Toughness

Toughness of a plastic is measured by its **resistance to impacts**. It is the ability of a material to resist both fracture and deformation. One common way to discuss the toughness of a polymer is to examine the area underneath the stress - strain curve for the particular polymer.

In general, ‘Hardness’, ‘Toughness’ and ‘Strength’ are similar terms to use, but in material science they are three distinct properties yet also share some overlap. Here are the key differences:

- **Hardness** is how well material holds together when friction is applied

- **Strength** is how much force is required before the material deforms. It tells us about the amount of load a material can bear

- **Toughness** is the ability of a material to resist breaking when force is applied

Toughness is the combination of strength and ductility

To be tough, a material must exhibit both fairly good strength and ductility to resist cracking and deformation under impact loading.
Impact test signifies toughness, or impact strength, of a material that is the ability of material to absorb energy during plastic deformation. This energy absorption is directly related to the brittleness of the material. **Results of impact tests** are expressed in terms of either:

- Amount of energy absorbed (Nm) or
- Amount of energy absorbed per unit cross sectional area (Nm/cm^2)

Applications include:
- Measure of the energy required to crack a material
- Screen materials for impact developments
- Define uses of materials in automotive applications

Check out more on toughness:

» Toughness values of Several Plastics

» How to Calculate the toughness of plastic

How to Measure Toughness of a polymer?

The energy absorption, or toughness, of a material is measured by various techniques and two most commonly used methods are: **Izod and Charpy Test**.

The **two methods** are based on common principle of applying the load at high rate and measuring the amount of energy absorbed (Kg/m or Joule) in breaking the sample due to impact. However, there are some difference also in these two methods in terms of:

- Sample size and shape,
- Method of holding of the sample and
- Maximum energy content of pendulum that hits the sample during test

Toughness Test	Sample	Holding
Izod	Held vertically on anvil as cantilever	Cantilever type and notch faces the pendulum
Charpy	Held horizontally on anvil as simply supported beam	Simply supported type and notch is opposite side of pendulum impact (not facing the pendulum)

Since most of the engineering components are invariably designed with notch and stress raisers, therefore, it becomes **important to know the behavior of material** with notch under impact loading.

- Hence, toughness test is usually conducted using sample with notch.
- Moreover, un-notched samples can also be used for the toughness test and the results are expresses accordingly.

These tests can be used as a quick and easy quality control check to determine if a material meets specific impact properties or to compare materials for general toughness.

Values of toughness are not directly used for design purpose, but these only indicate the ability of the material to withstand against shock/impact load. These tests are useful for comparing the resistance to impact loading of different materials or the same material in different processing conditions such as heat treatment, procedure and mechanical working etc.

The toughness of polymers, or resistance to impact, varies with the:

- Molecular structure,
- surrounding temperature and
- type of stress applications

Case must be taken in relating flexibility to toughness, but generally, a more rubbery character gives higher elongation at break and better impact resistance values, although such materials would have **lower stiffness**.

Factors Affecting Toughness of Plastics

» **Degree of Crystallinity -** Greater the crystallinity, the harder the polymer
» **Temperature -** Change in behavior at ductile - brittle transition temperature
» **Long Chain Branches -** Long chain branches may increase the polymer toughness

Toughness Values of Several Plastics

We have selected **Notched Izod Impact test** performed at room temperature (23°C for ISO and 73°F for ASTM) for different polymers. As discussed above, it measures the energy to be applied to a notched standardized sample to break it.

The result of the Izod test is reported in **energy lost during the impact per unit of specimen thickness** (such as ft-lb/in or J/cm) at the notch. Tests results, especially in Europe, may be reported as energy lost per unit cross-sectional area at the notch (J/m^2 or $ft\text{-}lb/in^2$).

Test methods used to measure Notched Izod Impact (Or notch sensitivity) in plastics are **ASTM D256 and ISO 180**.

