Strength at Yield (Tensile)

Mechanical Properties of Plastics

What is tensile strength? Tensile strength is an ability of plastic material to withstand maximum amount of tensile stress while being pulled or stretched without failure. It is the point when a material goes from elastic to plastic deformation.

- **Elastic deformation -** When the stress is removed, the material returns to the dimension it had before the load was applied. Valid for small strains (except the case of rubbers). Deformation is reversible, non-permanent
- **Plastic deformation** -When the stress is removed, the material does not return to its previous dimension but there is a permanent, irreversible deformation.

Tensile strength is often referred to as ultimate tensile strength and is **measured in units of force per cross-sectional area**.

There are three types of tensile strength (**See Graph 1 below**):

- **Yield strength (A) -** The stress a material can withstand without permanent deformation
- **Ultimate strength (B) -** The maximum stress a material can withstand
- **Breaking strength (C) -** The stress coordinate on the stress-strain curve at the point of rupture

In other words, materials first deform elastically - when you release the stress they return to their original shape. Then with more force they deform plastically, this is yield - when you release the stress they have permanently been stretched into a new shape. Finally, they break; this is ultimately tensile stress, or breaking point.

» Select the Suitable Plastic with 'Good Tensile Strength' Meeting your Requirement

Tensile strength (TS) at yield, sometimes called **tensile stress at yield**, measures the stress a plastic can withstand at the yield point, i.e. when an increase in strain is not provoked by an increase of stress. It is an important for a material that is going to be stretched or under tension. For structural applications, the yield stress is usually a more important property than the tensile strength, since once it is passed, the structure has deformed beyond acceptable limits.

Hence, it is one of the important mechanical properties for:

- Material evaluation
- Quality control
- Structure design
- Modeling, and
- Failure analysis

Check out more on Tensile strength at yield:

» Strength at Yield (Tensile)– Property values for several plastics
» Difference between tensile strength and yield strength
» How to measure tensile properties of plastics?
» Significance of tensile properties and factors affecting tensile strength of plastics

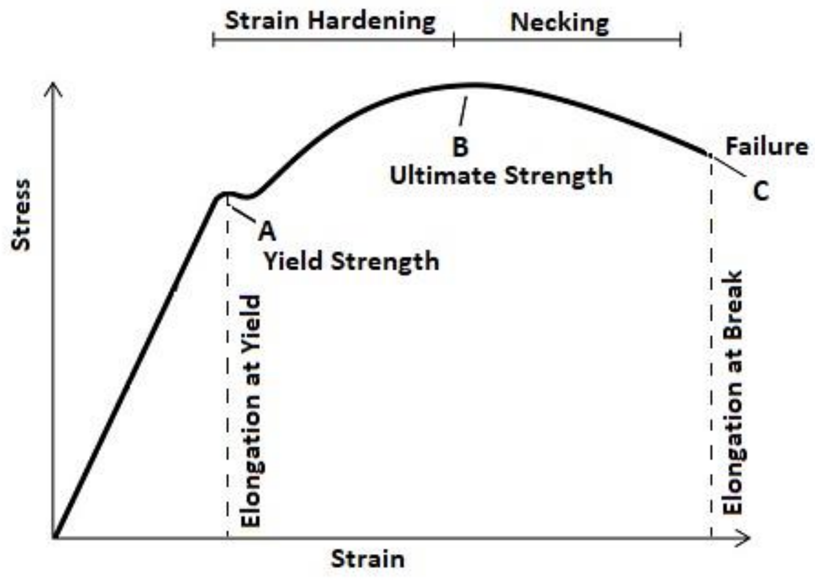
Yield Strength vs. Tensile Strength

Yield Strength is the stress a material can withstand without permanent deformation or a point at which it will no longer return to its original dimensions (by 0.2% in length). Whereas, **Tensile Strength** is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking.

Yield Strength can be seen on a stress-strain curve as the point where the graph is no longer linear.

- Since it is quite difficult to determine an exact point where a line stops being linear, Yield Strength is usually the point where the value on the stress-strain curve is 0.2% off from what it would be if it was completely linear

Typical Stress-Strain Curve



Stress-Strain Curve

When a stretching force (tensile force) is applied to an object, it extends, and its behavior can be obtained using stress-strain curve in the elastic deformation region (Known Hooke's Law). The extension that a force produces is not only dependent on the material but also on other factors like dimensions of the object (e.g. length, thickness etc.)

