

Young's Modulus

Stress, Strain & Young's Modulus

Young's modulus (E) is defined as the ratio of the stress applied to the material along the longitudinal axis of the specimen tested and the deformation or strain, measured on that same axis. Young's Modulus is also known as tensile modulus, elastic modulus or modulus of elasticity.

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.

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

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.

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

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.

Using measurements of tensile stress and tensile strain, the **stiffness of different materials** is compared by **Young's modulus, E**. E is constant and does not change for a given material. **Elastic Modulus formula** is:

$$E = \text{stress/strain} = \sigma / \epsilon$$

The greater the value of young's modulus, the stiffer is the material
Units of Modulus of Elasticity/Young's modulus are: Nm^{-2} or Pa.

The practical units used in plastics are megapascals (MPa or N/mm^2) or gigapascals (GPa or kN/mm^2). In the United States customary units, it is often expressed as pounds (force) per square inch (psi).

Applications include:

Elastic modulus is an important mechanical property for material selection, product design, and performance analysis in several engineering as well as **medical applications**.

- Used for selection of materials for various purposes considering how it will react under different types of forces
- To aid design process
- To reduce material costs, determine batch quality and consistency in manufacture

Check out more on Young's modulus:

- » **Young's modulus Values of Several Plastics**
- » **How to Calculate the Young's modulus of Plastic**
- » **Factors Affecting Elastic Modulus**

How to calculate modulus of elasticity?

In general, "tensile test methods" are applied measure elastic modulus of materials. 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

Ofcourse there exist 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/ Young's 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 used to determine elongation and tensile modulus.

Factors Affecting Young's Modulus

The modulus is closely related to the **binding energies of the atoms**. Binding forces, and thus the modulus of elasticity, are typically higher for high melting point materials. Young's modulus does depend on orientation of a single crystal material.

Higher temperature in the material increases atomic vibration which, in turn, decreases the necessary energy to further separate the atoms from one another (and thus generally decreases the stress needed to produce a given strain.)

Presence of impurity atoms, alloying atoms, nonmetallic inclusions, secondary phase particles, dislocations (shifts or mismatches in the lattice structure), and defects (cracks, grain boundaries, etc.). All of these things can serve to either weaken or strengthen a material.

- Anything that impedes the motion of dislocations through the lattice will tend to increase the modulus, and thus the yield strength.

- Anything that facilitate dislocation movement (like increased temperature) or creates localized stress risers (like cracks, inclusions, etc.) will tend to decrease strength (e.g. by promoting early onset of failure).

» **Get Inspired: Prevent plastics component's failure by understanding the top 3 root causes & implementing corrective actions right from the start.**

The modulus of elasticity of plastics is much smaller than that for metals or ceramics and glasses. For example:

- The modulus of elasticity of **nylon** is 2.7 GPa (0.4×10^6 psi)
- The modulus of glass fibers is 72 GPa (10.5×10^6 psi)
- The Young's modulus of composites such as **glass fiber-reinforced composites** (GFRC) or **carbon fiber-reinforced composites** (CFRC) lies between the values for the matrix polymer and the fiber phase (carbon or glass fibers) and depends upon their relative volume fractions.

Elastic Modulus Values of Several Plastics

Polymer Name	Min Value (GPa)	Max Value (GPa)
ABS - Acrylonitrile Butadiene Styrene	1.79	3.20
ABS Flame Retardant	2.00	3.00
ABS High Heat	1.50	3.00
ABS High Impact	1.00	2.50
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	2.00	2.20
ABS/PC Blend 20% Glass Fiber	6.00	6.00
ABS/PC Flame Retardant	2.60	3.00
Amorphous TPI Blend, Ultra-high heat, Chemical Resistant (High Flow)	3.50	3.50
Amorphous TPI, High Heat, High Flow, Lead-Free Solderable, 30% GF	10.53	10.53
Amorphous TPI, High Heat, High Flow, Transparent, Lead-Free Solderable (High Flow)	3.10	3.10

