Experimental Methods of Materials Testing in Tension and Compression

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Abstract

Tensile testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. On the other hand, a compression test is a method for determining the behavior of materials under a compressive load. Compression tests are conducted by applying a force to a material and measuring its response.

One of the main reasons why tensile testing is considered better than compression testing is its ability to test material ductility. Ductility is the ability of a material to deform under tensile stress, and it is an important property for many applications. Tensile testing provides a clear and accurate measure of a material's ductility by measuring the elongation and reduction in the area of the sample as it is pulled apart. This information is crucial for understanding how a material will perform in real-world applications where it may be subjected to tensile forces.

In contrast, compression testing does not provide a direct measure of ductility. While it can provide information about a material's compressive strength and stiffness, it does not give a clear indication of how the material will behave under tensile stress. This limitation makes compression testing less useful for applications where ductility is a critical factor.

Another advantage of tensile testing is that it can be used to determine other important material properties, such as tensile strength, yield strength, and Young's modulus. These properties are essential for understanding how a material will perform under different types of loads and can be used to predict its behavior in various applications. Compression testing, on the other hand, is limited to measuring compressive strength and stiffness, which are not as widely applicable.

Tensile testing is also more versatile than compression testing. It can be performed on a wide range of materials, including metals, plastics, and composites, and can be used to test both small samples and full-scale components. Compression testing is typically limited to materials that can withstand compressive loads without buckling or collapsing, which excludes many materials that are commonly used in engineering applications.

Furthermore, tensile testing is a more standardized test method, with well-established procedures and equipment. This standardization makes it easier to compare results from different tests and to ensure that tests are conducted consistently and accurately. Compression testing, on the other hand, is less standardized, which can make it more difficult to compare results and to ensure the accuracy of the test.

Keywords: Working Portion of the Specimen; Testing Machines; Effect of Rate of Loading; Gauge Length and Cross – Sectional Area; Overstrain; Proof Stress; Failure in Brittle Materials.

1. Introduction

Materials testing is a popular and well-known field of measurement to obtain physical and mechanical properties of materials from powders or raw materials, components and composite finished products. It is a wide-ranging field offering force and distance (stress/strain) measurement solutions from the tension of a shoelace to the crush resistance of cardboard packaging, the actuation force of switches to the measurement of friction between two materials.

Materials testing breaks down into five major categories: mechanical testing; testing for thermal properties; testing for electrical properties; testing for resistance to corrosion, radiation, and biological deterioration; and nondestructive testing.
The experimental procedure for tensile test is as follows: A material is gripped at both ends by an apparatus, which slowly pulls lengthwise on the piece until it fractures. The pulling force is called a load, which is plotted against the material length change (extension), or displacement. The load is converted to a stress value and the displacement is converted to a strain value.
Tensile testing is a fundamental type of mechanical testing performed by engineers and materials scientists in manufacturing and research facilities all over the world. A tensile test (or tension test) applies force to a material specimen in order to measure the material's response to tensile (or pulling) stress.
A tensile tester is used to measure tensile strength. A load cell is fitted to the tensile tester to measure tensile force. In addition, a tensile test is commonly used to measure other properties of materials such as Young's modulus of elasticity, yield stress, elongation, strain and ultimate tensile stress.
Compression testing is a widely used mechanical test that provides valuable insights into the behavior of materials when subjected to compressive loads. The test is essential in selecting the right material for various applications in industries such as aerospace, automotive, and construction. In a compression test, a sample of the material is placed between two plates or jaws of a testing machine. A compressive force is applied to the sample until it reaches a specific deformation or until it fractures. The machine, a deflectometer or an extensometer, can be used to measure the deflection or strain of the sample.
Compression testing's objective is to ascertain a material's behavior or response to a compressive load by measuring key parameters such as strain, stress, and deformation. Compressive testing allows for the determination of a material's compressive strength, ultimate strength, yield strength, elastic modulus, and elastic limit among other properties. Once these various factors and the values associated with a particular material are understood, it is possible to assess whether or not the material is suitable for a given application or whether it will fail under the given stresses.
Compressive testing works by subjecting a material to a compressive force until it reaches a specified deformation or until it fractures. The process typically involves the following steps:
Preparation of the Sample: A sample of the material to be tested is selected and prepared according to the testing standard. The sample may be a cylindrical or cubical shape, depending on the requirements of the test.
Mounting of the Sample: The sample is mounted between two plates or jaws of a testing machine. The machine may use hydraulic, pneumatic, or mechanical force to apply pressure to the sample.
Application of Force: A compressive force is applied to the sample at a constant rate until it reaches a specified deformation or until it fractures. During the test, the applied force and the resulting deformation are measured and recorded.
Analysis of the Results: The data collected during the test is used to calculate various properties of the material, including compressive strength, elastic modulus, and deformation characteristics [1] – [27].