Stress is defined as the force per unit area of plastic and has units Nm^{-2} or Pa. The formula to calculate tensile stress is:

$$\sigma \text{ (stress)} = F/A$$

Where σ is stress (in Newtons per square metre or, equivalently, Pascals), F is force (in Newtons, commonly abbreviated N), and A is the cross-sectional area of the sample.

While, Strain is defined as extension per unit length. And, since it is a ratio of lengths, strain has no units.

$$\varepsilon \text{ (strain)} = \Delta L/L_0; \quad \Delta L = L - L_0$$

Where L_0 is the original length of a bar being stretched, and L is its length after it has been stretched. ΔL is the extension of the bar, the difference between these two lengths.

Learn More about Other Mechanical Properties: **Young's Modulus**, **Toughness**, **Hardness**, **Elongation at Yield**, **Elongation at Break**, **Strength at Break(Tensile)**

Units to Measure Tensile Strength

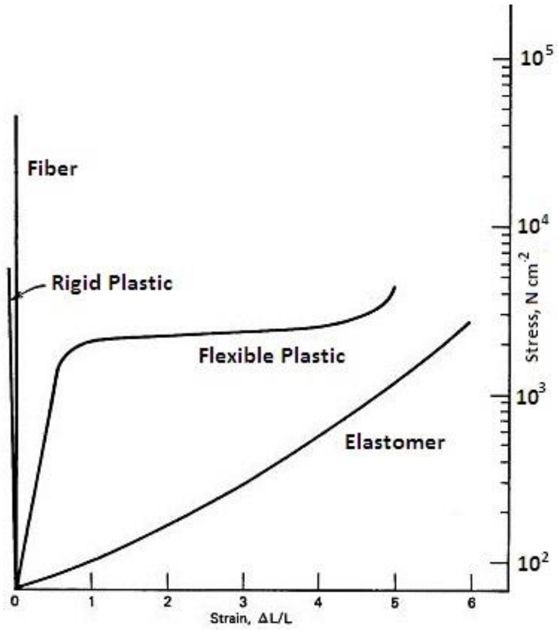
In the International System, the **unit of Tensile Strength** is the pascal (Pa) (or megapascals, MPa or even GPa, megapascals), which is equivalent to newtons per square meter (N/m^2).

In the US, pounds-force per square inch (lbf/in^2 or psi), or kilo-pounds per square inch (kpsi) are commonly used for convenience when measuring tensile strengths.

NOTE: In engineering, strength and stiffness are concepts which are confuse often. For the right material classification, read about "**Stiffness**" here.

Stress-Strain Plots for a Typical Elastomer, Flexible Plastics, Rigid Plastic, and Fiber

(Source: Principles of Polymerization, Fourth Edition, George Odian)



How to Measure Tensile Properties of Plastics?

Tensile tests measure the force required to break a specimen and the extent to which the specimen stretches or elongates to that breaking point.

In general, “tensile test methods” are applied to measure the tensile properties of plastics. The common methods used are:

- **ASTM D638 -** Standard Test Method for Tensile Properties of Plastics
- **ISO 527-1:2012 -** Determination of tensile properties. General principles

Of course, there exists several other methods as well as listed below, but they are not discussed here.

ASTM D638 and ISO 527 Test Methods

ASTM D638 and **ISO 527** test methods cover the determination of the tensile properties of plastics and plastic composites under defined conditions in the form of standard dumbbell-shaped test specimens. The defined conditions can range from pretreatment, temperature, humidity, to testing machine speed.

The methods are used to investigate the tensile behavior of the test specimens.

