The Difference Between Yield Strength and Tensile Strength

When selecting materials for an engineering application, critical mechanical properties of the material must be reviewed. Two such properties are yield strength and tensile strength. They are both measures of a material's resistance to failure, either by deformation or fracture. Despite this similarity, yield strength and tensile strength are two very different parameters.

Yield strength

When subjected to stress, a material undergoes recoverable deformation. The yield strength of a material represents the stress beyond which its deformation is plastic. Any deformation that occurs as a result of stress higher than the yield strength is permanent. Because of the linearity of elastic deformation, yield strength is also defined as the greatest stress achievable without any deviation from the proportionality of stress and strain. Beyond this point, large deformations can be observed with little or no increase in the applied load. Yield strength is measured in N/m^2 or pascals.

The yield strength of a material is determined using a tensile test. The results of the test are plotted on a stress-strain curve. The stress at the point where the stress-strain curve deviates from proportionality is the yield strength of the material. It is difficult to define an exact yield point for certain materials from the stress-strain curve. This is because these materials do not display an abrupt curve; rather the onset of yield occurs over a range. It is therefore practical to use proof stress as a representation of the yield strength.

Proof stress

Proof stress is measured by drawing a line at 0.2% of the plastic strain, parallel to the straight-line elastic region of the stress-strain curve. The stress at the point where this line intercepts the curve is the proof stress. The yield strength of a material can be increased by certain material processes.

Tensile strength

Often referred to as ultimate tensile strength (UTS), tensile strength is the maximum tensile load a material can withstand prior to fracture. It is a measure of a material's resistance to failure under tensile loading.

The tensile strength of a material is determined using a tensile test. It is the highest point on the stress-strain curve, which is plotted after the test. Tensile strength can also be determined using this formula:

$\sigma f = Pf/Ao$

Where Pf is the load at fracture, Ao is the original cross-sectional area, and σf is the tensile strength, measured in N/m^2 or pascals. It is important to note that the tensile strength of a material is a specific value under controlled standard test conditions. However, in practical applications, tensile strength varies with temperature. At 100°C, the tensile strength of copper falls from 220Mpa at room temperature, to 209Mpa. These variations are compensated for by using a factor of safety, which is usually a fraction of the original tensile strength in design considerations.

Comparative analysis of yield strength and tensile strength

The following are some of the major differences between yield strength and tensile strength:

- Yield strength is measured at the point of plastic deformation.
- Tensile strength is measured at the point of fracture. Tensile strength is rarely used in the design consideration of structures made from ductile materials. This is because these materials undergo substantial deformation before their tensile strength is reached. Rather, yield strength is considered for ductile materials, while tensile strength is used for brittle materials.
- During design considerations, tensile strength is analysed only in uni-axial loading. Multi-axial stress states are estimated in yield strength analysis.
- Deformation of materials occurs after yield strength has been surpassed, while tensile strength is reached after deformation has taken place. In brittle materials, tensile strength is reached with minimal or no yield.
- Tensile strength is usually of a higher numerical value than the yield strength of a particular material.
- The tensile strength of a material can be ascertained with 100% accuracy. However, yield strength has to be estimated for most materials.

Yield and tensile strengths of some common engineering materials

Below are examples of the yield and tensile strengths of some engineering materials.

Material	Yield strength (Mpa)	Tensile strength (Mpa)
copper	70	220
aluminium	95	110
structural steel ***(ASTM A36)***	250	400
cast iron 4.5% (***ASTM A48)***	130	200
stainless steel ***(AISI 302)***	502	860

titanium alloy	730	900
high strength alloy steel ***(ASTM A514)***	690	760
chromium-vanadium steel	620	940
tungsten	941	1510
kevlar	3620	3757

(Table Source: https://www.engineeringtoolbox.com/young-modulus-d_417.html)