Amorphous TPI, High Heat, High Flow, Transparent, Lead-Free Solderable (Standard Flow)	3.16	3.16
Amorphous TPI, Highest Heat, Chemical Resistant, 260C UL RTI	3.90	3.90
Amorphous TPI, Moderate Heat, Transparent	3.11	3.11
Amorphous TPI, Moderate Heat, Transparent (Food Contact Approved)	3.11	3.10
Amorphous TPI, Moderate Heat, Transparent (Mold Release grade)	3.12	3.12
Amorphous TPI, Moderate Heat, Transparent (Powder form)	3.11	3.11
ASA - Acrylonitrile Styrene Acrylate	2.00	2.60
ASA/PC Blend - Acrylonitrile Styrene Acrylate/Polycarbonate Blend	2.00	2.60
ASA/PC Flame Retardant	2.50	2.50
ASA/PVC Blend - Acrylonitrile Styrene Acrylate/Polyvinyl Chloride Blend	2.00	2.20
CA - Cellulose Acetate	0.60	2.80
CAB - Cellulose Acetate Butyrate	0.40	1.70
Cellulose Diacetate-Pearlescent Films	2.00	2.50
Cellulose Diacetate-Gloss Film	2.00	2.50
Cellulose Diacetate-Integuard Films	2.50	2.90
Cellulose Diacetate-Matt Film	2.00	2.90
Cellulose Diacetate-Window Patch Film (Food Grade)	2.00	2.50
Cellulose Diacetate-Clareflect metallized film	2.10	2.60
Cellulose Diacetate-Colored Films	2.00	2.50

Cellulose Diacetate-Flame retardant Film	2.00	2.50
Cellulose Diacetate-High Slip Film	2.30	2.80
Cellulose Diacetate-Semitone Films	2.00	2.50
CP - Cellulose Propionate	0.45	1.40
COC - Cyclic Olefin Copolymer	2.60	3.20
CPVC - Chlorinated Polyvinyl Chloride	2.50	3.20
ECTFE	1.70	1.70
ETFE - Ethylene Tetrafluoroethylene	0.80	0.80
EVA - Ethylene Vinyl Acetate	0.01	0.20
EVOH - Ethylene Vinyl Alcohol	1.90	3.50
FEP - Fluorinated Ethylene Propylene	0.30	0.70
HDPE - High Density Polyethylene	0.50	1.10
HIPS - High Impact Polystyrene	1.50	3.00
HIPS Flame Retardant V0	2.00	2.50
Ionomer (Ethylene-Methyl Acrylate Copolymer)	0.80	0.40
LCP - Liquid Crystal Polymer	10.00	19.00
LCP Carbon Fiber-reinforced	31.00	37.00
LCP Glass Fiber-reinforced	13.00	24.00
LCP Mineral-filled	12.00	22.00
LDPE - Low Density Polyethylene	0.13	0.30
LLDPE - Linear Low Density Polyethylene	0.266	0.525
MABS - Transparent Acrylonitrile Butadiene Styrene	1.90	2.00
PA 11 - (Polyamide 11) 30% Glass fiber reinforced	3.80	5.20
PA 46 - Polyamide 46	1.00	3.30

PA 46, 30% Glass Fiber	7.80	8.20
PA 6 - Polyamide 6	0.80	2.00
PA 6-10 - Polyamide 6-10	1.00	2.00
PA 66 - Polyamide 6-6	1.00	3.50
PA 66, 30% Glass Fiber	5.00	8.00
PA 66, 30% Mineral filled	1.40	5.50
PA 66, Impact Modified, 15-30% Glass Fiber	2.00	11.00
PA 66, Impact Modified	0.80	1.20
Polyamide semi-aromatic	2.07	2.23
PAI - Polyamide-Imide	4.00	5.00
PAI, 30% Glass Fiber	11.00	15.00
PAI, Low Friction	5.00	7.00
PAN - Polyacrylonitrile	3.10	3.80
PAR - Polyarylate	2.00	2.30
PARA (Polyarylamide), 30-60% glass fiber	11.50	24.00
PBT - Polybutylene Terephthalate	2.00	3.00
PBT, 30% Glass Fiber	9.00	11.50
PC (Polycarbonate) 20-40% Glass Fiber	6.00	10.00
PC (Polycarbonate) 20-40% Glass Fiber Flame Retardant	7.00	8.00
PC - Polycarbonate, high heat	2.20	2.50
PC/PBT Blend - Polycarbonate/Polybutylene Terephthalate Blend	1.80	2.30
PC/PBT blend, Glass Filled	4.50	5.10
PCL - Polycaprolactone	0.38	0.43