And, the following calculations can be made from tensile test results:

- Tensile strength (at yield and at break)
- **Tensile modulus**
- Strain
- **Elongation and percent elongation at yield**
- **Elongation and percent elongation at break**

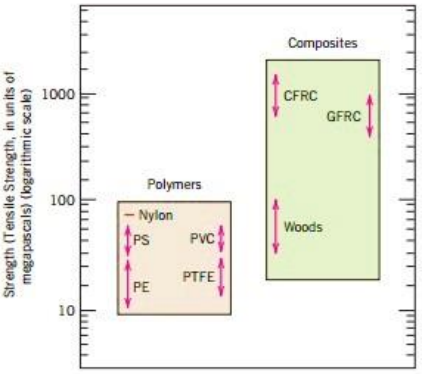
For **ASTM D638** the test speed is determined by the material specification. For **ISO 527** the test speed is typically 5 or 50mm/min for measuring strength and elongation and 1mm/min for measuring modulus.

An extensometer is a device that is used to measure changes in the length of an object. It is useful for stress-strain measurements and tensile tests.

Significance of Tensile Properties

- Tensile properties provide useful data for plastics engineering design purposes.

- Tensile properties frequently are included in material specifications to ensure quality.
- Tensile properties often are measured during development of new materials and processes, so that different materials and processes can be compared.
- Finally, tensile properties often are used to predict the behavior of a material under forms of loading other than uniaxial tension.



Factors Affecting Tensile Strength of Plastics

The strength of polymers is further governed by their:

- **Molecular Weight**: The strength of the polymer rises with increase in molecular weight and reaches the saturation level at some value of the molecular weight.
  - At lower molecular weight - the polymer chains are loosely bonded by weak van der Waals forces and the chains can move easily, responsible for low strength, although crystallinity is present
  - At higher molecular weight polymer - The polymer chains become large and hence are crosslinked, giving strength to the polymer

- **Cross-linking**: The cross-linking restricts the motion of the chains and increases the strength of the polymer.

- **Crystallinity**: The crystalline phase of polymer increases strength; hence the intermolecular bonding is more significant. Therefore, the polymer deformation can result in the higher strength leading to oriented chains.

Other than that velocity of testing, orientation level of fibers, temperature, filler content etc. also impact tensile strength values of thermoplastics.

Strength at Yield (Tensile) Values of Several Plastics

Polymer Name	Min Value (MPa)	Max Value (MPa)
ABS - Acrylonitrile Butadiene Styrene	29.6	48.0
ABS Flame Retardant	25.0	50.0

ABS High Heat	30.0	50.0
ABS High Impact	20.0	40.0
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	45.0	55.0
ABS/PC Blend 20% Glass Fiber	75.0	80.0
ABS/PC Flame Retardant	50.0	60.0
Amorphous TPI Blend, Ultra-high heat, Chemical Resistant (High Flow)	112.0	112.0
Amorphous TPI, High Heat, High Flow, Lead-Free Solderable, 30% GF	147.0	147.0
Amorphous TPI, High Heat, High Flow, Transparent, Lead-Free Solderable (High Flow)	101.0	101.0
Amorphous TPI, High Heat, High Flow, Transparent, Lead-Free Solderable (Standard Flow)	101.0	101.0
Amorphous TPI, Moderate Heat, Transparent	95.0	95.0
Amorphous TPI, Moderate Heat, Transparent (Food Contact Approved)	95.0	95.0
Amorphous TPI, Moderate Heat, Transparent (Mold Release grade)	95.0	95.0
Amorphous TPI, Moderate Heat, Transparent (Powder form)	95.0	95.0
ASA - Acrylonitrile Styrene Acrylate	35.0	40.0
ASA/PC Blend - Acrylonitrile Styrene Acrylate/Polycarbonate Blend	50.0	65.0
ASA/PC Flame Retardant	58.0	58.0
ASA/PVC Blend - Acrylonitrile Styrene Acrylate/Polyvinyl Chloride Blend	45.0	50.0
CA - Cellulose Acetate	19.0	43.0

