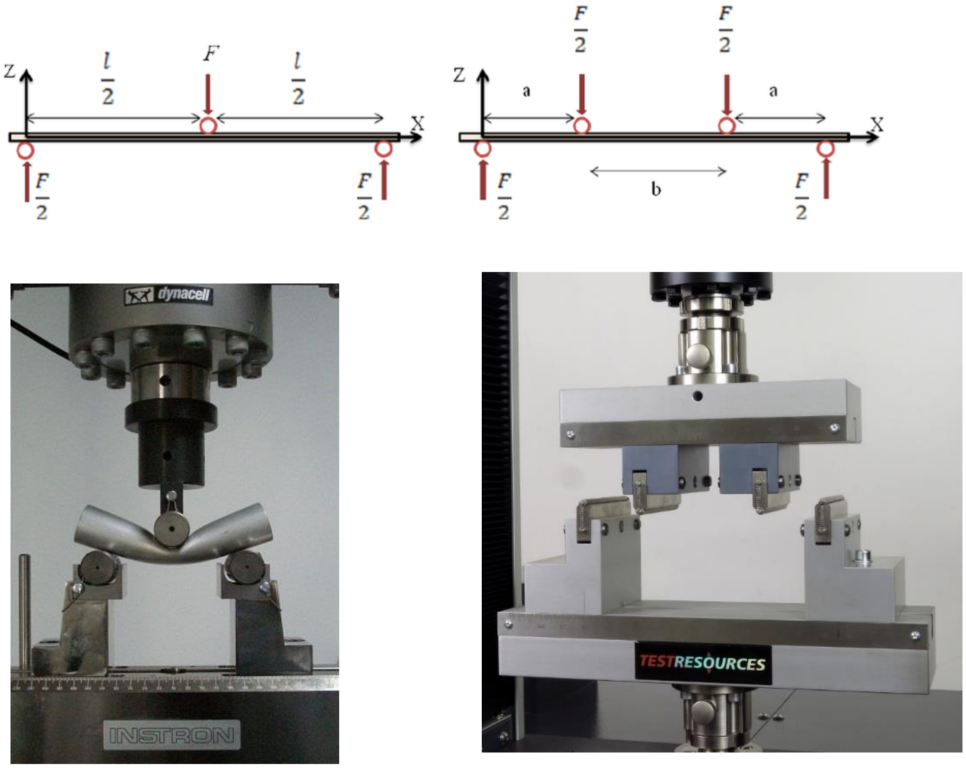

Figure 7: The three and four-point methods loading configurations

Under tensile or compressive loading parallel to the axis of some uniform load-bearing member, the stresses are typically constant over the entire component. In bending, however, when stresses are applied normal to the component main axis the axial stress (i.e., in the L direction) varies from one location to another within the beam. The surface on one side of the beam will be in compression, while the other side is under tension. The stress through the thickness of the beam varies linearly between the surface compression and tension stress values, with zero stress at the neutral axis.