PCTFE - Polymonochlorotrifluoroethylene	1.20	1.50
PE - Polyethylene 30% Glass Fiber	4.90	6.30
PE/TPS Blend - Polyethylene/Thermoplastic Starch	0.19	0.30
PEEK - Polyetheretherketone	3.50	3.90
PEEK 30% Carbon Fiber-reinforced	13.00	22.30
PEEK 30% Glass Fiber-reinforced	9.00	11.40
PEI - Polyetherimide	3.00	3.00
PEI, 30% Glass Fiber-reinforced	9.00	9.00
PEI, Mineral Filled	5.00	7.00
PEKK (Polyetherketoneketone), Low Cristallinity Grade	3.40	3.50
PESU - Polyethersulfone	2.30	2.80
PESU 10-30% glass fiber	3.50	8.50
PET - Polyethylene Terephthalate	2.80	3.50
PET, 30% Glass Fiber-reinforced	9.00	12.00
PET, 30/35% Glass Fiber-reinforced, Impact Modified	7.00	9.00
PETG - Polyethylene Terephthalate Glycol	1.90	2.00
PFA - Perfluoroalkoxy	0.70	0.80
PGA - Polyglycolides	6.50	6.90
PHB - Polyhydroxybutyrate	3.10	3.30
PI - Polyimide	1.30	4.00
PLA - Polylactide	3.40	3.60
PLA, High Heat Films	3.30	3.50
PLA, Injection molding	3.50	3.60

PMMA - Polymethylmethacrylate/Acrylic	2.50	3.50
PMMA (Acrylic) High Heat	2.50	4.30
PMMA (Acrylic) Impact Modified	1.50	3.50
PMP - Polymethylpentene	0.50	1.60
PMP 30% Glass Fiber-reinforced	5.00	6.00
PMP Mineral Filled	1.70	2.00
POM - Polyoxymethylene (Acetal)	2.80	3.70
POM (Acetal) Impact Modified	1.40	2.30
POM (Acetal) Low Friction	1.80	3.00
POM (Acetal) Mineral Filled	4.00	5.50
PP - Polypropylene 10-20% Glass Fiber	2.80	4.00
PP, 10-40% Mineral Filled	1.00	3.50
PP, 10-40% Talc Filled	1.50	3.50
PP, 30-40% Glass Fiber-reinforced	4.00	10.00
PP (Polypropylene) Copolymer	1.00	1.20
PP (Polypropylene) Homopolymer	1.10	1.60
PP Homopolymer, Long Glass Fiber, 30% Filler by Weight	7.00	7.00
PP Homopolymer, Long Glass Fiber, 40% Filler by Weight	9.00	9.00
PP Homopolymer, Long Glass Fiber, 50% Filler by Weight	12.00	13.50
PP, Impact Modified	0.40	1.00
PPA - Polyphthalamide	3.70	3.70
PPA, 33% Glass Fiber-reinforced – High Flow	13.00	13.20
PPA, 45% Glass Fiber-reinforced	17.10	17.30

PPE - Polyphenylene Ether	2.10	2.80
PPE, 30% Glass Fiber-reinforced	7.00	9.00
PPE, Flame Retardant	2.40	2.50
PPE, Impact Modified	2.10	2.80
PPE, Mineral Filled	2.90	3.50
PPS - Polyphenylene Sulfide	3.30	4.00
PPS, 20-30% Glass Fiber-reinforced	6.00	11.00
PPS, 40% Glass Fiber-reinforced	8.00	14.00
PPS, Conductive	13.00	19.00
PPS, Glass fiber & Mineral-filled	10.00	17.00
PPSU - Polyphenylene Sulfone	2.34	2.34
PS (Polystyrene) 30% glass fiber	10.00	10.00
PS (Polystyrene) Crystal	2.50	3.50
PS, High Heat	3.00	3.50
PSU - Polysulfone	2.50	2.70
PSU, 30% Glass fiber-reinforced	7.60	10.00
PSU Mineral Filled	3.80	4.50
PTFE - Polytetrafluoroethylene	0.40	0.80
PTFE, 25% Glass Fiber-reinforced	1.40	1.70
PVC (Polyvinyl Chloride), 20% Glass Fiber-reinforced	4.50	7.00
PVC, Plasticized	0.001	1.800
PVC, Plasticized Filled	0.001	1.00
PVC Rigid	2.40	4.00
PVDC - Polyvinylidene Chloride	0.35	0.50
PVDF - Polyvinylidene Fluoride	1.50	2.00

SAN - Styrene Acrylonitrile	2.80	4.00
SAN, 20% Glass Fiber-reinforced	8.00	11.00
SMA - Styrene Maleic Anhydride	2.40	3.00
SMA, 20% Glass Fiber-reinforced	5.00	6.00
SMA, Flame Retardant V0	1.80	2.00
SMMA - Styrene Methyl Methacrylate	2.10	3.40
SRP - Self-reinforced Polyphenylene	5.90	8.30
TPI-PEEK Blend, Ultra-high heat, Chemical Resistant, High Flow, 240C UL RTI	4.20	4.20
TPS, Injection General Purpose	0.80	3.00
TPS, Injection Water Resistant	0.63	0.72
UHMWPE - Ultra High Molecular Weight Polyethylene	0.30	0.60
XLPE - Crosslinked Polyethylene	0.35	3.50