

# Strength at Break (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 break** measures the maximum stress a plastic specimen can withstand while being stretched before breaking. Some materials can break sharply (brittle failure) while some others will deform or elongate before breaking. It is measured as the tensile or compressive load required to fracture something.

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

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

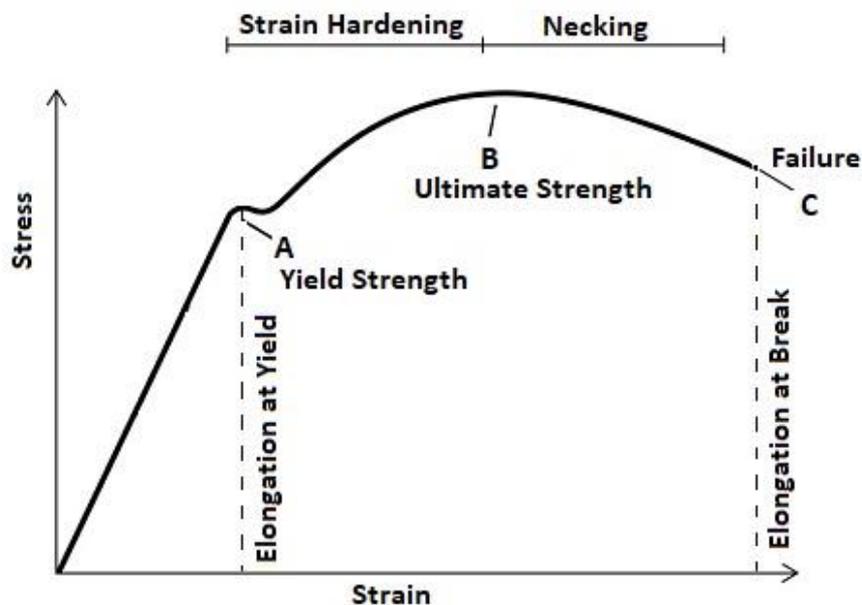
*Check out more on Tensile strength at yield:*

- » **Strength at Break (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



## 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  $\text{Nm}^{-2}$  or Pa. The formula to calculate tensile stress is:

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

Where  $\sigma$  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.

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

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

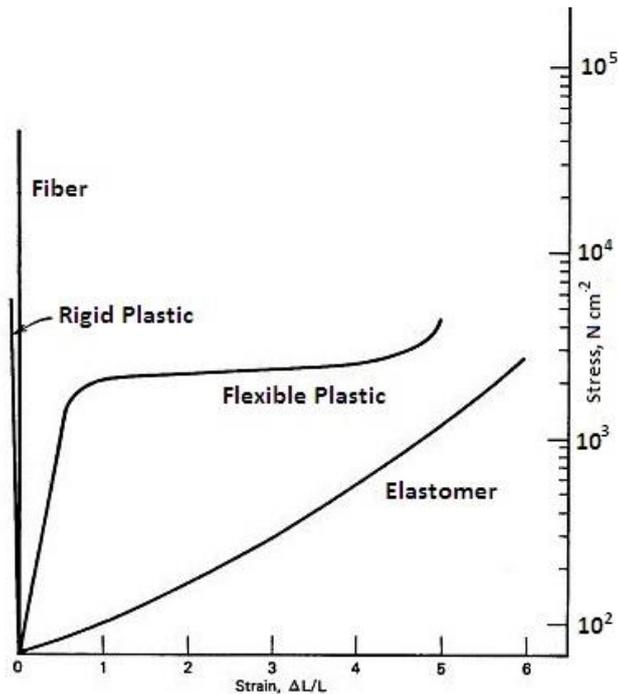
Learn More about Other Mechanical Properties: **Young's Modulus, Toughness, Hardness, Elongation at Yield, Elongation at Break, Strength at Yield (Tensile)**

## 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 ( $\text{N/m}^2$ ).

In the US, pounds-force per square inch ( $\text{lbf/in}^2$  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**

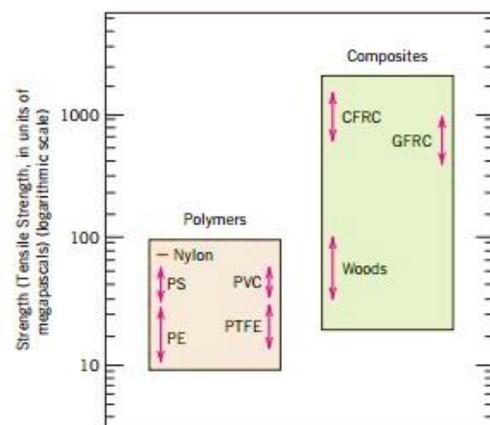
For **ASTM D638** the test speed is determined by the material specification. For **ISO 527** the test speed is typically 5 or 50mm/min for measuring strength and elongation and 1mm/min for measuring modulus.

