TESTS

FOR

MECHANICAL PROPERTIES / STRENGTH

TENSILE TEST

CONTENT

1. INTRODUCTION

The performance of a material is frequently determined by the amount of stress and deformation that can be permitted with an applied force in tension. These are the 2 major criteria for the designer:

1. Which stress will cause fracture?
2. How much deformation is allowed?

These criteria are different depending on the application and design. A deflection of a few tenths of a milimeter on a machine tool would make it useless, whereas a deflection of several milimeter is normal for the wing of an aircraft.

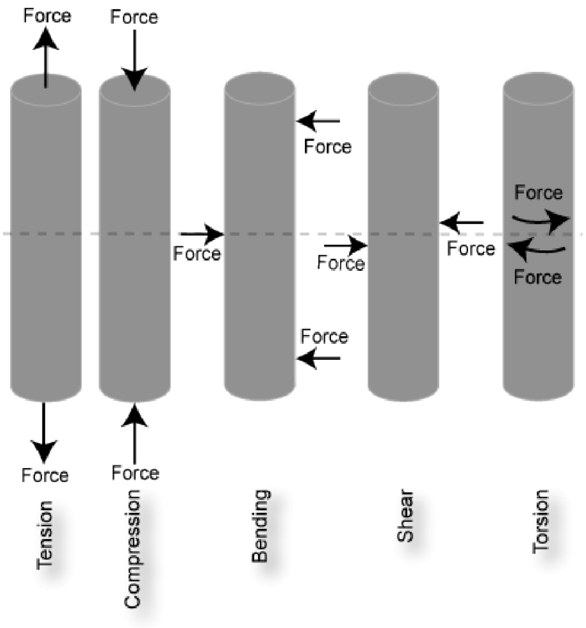
The important properties are:

1. amount of elongation permitted (and reduction in area)
2. tensile strength
3. yield strength
4. Young' s modulus of elasticity
5. ductility, indicated by total elongation and reduction of area.

The tensile test is one of the tests that measure the mechanical properties, strength of materials.

The tensile test does measure these design criteria: tensile strength, yield strength and Young modulus (strength) and ductility with the elongation and reduction in area.

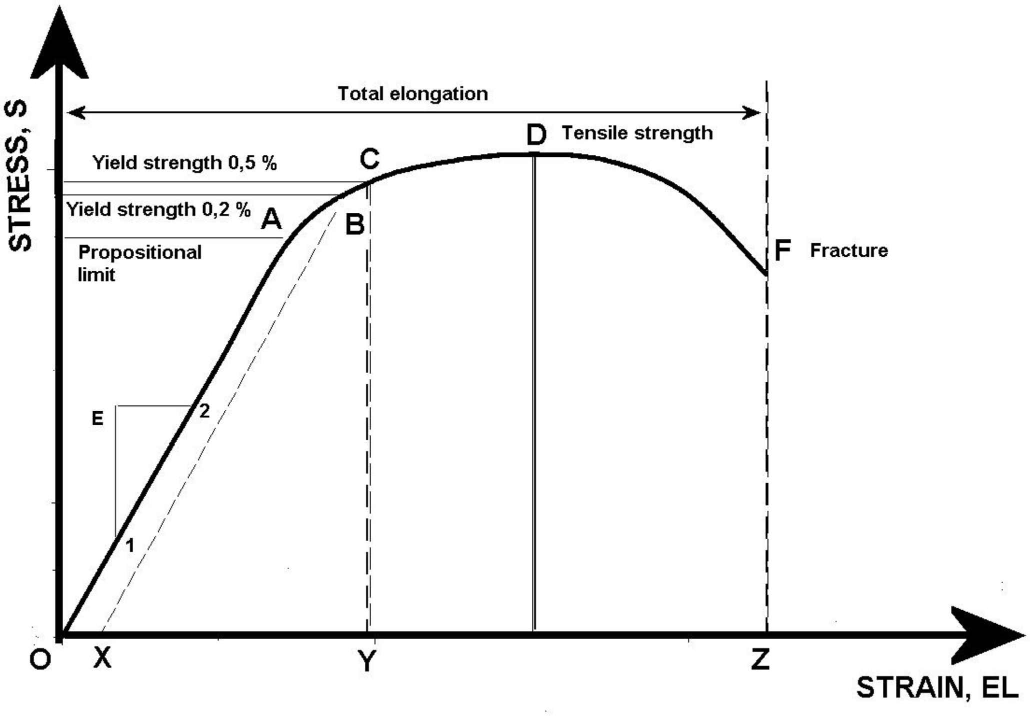
For suppliers, these mechanical properties are an important measure of metal product quality and buyers frequently require certification of the values.



