

# Flexibility

## Flexural Modulus or Bend Modulus

Flexibility is a property of a polymers that is described by Flexural modulus or bending modulus of elasticity. It is therefore one of the most important properties of solid materials.

Flexural Modulus denotes the ability of a material to bend. It is a measure of a materials stiffness/ flexibility when a force is applied perpendicular to the long edge of a sample - known as the three point bend test.

The flexural modulus is represented by the slope of the initial straight line portion of the stress-strain curve and is calculated by dividing the change in stress by the corresponding change in strain. Hence, the ratio of stress to strain is a measure of the flexural modulus.

*The property is often used to measure flexibility of plastic materials*

It is called as “modulus of elasticity in bending,” but other names are also used, such as **modulus of elasticity**, elastic modulus, or simply modulus.

- The International Standard unit of Flexural Modulus is the pascal (Pa or  $\text{N/m}^2$  or  $\text{m}^{-1} \cdot \text{kg} \cdot \text{s}^{-2}$ ).
- The practical units used are megapascals (MPa or  $\text{N/mm}^2$ ) or gigapascals (GPa or  $\text{kN/mm}^2$ ).
- In the US customary units, it is expressed as pounds (force) per square inch (psi).

*The higher the Flexural Modulus, the stiffer the material*

*The lower the Flexural Modulus, the more flexible it is*

Flexural modulus is important because:

- It influences composite selection in high stress situations
- It helps to improve design quality for load bearing applications

Further, flexibility is an important end-use property for elastomers. The **glass**

**transition temperature, T<sub>g</sub>** (temp. at which an elastomer upon cooling goes from a flexible more rubber-like form to a more rigid inflexible form) is a critical parameter in determining the suitability of the elastomer for specific applications.

Plots of flexural storage modulus (in GPa) versus specimen temperature by DMA are very useful in evaluating the **stiffness** and flexibility of polymeric materials.

*Check out more on Flexural Modulus:*

» **Flexural Modulus Values (GPa) of Several Plastics**  
» **How to Calculate the Flexural Modulus of Plastic**  
» **Factors Affecting Flexural Modulus and Impact on Other Mechanical Properties**

**How to measure Flexural Modulus (Stiffness)?**

Most commonly used standards to measure Flexural Modulus are ASTM D790 and ISO 178.

*Ofcourse there exist several other methods as well as listed below, but they are not discussed here.*

**ASTM D790 and ISO 178 test methods**

These are specifies methods for determining the flexural properties (bending properties) of reinforced and unreinforced plastics and electrical insulation materials.

The values are significantly different from the tensile modulus because the stress pattern in the specimen is a combination of tension and compression. The data is useful for comparing the strength and stiffness of different plastics when a load carrying part is subjected to bending in service.

ISO 178 standard describes a similar method for determining flexural properties.

- For ASTM D790, the test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%.

- For ISO 178, the test is stopped when the specimen breaks. If the specimen does not break, the test is continued as far as possible and the stress at 3.5% (conventional deflection) is reported.

Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment.

### Flexural Modulus – Impact of Fillers and Blends

Also, addition of fillers increases the stiffness or flexural modulus of a polymer system, especially polyolefins (PP, TPOs...) & hence decreases the flexibility. Selection of filler majorly depends on its aspect ratio and particle size. Higher the aspect ratio, high is the stiffness. For example, talc has high aspect ratio, typically 20:1, and is one of the most efficient minerals for improving flexural modulus.

Epoxy resins have excellent tensile strength and flexible modulus as well as detergent resistance, they have low resistance to gamma radiation, poor **heat distortion performance**, and a poor wear properties. They are also expensive and have a poor volume sensitivity and surface finish.