2. Tensile Tests

The behavior of a ductile material, such as mild steel, when it is subjected to a slight tensile stress explained that, up to a certain value of the stress, the strain is proportional to the stress causing it, and when the load is removed during this range, there will be no permanent strain (i.e. the material is stressed in the elastic range). If the load increases, the material will undergo plastic strain at the constant stress value. If the load is increased further there will be obvious strain (i.e. mostly plastic) extending up to the maximum stress value. At this stage, the sample begins to neck in some places along its length (i.e. approximately in the middle of the sample) and the load decreases until fracture occurs. Most engineering materials display these features to varying degrees [1] – [9].

2.1 The Working Portion of the Specimen

It is either round or rectangular in cross-section, and is expanded at each end to a length suitable for grips. Screws can be cut at the ends of the sample to attach it to clamps, or a shoulder can be made for the sample through which the load is transferred, or it can be held with a wedge clamp with rough internal faces (wedge). The latter method is the simplest and cheapest to use and is almost used for flat samples, but is limited to soft steel and other materials. The clamps must be self-centering so that the load is applied axially and uniformly on the sample (i.e. for a circular cross section, eccentricity of 0.01d (1% of the diameter) in the load increases the maximum stress by 8%).

2.2 Testing Machines

It can be classified into two categories: the first category in which the load is placed manually, and the other category in which hydraulic pressure is used, where the choice depends more on the required capacity. In both cases, the load is measured with counterweights through a system of levers. Modern types of hydraulically operated testing machines are self-priming, where the balancing mechanism is activated by a piston operating in a cylinder supplied with the same pressure as the testing unit.

In the elastic range, strain is measured with an extensometer fixed to the standard length. It is a device that detects very small changes in length. A strain gauge can also be used. As for plastic strains, they are measured using a pair of dividers and graduated rule.

2.3 Effect of Rate of Loading

It was found that, with the exception of hardened steel, the faster the test speed, the greater the values of yield stress and maximum stress, and thus elongation were obtained.

2.4 Variation of Elongation with Gauge Length and Cross – Sectional Area

If the specimen has been marked for a large number of divisions along its length and tested to breakage, the two pieces can be connected to each other and the distance of each mark measured from one end. By subtracting the dimensions taken initially from those taken after fracture, we obtain the total elongation of one end. When the total elongation is plotted against the distance from that end, we get the diagram shown in Figure 1 below:

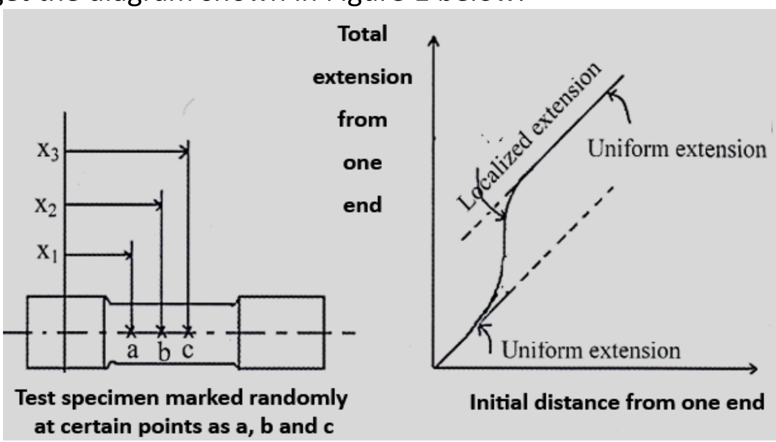

Figure 1 Variation of elongation with the original length of the specimen

Let e be the elongation over a standard-length l, considering that the fracture is approximately at the middle of the nominal length of the sample, so $e = a + bl$ expresses the shape of the diagram.

$$Percentage\ Strain = 100e/l = 100a/l + 100b$$

The scientist Unwin found that for a given material, the constant value a is proportional to the square root of the original cross-sectional area of the specimen A, and by writing it $C\sqrt{A} = 100a$ and $100b = B$, then the law becomes:

$$100\frac{e}{l} = \frac{C\sqrt{A}}{l} + B$$

The following values are given for the constants B and C for mild steel: $B = 20$ and $C = 70$. In order to avoid any error in comparing elongation figures, it is recommended, according to the British Institution for Standardization and Measurement B.S. 18, that the nominal length should be equal to $l = 4\sqrt{A}$.