2. TEST

The tensile test is giving a ñstress-strain curveò. From this curve it is possible to calculate all the necessary mechanical properties, mentioned in the chapter 1. Introduction.

The stress-strain curve is a graphical description of the amount of deflection under load for a given material (Fig. 1).



Engineering stress (**S**) is calculated by dividing the load *(P)* at any given time by the original cross sectional area (A_0) of the specimen.

$$S = P / A_0$$

Engineering strain *(***EL***)* is calculated by dividing the ñelongationò of the gage length of the specimen (œL) by the original gage length (L_0).

$$EL = \text{œ}L / L_0 = (L - L_0) / L_0$$

The shape and magnitude of the stress-strain curve depend on the type of metal being tested.

In figure 1, point **A** represents the proportional limit of a material.
A material loaded with a stress in the range of ñOAòwill behave ñelasticallyòand always return to its original state.

The initial segment of the curve below point **A** represents the **elastic range** and is approximated by a straight line. The slope **(E)** of the curve in the elastic range is defined as **Young' s modulus of elasticity** and is a measure of material stiffness.

$$\mathbf{E = \varphi S / \varphi EL = (S_2 \text{ ï } S_1) / (EL_2 \text{ ï } EL_1)}$$

A material loaded in tension beyond point **A** exhibits permanent deformation even when the load is removed. The proportional limit is often difficult to calculate. For this reason, two practical measurements are taken:

1. offset yield strength or 0,2 % permanent elongation
2. yield by extension under load or 0,5 % permanent elongation.

They approximate the proportional limit.

In figure 1, point **B** represents the offset yield strength and is found by constructing a line ñX-Bòparallel to the curve in the elastic region. Line ñX-Bòis offset a strain amount ñO-Xò which is typically 0.2% of the gage length for metals.

In figure 1, point **C** represents the yield strength by extension under load and is found by constructing a vertical line ñY-Cò Line ñY ï Còis offset a strain amount ñ0-Yò which is typically 0.5% of gage length.

In figure 1, point **D** represents the tensile strength or peak stress. It is the highest stress. The test specimen will continuously become longer, even with decreasing stress.

In figure 1, point **F** (strain **Z)** is depicted as strain and it represents the total elongation or the amount of uni-axial strain at fracture. It includes both elastic and plastic deformation and is commonly reported as percent elongation at break (The gage length is also reported with the result.).

Elongation at break (%) = $\mathbf{EL_z = 100 \times (El_z - EL_0) / EL_o}$

Reduction of area (similar to elongation at break) is a measure of ductility and is expressed in percent. Reduction of area is calculated by measuring the cross sectional area at the fracture point (A_z) and the initial one (A_0).

Reduction of area (%) = $\mathbf{(A_0 - A_z) / A_0}$

With most of the steels, an increasing reduction of area will go together with an increasing notch impact (Charpy V) property.

Table 1 lists average properties for selected metals. Exact values may vary widely with changes in composition, heat treating and cold working.