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 Break (Tensile) Values of Several Plastics

Polymer Name	Min Value (MPa)	Max Value (MPa)
ABS - Acrylonitrile Butadiene Styrene	29.8	43.0
ABS Flame Retardant	30.0	50.0
ABS High Heat	30.0	60.0
ABS High Impact	30.0	45.0
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	40.0	50.0
ABS/PC Blend 20% Glass Fiber	75.0	80.0
ABS/PC Flame Retardant	40.0	55.0
Amorphous TPI Blend, Ultra-high heat, Chemical Resistant (High Flow)	105.0	105.0

Amorphous TPI Blend, Ultra-high heat, Chemical Resistant (Standard Flow)	160.0	160.0
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)	74.0	74.0
Amorphous TPI, High Heat, High Flow, Transparent, Lead-Free Solderable (Standard Flow)	70.0	70.0
Amorphous TPI, Highest Heat, Chemical Resistant, 260C UL RTI	119.0	119.0
Amorphous TPI, Moderate Heat, Transparent	78.0	78.0
Amorphous TPI, Moderate Heat, Transparent (Food Contact Approved)	78.0	78.0
Amorphous TPI, Moderate Heat, Transparent (Mold Release grade)	78.0	78.0
Amorphous TPI, Moderate Heat, Transparent (Powder form)	78.0	78.0
ASA - Acrylonitrile Styrene Acrylate	47.0	56.0
ASA/PC Blend - Acrylonitrile Styrene Acrylate/Polycarbonate Blend	45.0	50.0
ASA/PC Flame Retardant	48.0	48.0
ASA/PVC Blend - Acrylonitrile Styrene Acrylate/Polyvinyl Chloride Blend	45.0	50.0
CA - Cellulose Acetate	24.0	52.0
CAB - Cellulose Acetate Butyrate	18.0	48.0
CP - Cellulose Propionate	14.0	50.0
COC - Cyclic Olefin Copolymer	46.0	63.0

CPVC - Chlorinated Polyvinyl Chloride	45.0	60.0
ETFE - Ethylene Tetrafluoroethylene	45.0	45.0
ECTFE	45.0	54.0
EVA - Ethylene Vinyl Acetate	7.0	30.0
EVOH - Ethylene Vinyl Alcohol	30.0	205.0
FEP - Fluorinated Ethylene Propylene	19.0	21.0
HDPE - High Density Polyethylene	30.0	40.0
HIPS - High Impact Polystyrene	20.0	45.0
HIPS Flame Retardant V0	15.0	30.0
Ionomer (Ethylene-Methyl Acrylate Copolymer)	11.0	37.0
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	25.0	45.0
PA 11 - (Polyamide 11) 30% Glass fiber reinforced	80.0	136.0
PA 11, Conductive	37.0	37.0
PA 11, Flexible	43.0	59.0
PA 11, Rigid	37.0	58.0
PA 12 (Polyamide 12), Conductive	39.0	-
PA 12, Fiber-reinforced	72.0	145.0
PA 12, Flexible	50.0	56.0
PA 12, Glass Filled	37.0	50.0

PA 12, Rigid	56.0	69.0
PA 46 - Polyamide 46	65.0	85.0
PA 46, 30% Glass Fiber	128.0	132.0
PA 6 - Polyamide 6	50.0	95.0
PA 6-10 - Polyamide 6-10	50.0	65.0
PA 66 - Polyamide 6-6	50.0	95.0
PA 66, 30% Glass Fiber	100.0	125.0
PA 66, 30% Mineral filled	45.0	200.0
PA 66, Impact Modified, 15-30% Glass Fiber	90.0	120.0
PA 66, Impact Modified	40.0	50.0
Polyamide semi-aromatic	60.0	60.0
PAI - Polyamide-Imide	190.0	195.0
PAI, 30% Glass Fiber	210.0	210.0
PAI, Low Friction	125.0	165.0
PAN - Polyacrylonitrile	50.0	65.0
PAR - Polyarylate	25.0	65.0
PARA (Polyarylamide), 30-60% glass fiber	190.0	280.0
PBT - Polybutylene Terephthalate	40.0	50.0
PBT, 30% 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	55.0	77.0
PC/PBT Blend - Polycarbonate/Polybutylene Terephthalate Blend Glass Filled	62.0	110.0