2.5 Overstrain and Repeated Loading

In a tensile test of a mild steel specimen, if the load is carried beyond the yield point and then gradually released, there will be permanent deformation of the specimen.

Upon reloading it was found that upon close observation the steel seemed to have lost its elasticity, i.e. no longer obeying Hook's law. The fact that the release and reload curves form a hysteretic loop, which represents the energy lost in the internal friction of the material particles. Figure 2 below shows the stress-to-strain curve for a ductile material subjected to repetitive loading. The yield point will rise greatly until it reaches a value approximately equal to the stress value at the end of the tensile test, and the material is said to have been work hardened as in the cold drawing and rolling processes.

Repetitive loading will raise the yield point to a value approaching the maximum stress. If the specimen persists until fracture, it will display the same properties as hard steel with a small decrease in cross-sectional area and very low elongation.

Elasticity can be restored by a long period of rest or by boiling in water for a few minutes. Annealing will return the steel to its original state before excessive strain and at the same yield point.

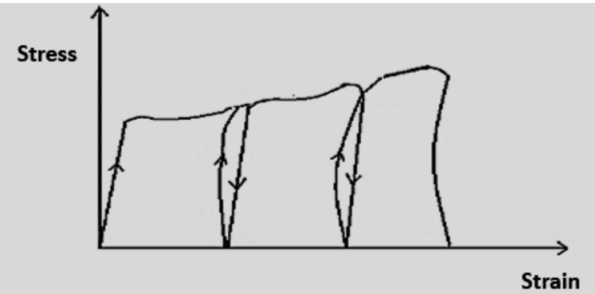

Figure 2 Stress-strain curve for a ductile material subjected to repeated loads

2.6 Proof Stress

Many engineering materials, including steel alloys and light alloys of aluminum and magnesium, do not have any specific limit of proportionality or point where they will undergo a tensile test, so the stress-strain diagram will be almost bent from the origin. Figure 3 below shows the stress versus strain curve for a brittle material.

If a tangent (OT) is drawn to the curve at the origin and a line PQ is drawn parallel to OT, intersecting the curve at Q, so that OP = 0.1%, then the stress at Q is called a 0.1% proof stress. Therefore, the proof stress is the stress in which the strain varies by 0.1% over the nominal length of the line of proportionality OT.

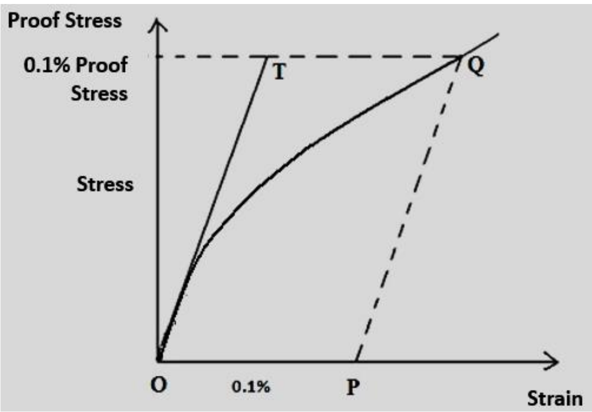

Figure 3 Stress-strain curve for a brittle material

3. Compression Tests

Compression test specimens for metals are usually circular, and for cement concrete they are square in cross-section. To prevent failure by buckling, the length must be approximately equal to the minimum width ($Length = minimum\,breadth$). For a ductile material such as mild steel or copper, there will be transverse deformation, and due to the effect of limiting friction at both sides of the load, the cross section will become large at the middle and the shape of the test piece will become similar to a barrel. Finally, failure occurs with cracks that appear on the outer tissue of the material and spread to the interior.

Brittle materials such as cast iron and cement usually fail in shear on planes inclined at an angle between 50 and 70 degrees relative to the longitudinal axis [10] – [22].

Failure in Brittle Materials

The fracture inclination angle for the brittle specimens is greater than 45 degrees.