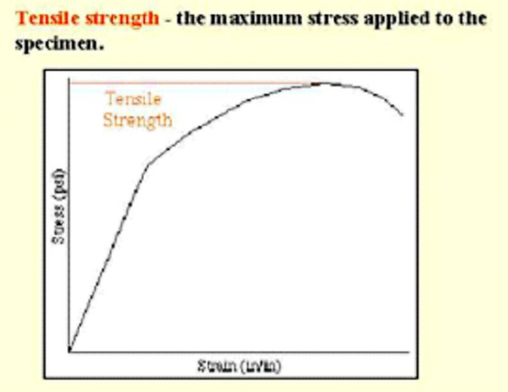
Table 1 Average mechanical properties

Material	Modulus of elasticity	Yield strength (0,2 %)	Tensile strength	Elonga-tion
	GPa	MPa	MPa	%
Construction steel	200	248	455	
Hot rolled steel, 0,4 % C	207	365	579	29
Hot rolled steel, 0,8 % C	207	524	841	8
Grey (flake) cast iron	103		172	0,5
Annealed 18-8 stainless steel	193	248	586	55
Cold rolled 18-8 stainless steel	193	1138	1310	8
Aluminium, 2024-T4	73	331	469	19
Aluminium, 6061-T6	70	276	310	17
Annealed Titanium	97	931	1069	13

Summary of terminology

Tensile Strength

The maximum stress applied to the specimen. Tensile strength is also known as Ultimate Strength. (The highest point on the stress-strain diagram).

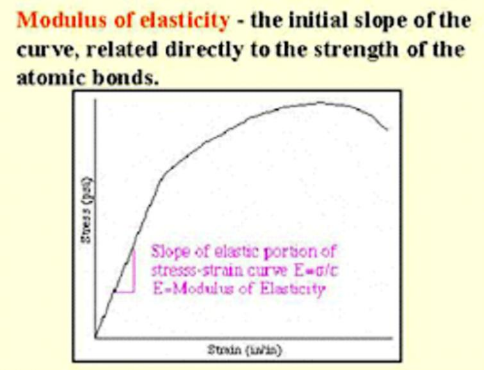


Tensile strength - the maximum stress applied to the specimen.

Modulus of Elasticity

The initial slope of the curve, related directly to the strength of the atomic bonds. This modulus indicates the stiffness of the material.
(Modulus Elasticity is also known as Young's Modulus)

Modulus of Elasticity = E = Change in Stress / Change in Strain



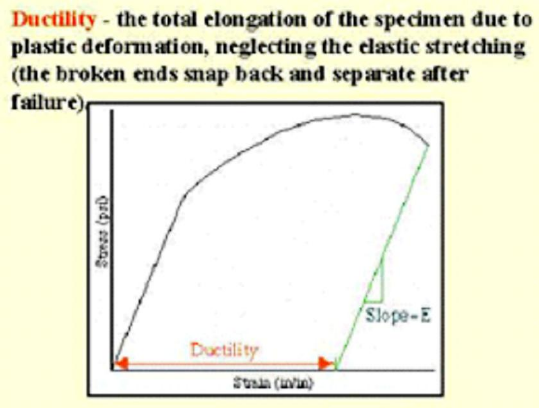
Modulus of elasticity - the initial slope of the curve, related directly to the strength of the atomic bonds.

Ductility

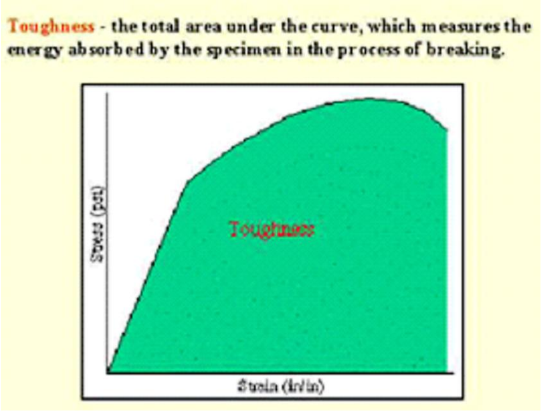
The total elongation of the specimen due to plastic deformation, neglecting the elastic stretching.