PCTFE - Polymonochlorotrifluoroethylene	32.0	40.0
PE - Polyethylene 30% Glass Fiber	52.0	63.0
PEEK - Polyetheretherketone	90.0	150.0
PEEK 30% Carbon Fiber-reinforced	200.0	220.0
PEEK 30% Glass Fiber-reinforced	150.0	180.0
PEI - Polyetherimide	90.0	100.0
PEI, 30% Glass Fiber-reinforced	150.0	160.0
PEI, Mineral Filled	90.0	100.0
PEKK (Polyetherketoneketone), Low Cristallinity Grade	89.5	89.5
PESU - Polyethersulfone	70.0	90.0
PESU 10-30% glass fiber	75.0	140.0
PET - Polyethylene Terephthalate	45.0	70.0
PET, 30% Glass Fiber-reinforced	140.0	160.0
PET, 30/35% Glass Fiber-reinforced, Impact Modified	100.0	110.0
PETG - Polyethylene Terephthalate Glycol	40.0	40.0
PE-UHMW - Polyethylene -Ultra High Molecular Weight	39.0	49.0
PFA - Perfluoroalkoxy	27.0	30.0
PGA - Polyglycolides	68.9	68.9
PHB - Polyhydroxybutyrate	25.0	27.0
PHB-V(5% valerate)	35.0	37.0
PI - Polyimide	72.0	120.0
PLA - Polylactide	52.0	54.0
PLA - Polylactide High heat films	102.2	104.2

PMMA - Polymethylmethacrylate/Acrylic	38.0	70.0
PMMA (Acrylic) High Heat	65.0	79.0
PMMA (Acrylic) Impact Modified	35.0	65.0
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)	60.0	70.0
POM (Acetal) Impact Modified	45.0	60.0
POM (Acetal) Low Friction	50.0	70.0
POM (Acetal) Mineral Filled	50.0	75.0
PP - Polypropylene 10-20% Glass Fiber	35.0	56.0
PP, 10-40% Mineral Filled	18.0	24.0
PP, 10-40% Talc Filled	21.0	28.0
PP, 30-40% Glass Fiber-reinforced	42.0	70.0
PP (Polypropylene) Copolymer	30.0	35.0
PP (Polypropylene) Homopolymer	20.0	40.0
PP, Impact Modified	23.0	35.0
PPA - Polyphthalamide	85.0	85.0
PPA, 30% Mineral-filled	79.0	81.0
PPA, 33% Glass Fiber-reinforced	192.0	194.0
PPA, 33% Glass Fiber-reinforced – High Flow	162.0	163.0
PPA, 45% Glass Fiber-reinforced	227.0	229.0
PPE - Polyphenylene Ether	45.0	60.0
PPE, 30% Glass Fiber-reinforced	100.0	130.0

PPE, Flame Retardant	45.0	55.0
PPE, Impact Modified	45.0	55.0
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	75.8	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	70.0	80.0
PSU, 30% Glass fiber-reinforced	100.0	125.0
PSU Mineral Filled	65.0	70.0
PTFE - Polytetrafluoroethylene	0.0	10.0
PTFE, 25% Glass Fiber-reinforced	15.0	20.0
PVC (Polyvinyl Chloride), 20% Glass Fiber-reinforced	60.0	90.0
PVC, Plasticized	7.0	25.0
PVC, Plasticized Filled	10.0	25.0
PVC Rigid	35.0	60.0
PVDC - Polyvinylidene Chloride	20.0	35.0
PVDF - Polyvinylidene Fluoride	40.0	50.0
SAN - Styrene Acrylonitrile	65.0	85.0
SAN, 20% Glass Fiber-reinforced	100.0	120.0

SMA - Styrene Maleic Anhydride	35.0	55.0
SMA, 20% Glass Fiber-reinforced	56.0	75.0
SMA, Flame Retardant V0	20.0	25.0
SMMA - Styrene Methyl Methacrylate	30.0	60.7
SRP - Self-reinforced Polyphenylene	159.0	207.0
TPS/PE - Thermoplastic Starch/ Polyethylene Blend (30 micron films tested)	20.0	20.0
XLPE - Crosslinked Polyethylene	11.0	32.0