$\theta = 45\,degree + \emptyset/2$, the angle of inclination of the fracture.

Where $\emptyset$ is the angle of internal friction of the tested metal.

The angle of internal friction $\emptyset$ is larger as the particles of the tested metal are larger.

Fracture inclination angle for cement, $\theta = 70$.

Fracture inclination angle for cast iron $\theta = 60$.

Fracture inclination angle for brass $\theta = 50$.

Cast iron as a brittle material has a large internal friction angle when compared to the angle of internal friction of brass as a semi-ductile material since its particles are finer than those of cast iron. Therefore, the relationship $\theta = 45 + \emptyset/2$ can be proven by the following analytical method:

The specimen is shown in Figures 4 and 5 below has a cross-sectional area = A, was fractured by the compressive load P, which caused a stress of σ in it at a plane making an angle of θ with the horizontal reference line. Angle $\emptyset$ represents the angle of internal friction of the metal to be tested and is a fixed number for a single metal.

$$Vertical\ compressive\ stress, \sigma = P/A \quad (1)$$

$$B = Cross - sectional\ area\ of\ the\ sample\ at\ the\ fracture\ plane$$

$$B = A/cos\,\theta \quad (2)$$

The force P that causes compression fracture has two components, one perpendicular to the fracture plane (N) and the other parallel to the fracture plane (Q), and the value of each is:

$$\mathrm{N} = \mathrm{P}\cos\theta \quad (3)$$

$$Q = P\,sin\,\theta \quad (4)$$

$$Stress\ perpendicular\ to\ the\ fracture\ plane, \sigma_N = \frac{Load\ perpendicular\ to\ the\ fracture\ plane}{Fracture\ plane\ area} = \frac{N}{B} \quad (5)$$

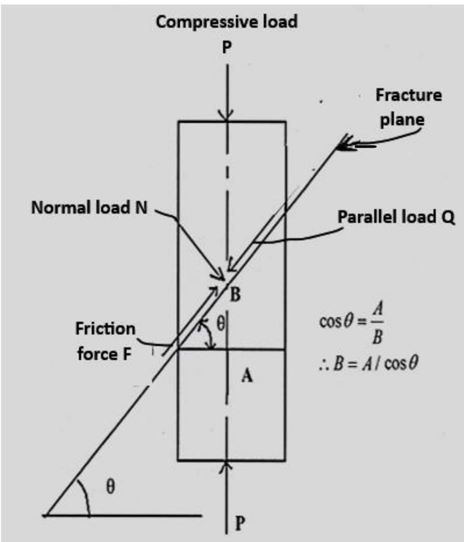

Figure 4 A specimen fractured by the compressive load P

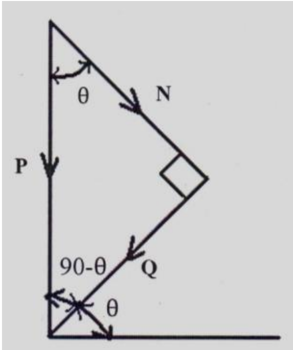

Figure 5 The normal and tangential components of the compressive load P

Substituting equations (1), (2), and (3) in equation (5) we obtain:

$$Stress\ perpendicular\ to\ the\ fracture\ plane, \sigma_N = \frac{N}{B} = \frac{p \cos\theta}{A/\cos\theta} = \frac{P}{A} cos^2 \theta = \sigma. cos^2 \theta \quad (6)$$

$$Shear\ stress\ parallelto\ the\ fracture\ plane,\ \ \tau_Q = \frac{Load\ parallel\ to\ the\ fracture\ plane}{Fracture\ plane\ area} \quad (7)$$

Substituting equations (1), (2), and (4) in equation (7) we obtain:

$$\tau_Q = \frac{Q}{B} = \frac{P\ sin\theta}{A/\ cos\theta} = \frac{P}{A}\ sin\theta\ cos\theta = \ \sigma\ sin\theta\ cos\theta \quad (8)$$

The stress perpendicular to the plane of the fracture also causes frictional stress opposite the direction of movement at the plane of the fracture.

$$\tan\phi = \frac{Tangential\ force}{Perpendicular\ force} = \frac{F}{N} \quad (9)$$