CAB - Cellulose Acetate Butyrate	16.0	43.0
CP - Cellulose Proprionate	22.0	50.0
CPVC - Chlorinated Polyvinyl Chloride	40.0	55.0
ETFE - Ethylene Tetrafluoroethylene	42.0	42.0
ECTFE	29.0	32.0
EVA - Ethylene Vinyl Acetate	7.00	40.0
EVOH - Ethylene Vinyl Alcohol	50.0	94.0
HDPE - High Density Polyethylene	25.0	30.0
HIPS - High Impact Polystyrene	20.0	40.0
HIPS Flame Retardant V0	20.0	30.0
Ionomer (Ethylene-Methyl Acrylate Copolymer)	3.1	30.0
LCP - Liquid Crystal Polymer	175.0	175.0
LCP Carbon Fiber-reinforced	190.0	240.0
LCP Glass Fiber-reinforced	160.0	220.0
LCP Mineral-filled	110.0	180.0
LDPE - Low Density Polyethylene	10.0	20.0
LLDPE - Linear Low Density Polyethylene	10.0	30.0
MABS - Transparent Acrylonitrile Butadiene Styrene	42.0	48.0
PA 11 - (Polyamide 11) 30% Glass fiber reinforced	32.0	40.0
PA 11, Conductive	23.0	40.0
PA 11, Flexible	25.0	27.0
PA 11, Rigid	40.0	45.0
PA 12 (Polyamide 12), Conductive	32.0	-
PA 12, Fiber-reinforced	23.0	40.0

PA 12, Flexible	23.0	24.0
PA 12, Glass Filled	39.0	49.0
PA 12, Rigid	38.0	44.0
PA 46 - Polyamide 46	65.0	85.0
PA 46, 30% Glass Fiber	128.0	132.0
PA 6 - Polyamide 6	50.0	90.0
PA 6-10 - Polyamide 6-10	50.0	65.0
PA 66 - Polyamide 6-6	45.0	85.0
PA 66, 30% Glass Fiber	100.0	125.0
PA 66, 30% Mineral filled	148.0	1152.0
PA 66, Impact Modified, 15-30% Glass Fiber	90.0	120.0
PA 66, Impact Modified	35.0	50.0
Polyamide semi-aromatic	70.0	78.0
PAI - Polyamide-Imide	150.0	150.0
PAI, 30% Glass Fiber	210.0	210.0
PAI, Low Friction	125.0	165.0
PAN - Polyacrylonitrile	50.0	65.0
PAR - Polyarylate	69.0	69.0
PBT - Polybutylene Terephthalate30% Glass Fiber	135.0	140.0
PC (Polycarbonate) 20-40% Glass Fiber	90.0	160.0
PC (Polycarbonate) 20-40% Glass Fiber Flame Retardant	90.0	140.0
PC - Polycarbonate, high heat	61.0	69.0
PCL - Polycaprolactone	24.0	25.0
PE - Polyethylene 30% Glass Fiber	52.0	63.0

PE/TPS - Thermoplastic Starch	30.0	55.0
PEEK - Polyetheretherketone	90.0	110.0
PEEK 30% Carbon Fiber-reinforced	200.0	220.0
PEEK 30% Glass Fiber-reinforced	150.0	180.0
PEI - Polyetherimide	100.0	110.0
PEI, 30% Glass Fiber-reinforced	150.0	160.0
PEI, Mineral Filled	90.0	100.0
PEKK (Polyetherketoneketone), Low Cristallinity Grade	100.0	105.0
PESU - Polyethersulfone	80.0	90.0
PESU 10-30% glass fiber	75.0	140.0
PET - Polyethylene Terephthalate	50.0	57.0
PET, 30% Glass Fiber-reinforced	130.0	150.0
PET, 30/35% Glass Fiber-reinforced, Impact Modified	100.0	110.0
PETG - Polyethylene Terephthalate Glycol	50.0	51.0
PE-UHMW - Polyethylene -Ultra High Molecular Weight	20.0	25.0
PFA - Perfluoroalkoxy	15.0	30.0
PI - Polyimide	120.0	120.0
PLA - Polylactide	59.0	61.0
PLA - injection molding	48.0	52.0
PMMA - Polymethylmethacrylate/Acrylic	38.0	70.0
PMMA (Acrylic) High Heat	65.0	79.0
PMP - Polymethylpentene	16.0	18.0
PMP 30% Glass Fiber-reinforced	60.0	68.0