The addition of a thermotropic liquid crystalline aromatic polyester produces an improvement in the tensile strength and modulus of blends with polyether ketone while simultaneously producing a significant decrease in **elongation at break**. (Son and co-workers)

### Flexural Modulus Values of Several Plastics

Polymer Name	Min Value (Gpa)	Max Value (Gpa)
ABS - Acrylonitrile Butadiene Styrene	1.60	2.40
ABS Flame Retardant	2.00	4.00
ABS High Heat	2.00	3.00
ABS High Impact	1.00	2.50
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	2.00	2.30

ABS/PC Blend 20% Glass Fiber	5.90	6.10
ABS/PC Flame Retardant	2.50	3.0
Amorphous TPI Blend, Ultra-high heat, Chemical Resistant (High Flow)	3.00	3.00
Amorphous TPI, High Heat, High Flow, Lead-Free Solderable, 30% GF	9.00	9.00
Amorphous TPI, High Heat, High Flow, Transparent, Lead-Free Solderable (High Flow)	0.12	0.12
Amorphous TPI, High Heat, High Flow, Transparent, Lead-Free Solderable (Standard Flow)	2.85	2.85
Amorphous TPI, Highest Heat, Chemical Resistant, 260C UL RTI	3.60	3.60
Amorphous TPI, Moderate Heat, Transparent	3.08	3.08
Amorphous TPI, Moderate Heat, Transparent (Food Contact Approved)	3.08	3.08
Amorphous TPI, Moderate Heat, Transparent (Mold Release grade)	3.07	3.07
Amorphous TPI, Moderate Heat, Transparent (Powder form)	3.08	3.08
ASA - Acrylonitrile Styrene Acrylate	1.50	2.40
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	0.60	2.10

CP - Cellulose Propionate	0.45	1.40
COC - Cyclic Olefin Copolymer	2.50	3.50
CPVC - Chlorinated Polyvinyl Chloride	2.50	3.20
ETFE - Ethylene Tetrafluoroethylene	0.80	1.40
ECTFE	1.70	1.70
EVA - Ethylene Vinyl Acetate	0.007	0.10
EVOH - Ethylene Vinyl Alcohol	2.80	5.80
FEP - Fluorinated Ethylene Propylene	0.30	0.70
HDPE - High Density Polyethylene	0.75	1.575
HIPS - High Impact Polystyrene	1.50	3.00
HIPS Flame Retardant V0	2.00	2.50
Ionomer (Ethylene-Methyl Acrylate Copolymer)	0.03	0.50
LCP - Liquid Crystal Polymer	10.0	19.0
LCP Carbon Fiber-reinforced	31.0	37.0
LCP Glass Fiber-reinforced	13.0	24.0
LCP Mineral-filled	12.0	20.0
LDPE - Low Density Polyethylene	0.245	0.335
LLDPE - Linear Low Density Polyethylene	0.28	0.735
PA 11 - (Polyamide 11) 30% Glass fiber reinforced	3.00	3.00
PA 11, Conductive	0.58	0.64
PA 11, Flexible	0.29	0.35
PA 11, Rigid	1.00	1.48
PA 12 (Polyamide 12), Conductive	0.740	-
PA 12, Fiber-reinforced	3.00	13.70