Toughness

The total area under the curve, which indicates the energy absorbed by the specimen in the process of breaking.



Ductility - the total elongation of the specimen due to plastic deformation, neglecting the elastic stretching (the broken ends snap back and separate after failure).



Toughness - the total area under the curve, which measures the energy absorbed by the specimen in the process of breaking.

3. TESTING EQUIPMENT

The most common testing machines are universal testers, which can test materials in tension, compression, bending and hardness.

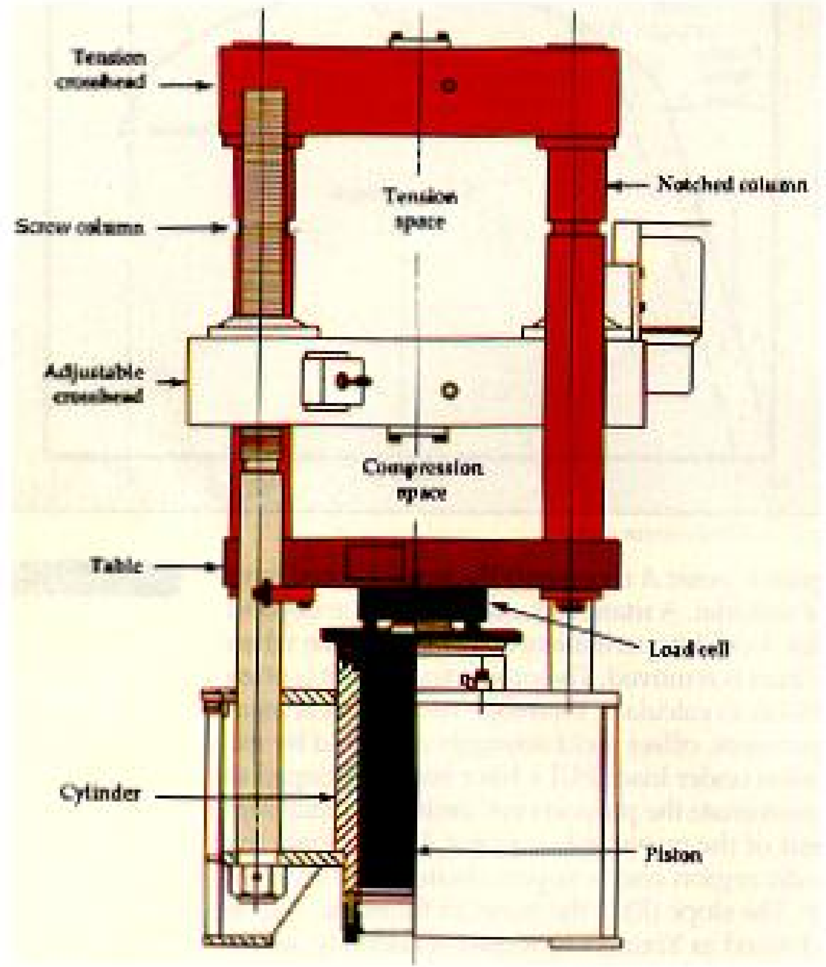
Their primary function is to create the stress-strain curve. Once the diagram is generated, a pencil and straight-edge or a computer algorithm can calculate yield strength, Young' s modulus, tensile strength and total elongation.

Testing machines are either electromechanical or hydraulic. The principal difference is the method by which the load is applied.