From which:

$$\therefore Frictional\ force, \qquad F = N \tan\phi \quad (10)$$

$$Frictional\ stress, \sigma_f = \frac{Frictional\ force}{Fracture\ plane\ area} = \frac{F}{B} \quad (11)$$

$$\therefore Frictional\ stress, \sigma_f = \frac{N\ \tan\phi}{\frac{A}{\cos\theta}} = \frac{Pcos^2\theta \cdot \tan\phi}{A} = \frac{P\ cos^2\ \theta\ tan\ \phi}{A} = \sigma\ cos^2\ tan\ \phi \quad (12)$$

It is clear from the above that the stresses causing fracture on the plane that makes an angle θ with the horizontal plane (σ_r) are the result of the difference in the stress effect parallel to the fracture plane resulting from the vertical force P and the effect of the frictional stress resulting from the resistance of the cohesion of the metal particles to sliding over each other, that is:

$$Stress\ causing\ fracture\ =\ shear\ stress\ -\ frictional\ stress \quad (13)$$

To obtain the stress causing fracture, substitute equations (8) and (12) into equation (13):

$$\sigma_r = \tau_Q - \sigma_f = \sigma\ sin\ \theta\ cos\ \theta - \sigma\ cos^2\ \theta\ tan\ \phi \quad (14)$$

Fracture occurs when the stress causing fracture, σ_r, is at its maximum value. Therefore, by differentiating the stress causing the fracture with respect to the fracture inclination angle and setting it equal to zero, the maximum value of the fracture inclination angle θ is obtained.

$$\frac{d\sigma_r}{d\theta} = 0$$

By differentiating equation (14) with respect to the fracture inclination angle and setting it equal to zero, the following expression is obtained:

$$\frac{d\sigma_r}{d\theta} = (\sigma\ sin\ \theta \times -\ sin\ \theta) + (cos\ \theta \times \sigma\ cos\ \theta) - \{(\sigma\ cos^2\ \theta \times zero) + tan\ \phi \times 2\sigma\ cos\ \theta \times -\ sin\ \theta)\} = 0$$

$$\frac{d\sigma_r}{d\theta} = -\sigma\ sin^2\ \theta + \sigma\ cos^2\ \theta + 2\sigma\ sin\ \theta\ cos\ \theta\ tan\ \phi = 0$$

$$\therefore \sigma(\cos^2\theta - \sin^2\theta) = -2\sigma \sin\theta \cos\theta \tan\phi$$
$$\therefore \tan\phi = -\frac{(\cos^2\theta - \sin^2\theta)}{2\sin\theta\cos\theta} = -\frac{\cos 2\theta}{\sin 2\theta} = -\cot 2\theta$$
$$\therefore \tan\phi = -\tan(90^\circ - 2\theta) = \tan(2\theta - 90^\circ)$$
$$\therefore \phi = 2\theta - 90^\circ$$
$$2\theta = 90^\circ + \varphi$$
$$\therefore \theta = 45^\circ + \phi/2$$

6. Conclusions

The evaluation of the mechanical behavior of a sample under conditions of tension and compression can be performed to provide basic material property data that is critical for component design and service performance assessment. The requirements for tensile and compression strength values and the methods for testing these properties are specified in various standards for a wide variety of materials. Testing can be performed on machined material samples or on full-size or scale models of actual components. These tests are typically performed using a universal mechanical testing instrument.

A tensile test is a method for determining behavior of materials under axial tensile loading. The tests are conducted by fixturing the specimen into the test apparatus and then applying a force to the specimen by separating the testing machine crossheads. The crosshead speed can be varied to control the rate of strain in the test specimen. Data from the test are used to determine tensile strength, yield strength, and modulus of elasticity. Measurement of the specimen dimensions after testing also provides reduction of area and elongation values to characterize the ductility of the material. Tensile tests can be performed on many materials, including metals, plastics, fibers, adhesives, and rubbers. Testing can be performed at sub ambient and elevated temperatures.

A compression test is a method for determining the behavior of materials under a compressive load. Compression tests are conducted by loading the test specimen between two plates, and then applying a force to the specimen by moving the crossheads together. During the test, the specimen is compressed, and deformation versus the applied load is recorded. The compression test is used to determine elastic limit, proportional limit, yield point, yield strength, and (for some materials) compressive strength.

In conclusion, tensile testing is considered better than compression testing for several reasons. Its ability to test material ductility, determine other important material properties, versatility, and standardization make it a more useful and reliable test method for a wide range of applications. While compression testing has its place, tensile testing is the preferred method for understanding how materials will perform under tensile stress, which is a critical factor in many engineering applications.

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