PMP Mineral Filled	17.0	18.0
Polyamide 66 (Nylon 66)/Carbon Fiber, Long, 30% Filler by Weight	290.0	290.0
Polyamide 66 (Nylon 66)/Carbon Fiber, Long, 40% Filler by Weight	305.0	305.0
Polyamide 66 (Nylon 66)/Glass Fiber, Long, 40% Filler by Weight	230.0	230.0
Polyamide 66 (Nylon 66)/Glass Fiber, Long, 40% Filler by Weight	210.0	210.0
Polyamide 66 (Nylon 66)/Glass Fiber, Long, 50% Filler by Weight	270.0	270.0
Polyamide 66 (Nylon 66)/Glass Fiber, Long, 50% Filler by Weight	230.0	230.0
Polyamide 66 (Nylon 66)/Glass Fiber, Long, 60% Filler by Weight	270.0	270.0
Polyamide 66 (Nylon 66)/Glass Fiber, Long, 60% Filler by Weight	250.0	250.0
Polypropylene Homopolymer (PP Homopolymer)/Glass Fiber, Long, 30% Filler by Weight	120.0	120.0
Polypropylene Homopolymer (PP Homopolymer)/Glass Fiber, Long, 40% Filler by Weight	130.0	130.0
Polypropylene Homopolymer (PP Homopolymer)/Glass Fiber, Long, 40% Filler by Weight	120.0	120.0
Polypropylene Homopolymer (PP Homopolymer)/Glass Fiber, Long, 50% Filler by Weight	130.0	130.0
Polypropylene Homopolymer (PP Homopolymer)/Glass Fiber, Long, 50% Filler by Weight	130.0	130.0

POM - Polyoxymethylene (Acetal)	54.0	78.0
POM (Acetal) Impact Modified	35.0	50.0
POM (Acetal) Low Friction	48.0	69.0
POM (Acetal) Mineral Filled	50.0	75.0
PP - Polypropylene 10-20% Glass Fiber	35.0	56.0
PP, 10-40% Mineral Filled	19.0	27.0
PP, 10-40% Talc Filled	22.0	28.0
PP, 30-40% Glass Fiber-reinforced	42.0	70.0
PP (Polypropylene) Copolymer	20.0	35.0
PP (Polypropylene) Homopolymer	35.0	40.0
PP, Impact Modified	11.0	28.0
PPE - Polyphenylene Ether	45.0	65.0
PPE, 30% Glass Fiber-reinforced	100.0	130.0
PPE, Flame Retardant	45.0	65.0
PPE, Impact Modified	50.0	56.0
PPE, Mineral Filled	65.0	75.0
PPS - Polyphenylene Sulfide	50.0	80.0
PPS, 20-30% Glass Fiber-reinforced	130.0	150.0
PPS, 40% Glass Fiber-reinforced	120.0	150.0
PPS, Conductive	60.0	140.0
PPS, Glass fiber & Mineral-filled	60.0	150.0
PPSU - Polyphenylene Sulfone	70.0	76.0
PS (Polystyrene) 30% glass fiber	70.0	70.0
PS (Polystyrene) Crystal	35.0	60.0
PS, High Heat	40.0	60.0

PSU - Polysulfone	69.0	80.0
PSU, 30% Glass fiber-reinforced	100.0	125.0
PSU Mineral Filled	65.0	70.0
PTFE - Polytetrafluoroethylene	9.0	30.0
PVC (Polyvinyl Chloride), 20% Glass Fiber-reinforced	60.0	90.0
PVC, Plasticized	4.0	7.0
PVC, Plasticized Filled	10.0	25.0
PVC Rigid	35.0	50.0
PVDC - Polyvinylidene Chloride	20.0	30.0
PVDF - Polyvinylidene Fluoride	20.0	56.0
SAN - Styrene Acrylonitrile	65.0	85.0
SAN, 20% Glass Fiber-reinforced	100.0	120.0
SMA - Styrene Maleic Anhydride	35.0	50.0
SMA, 20% Glass Fiber-reinforced	56.0	75.0
SMA, Flame Retardant V0	20.0	25.0
SMMA - Styrene Methyl Methacrylate	36.0	85.0
TPI-PEEK Blend, Ultra-high heat, Chemical Resistant, High Flow, 240C UL RTI	105.0	105.0
TPS/PE - Thermoplastic Starch/ Polyethylene Blend (30 micron films tested)	25.0	25.0
TPS-Injection General Purpose, Starch GP	19.0	45.0
TPS-Injection Water Resistant, Starch WR	7.0	11.0