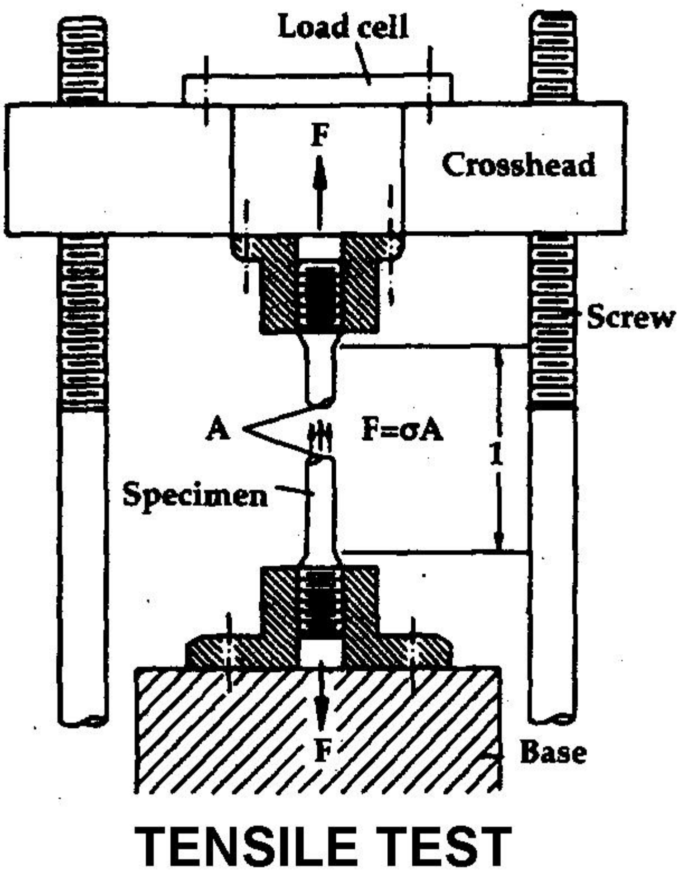
Electromechanical machines are based on a variable-speed electric motor, a gear reduction system and one, two or four screws that move the crosshead up or down. This motion loads the specimen in tension or compression. Changing the speed of the motor can change crosshead speeds. A microprocessor-based closed-loop servo system can be implemented to accurately control the speed of the crosshead.

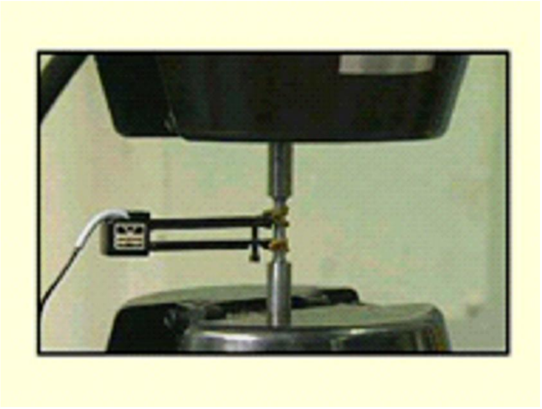
Hydraulic testing machines (figure 2) are based on either a single or dual-acting piston that moves the crosshead up or down. However, most static hydraulic testing machines have a single acting piston or ram.

Another figure is shown on next page.

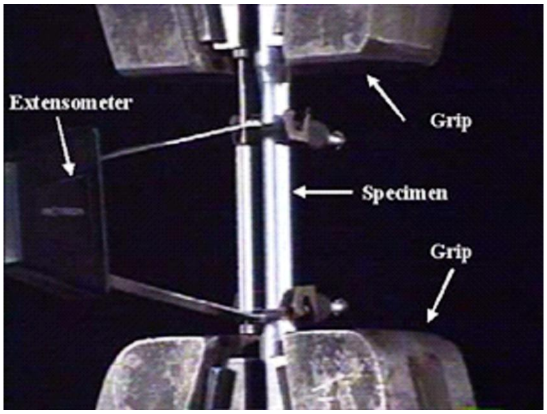


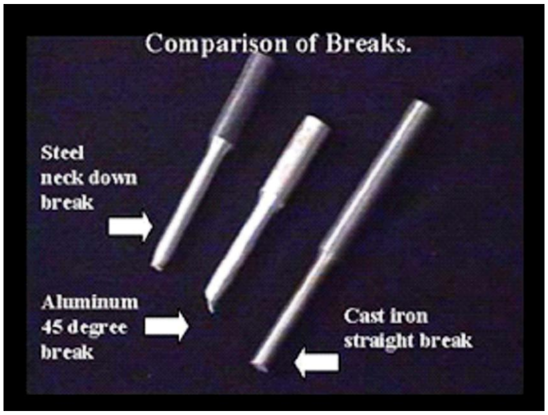
Schematic illustration of tensile test equipment and picture.