PA 12, Flexible	0.36	0.46
PA 12, Glass Filled	1.75	2.00
PA 12, Rigid	1.17	1.48
PA 46 - Polyamide 46	1.00	3.20
PA 46, 30% Glass Fiber	7.80	3.20
PA 6 - Polyamide 6	0.80	2.00
PA 6-10 - Polyamide 6-10	1.00	2.00
PA 66 - Polyamide 6-6	0.80	3.00
PA 66, 30% Glass Fiber	5.00	8.00
PA 66, 30% Mineral filled	3.90	4.10
PA 66, Impact Modified, 15-30% Glass Fiber	3.00	7.00
PA 66, Impact Modified	0.80	1.20
PA 66, Carbon Fiber, Long, 30% Filler by Weight	18.00	18.00
PA 66, Carbon Fiber, Long, 40% Filler by Weight	24.00	24.00
PA 66, Glass Fiber, Long, 40% Filler by Weight	10.50	10.50
PA 66, Glass Fiber, Long, 50% Filler by Weight	13.00	13.00
PA 66, Glass Fiber, Long, 60% Filler by Weight	17.00	17.00
Polyamide semi-aromatic	1.80	2.11
PAI - Polyamide-Imide	4.00	7.00
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	11.00	21.00
PBT - Polybutylene Terephthalate	2.00	4.00
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	1.60	3.90
PC/PBT blend, Glass Filled	2.80	6.90
PCL - Polycaprolactone	0.50	0.60
PCTFE - Polymonochlorotrifluoroethylene	1.20	1.50
PE - Polyethylene 30% Glass Fiber	4.90	5.60
PEEK - Polyetheretherketone	3.70	4.00
PEEK 30% Carbon Fiber-reinforced	13.00	19.00
PEEK 30% Glass Fiber-reinforced	9.00	10.00
PEI - Polyetherimide	3.00	3.40
PEI, 30% Glass Fiber-reinforced	9.00	9.00
PEI, Mineral Filled	5.00	7.00
PEKK (Polyetherketoneketone), Low Crystallinity Grade	3.30	3.40
PESU - Polyethersulfone	2.50	2.70
PESU 10-30% glass fiber	3.80	8.40
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	2.20	2.20
PFA - Perfluoroalkoxy	0.70	0.80
PHB - Polyhydroxybutyrate	3.00	3.20
PI - Polyimide	2.48	4.10
PLA - Polylactide	3.80	3.80
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	0.80	1.50
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	2.00	3.00
POM (Acetal) Mineral Filled	4.00	5.50
PP - Polypropylene 10-20% Glass Fiber	2.50	3.50
PP, 10-40% Mineral Filled	1.40	3.10
PP, 10-40% Talc Filled	1.50	4.00
PP, 30-40% Glass Fiber-reinforced	4.00	7.00
PP (Polypropylene) Copolymer	1.00	1.40
PP (Polypropylene) Homopolymer	1.20	1.60
PP Homopolymer, Long Glass Fiber, 30% Filler by Weight	5.50	5.50

PP Homopolymer, Long Glass Fiber, 40% Filler by Weight	7.00	7.00
PP Homopolymer, Long Glass Fiber, 50% Filler by Weight	9.00	9.00
PP, Impact Modified	0.40	1.00
PPA - Polyphthalamide	2.10	3.70
PPA, 30% Mineral-filled	5.40	5.60
PPA, 33% Glass Fiber-reinforced	11.30	11.50
PPA, 33% Glass Fiber-reinforced – High Flow	10.00	12.00
PPA, 45% Glass Fiber-reinforced	13.70	13.90
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	3.80	4.20
PPS, 20-30% Glass Fiber-reinforced	6.00	12.00
PPS, 40% Glass Fiber-reinforced	12.00	15.00
PPS, Conductive	17.00	19.00
PPS, Glass fiber & Mineral-filled	10.00	17.00
PPSU - Polyphenylene Sulfone	2.38	2.41
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	2.70	3.00

PSU, 30% Glass fiber-reinforced	7.00	8.50
PSU Mineral Filled	4.00	5.00
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	1.80
PVC, Plasticized Filled	0.001	1.000
PVC Rigid	2.10	3.50
PVDC - Polyvinylidene Chloride	0.35	0.60
PVDF - Polyvinylidene Fluoride	1.50	2.00
SAN - Styrene Acrylonitrile	3.50	4.20
SAN, 20% Glass Fiber-reinforced	7.00	9.00
SMA - Styrene Maleic Anhydride	2.30	3.30
SMA, 20% Glass Fiber-reinforced	5.00	6.00
SMA, Flame Retardant V0	1.90	2.00
SMMA - Styrene Methyl Methacrylate	2.00	3.20
SRP - Self-reinforced Polyphenylene	6.20	8.30
TPI-PEEK Blend, Ultra-high heat, Chemical Resistant, High Flow, 240C UL RTI	3.60	3.60
UHMWPE - Ultra High Molecular Weight Polyethylene	0.45	0.60
XLPE - Crosslinked Polyethylene	0.35	3.50