In a manually operated machine, the operator adjusts the orifice of a pressure-compensated needle valve to control the rate of loading. In a closed-loop hydraulic servo system, an electrically operated servo valve for precise control replaces the needle valve.





In general, electromechanical machines are capable of a wider range of test speeds and longer crosshead displacements, whereas hydraulic machines are more cost-effective for generating higher forces.

The most common possibilities of the 2 types of equipment are summarised in table 2 on next page.

Table 2 Tensile testing equipment

Machine type	Test speed	Maximum displacement	Load capacity
	mm / min	mm	N
Electromechanical	0,0025 ï 1000	1000	500 ï 300000
Hydraulic	0,125 ï 75	1500 - 3000	300000 ï 5000000

All equipment must be tested regularly according to standards and be certified by an ñorganisationò, which is allowed to do this!

4. IMPORTANT FACTORS

Many factors affect the shape and magnitude of the stress-strain diagram. If they are not handled properly, errors may make the test worthless. All lab managers and test technicians should be mindful of the following common sources of error.

4.1 The extensometer

When testing metals, the deflection of the load frame in comparison to the deflection of the specimen may be large enough to introduce significant error. Therefore, metals tests require an extensometer, which measures the deflection of the specimen only (figure 3).
Most extensometers are attached directly to the specimen, but non-contacting systems are also available.

The five most important characteristics of an extensometer are the attachment mechanism, knife edges, gage length, percent travel and accuracy.

Extensometer slippage due to poor adjustment of the damping mechanism and or worn knife edges can result in an indeterminate stress-strain curve. Slippage is the most common source of error in metals testing. An appropriate maintenance program should be established to ensure that the knife edges are replaced when worn and that the springs and clips create enough pressure on the specimen.

Standard extensometer gage lengths are available. The gage length needed for a given test is dictated by the size of the specimen and the test method. Care must be taken to establish the initial gage length when attaching the extensometer. Proper adjustment and operation of the mechanical stops will eliminate gage length errors.

The amount of extensometer travel should match the amount of specimen elongation. An extensometer with too much travel may make it difficult to accurately measure Young's modulus. An extensometer with insufficient travel will prevent certain measurements altogether. Many test methods require a certain extensometer accuracy class (see ASTM E83). Make sure that the extensometer meets the accuracy required prior to testing.

4.2 The grips

Wedge-action grips are the most common grips in metals testing. As the axial load increases, the wedge acts to increase the squeezing pressure applied to the specimen. Wedge grips are manually, pneumatically or hydraulically actuated. For high-volume testing, pneumatic or hydraulic grips are recommended.

Worn or dirty grip faces can result in specimen slippage, which often renders the stress-strain diagram useless. Therefore, the grip faces should be inspected periodically. Worn inserts should be replaced, and dirty inserts cleaned with a wire brush.

Proper alignment of the grips and the specimen when clamped in the grips is important. Offsets in alignment will create bending stresses and tower tensile stress readings. It may even cause the specimen to fracture outside the gage length. Some test machines require backlash nuts to hold the grips in place. The backlash nuts should be tightened while a specimen loaded to machine capacity is installed in the machine.

4.3 The test specimen

Most ASTM or similar test methods require a shaped specimen that concentrates the stress within the gage length. If the specimen is improperly machined, it could fracture outside the gage length, resulting in strain errors.

Improper reading of specimen dimensions also creates stress measurement errors. Therefore, worn micrometers or callipers should be replaced and care should be taken when recording specimen dimensions. Some computer-based test systems read the micrometer or calliper directly, thus eliminating data entry errors.

The elongation is depending on the ratio L / D (length to diameter) of the test specimen. An increasing L / D ratio will lead to a decreasing elongation!
If this ratio is not correct, the result will be not correct.

4.4 Test speed

The share and magnitude of the stress-strain diagram can be affected by the test speed.

For example, some materials exhibit an appreciable increase in strength with faster test speeds. Therefore, make sure that the load rate is in accordance with the specific test method.

4.5 Misalignment

In addition, worn machine components can result in misalignment, creating bending stresses that tower tensile stress readings. Check the test machine's alignment and play, to ensure concentricity of the crosshead over the full travel.

4.6 Incorrect ñzeroed outò

Finally, with the presence of microprocessor-based test systems, applied loads can inadvertently be "zeroed out," resulting in lower stress readings. To prevent this, clamp the specimen in the upper grip, then zero the load, then dose the lower grip.

Note

The **transverse rupture test** is a strength test designed for low-ductility materials, including carbides and powder metallurgy (P/M) materials.

This destructive test involves bending rather than pulling of the specimen. Maximum load, specimen dimensions and test time are used to calculate the stress needed to cause failure.

A typical transverse rupture strength is 1,5 to 2,0 times the tensile strength.

5. STANDARDS

1. European standards

New standards

EN 10002 Part 1 Metallic Materials; Tensile testing; Part 1: Method of testing at ambient temperature.

EN 10002 Part 5 Metallic Materials; Tensile testing; Part 1: Method of testing at high temperature.

Older standards

DIN 50145 PrŤfung metallischer Werkstoffe; Zugversuch

DIN 50125 PrŤfung metallischer Werkstoffe; Zugproben

DIN 51221 Teil 1 : WerkstofprŤfmaschinen; ZugprŤfmaschinen, Algemeine Anforderungen

DIN 51221 Teil 2 : WerkstofprŤfmaschinen; ZugprŤfmaschinen, Grosse ZugprŤfmaschinen und UniversalprŤfmaschinen

DIN 51221 Teil 2 : WerkstofprŤfmaschinen; ZugprŤfmaschinen, Kleine ZugprŤfmaschinen

2. USA standards

The following is a partial list of ASTM test methods and practices for metals testing.

1. Test Method E8-00b Standard Test Methods for Tension Testing of Metallic: Materials and Test Method E8M-00b Standard Test Methods for Tension Testing of Metallic Materials (Metric)

2. Test Method E111-97 Standard Test Method for Youngôs Modulus, Tangent Modulus and Chord Modulus

3. Specification A356 / A356M-98e1 Standard Specification for Steel Castings, Carbon, Low Alloy and Stainless Steel, Heavy-Walled for Steam Turbines

4. Practice E1012-99 Standard Practice for Verification of Specimen Alignment under Tensile loading

5. Test Method A370-97a Standard Test Methods and Definitions for Test Methods of Tension Testing of Steel Products

6. Test Method A345-93 (1998) Standard Test Methods and Definitions for Test Methods of Tension Testing of Metallic Foil

7. Practice E29-93a (1999) Standard Practice for Using significant Digits in Test Data to Determine Conformance with Specifications

8. Practice E83-00 Standard Practice for Verification and Classification of Extensometer

9. Test Method E21-92 (1998) Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials

3. Test on welds

EN 895
DIN 50120
ASME Code Sect. I a IX

6. CONCLUSION

The tensile test is most common test.

The tensile strength is the highest stress encountered in the tensile test.
This mostly corresponds with the stress at fracture. But for very ductile materials, the stress at fracture is lower than the tensile strength. For very brittle materials, the yield strength equals the tensile strength.

The ductility is measured by the elongation at rupture as well as the reduction in area.

It provides the producer of the metallic components and the customer (designer of the components) with most of the required mechanical properties.

It is important to do the test in a correct method with equipment that is properly certified.