Polymer Name	Min Value (J/m^2)	Max Value (J/m^2)
ABS - Acrylonitrile Butadiene Styrene	200.0	215.0
ABS Flame Retardant	70.0	350.0
ABS High Heat	100.0	350.0
ABS High Impact	300.0	500.0
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	400.0	600.0
ABS/PC Blend 20% Glass Fiber	73.0	76.0
ABS/PC Flame Retardant	250.0	700.0
ASA - Acrylonitrile Styrene Acrylate	100.0	600.0
ASA/PC Blend - Acrylonitrile Styrene Acrylate/Polycarbonate Blend	600.0	700.0
ASA/PC Blend - Flame Retardant	400.0	500.0
ASA/PVC Blend - Acrylonitrile Styrene Acrylate/Polyvinyl Chloride Blend	300.0	600.0
CA - Cellulose Acetate	50.0	400.0
CAB - Cellulose Acetate Butyrate	50.0	500.0
CP - Cellulose Proprionate	25.0	999.0
CPVC - Chlorinated Polyvinyl Chloride	50.0	250.0
ETFE - Ethylene Tetrafluoroethylene	999.0	999.0
EVA - Ethylene Vinyl Acetate	999.0	999.0
EVOH - Ethylene Vinyl Alcohol	50.0	90.0
FEP - Fluorinated Ethylene Propylene	999.0	999.0
HDPE - High Density Polyethylene	20.0	220.0
HIPS - High Impact Polystyrene	50.0	350.0
HIPS Flame Retardant V0	100.0	150.0

Ionomer (Ethylene-Methyl Acrylate Copolymer)	500.0	999.0
LCP - Liquid Crystal Polymer	70.0	450.0
LCP Carbon Fiber-reinforced	70.0	100.0
LCP Glass Fiber-reinforced	80.0	300.0
LCP Mineral-filled	50.0	600.0
LDPE - Low Density Polyethylene	999.0	999.0
LLDPE - Linear Low Density Polyethylene	54.0	999.0
MABS - Transparent Acrylonitrile Butadiene Styrene	60.0	100.0
PA 46 - Polyamide 46	30.0	250.0
PA 46, 30% Glass Fiber	145.0	155.0
PA 6 - Polyamide 6	50.0	160.0
PA 6-10 - Polyamide 6-10	70.0	999.0
PA 66 - Polyamide 6-6	50.0	150.0
PA 66, 30% Glass Fiber	130.0	160.0
PA 66, 30% Mineral filled	40.0	200.0
PA 66, Impact Modified, 15-30% Glass Fiber	150.0	270.0
PA 66, Impact Modified	70.0	999.0
PAI - Polyamide-Imide	100.0	150.0
PAI, 30% Glass Fiber	70.0	80.0
PAI, Low Friction	50.0	80.0
PAN - Polyacrylonitrile	130.0	480.0
PAR - Polyarylate	70.0	290.0
PARA (Polyarylamide), 30-60% glass fiber	70.0	120.0

PBT - Polybutylene Terephthalate	27.0	999.0
PBT, 30% Glass Fiber	50.0	90.0
PC (Polycarbonate) 20-40% Glass Fiber	90.0	200.0
PC (Polycarbonate) 20-40% Glass Fiber Flame Retardant	90.0	110.0
PC - Polycarbonate, high heat	80.0	650.0
PC/PBT Blend - Polycarbonate/Polybutylene Terephthalate Blend	50.0	960.0
PC/PBT blend, Glass Filled	90.0	190.0
PCTFE - Polymonochlorotrifluoroethylene	130.0	250.0
PE - Polyethylene 30% Glass Fiber	60.0	80.0
PEEK - Polyetheretherketone	80.0	94.0
PEEK 30% Carbon Fiber-reinforced	85.0	120.0
PEEK 30% Glass Fiber-reinforced	95.0	130.0
PEI - Polyetherimide	50.0	60.0
PEI, 30% Glass Fiber-reinforced	90.0	100.0
PEI, Mineral Filled	40.0	60.0
PESU - Polyethersulfone	70.0	100.0
PESU 10-30% glass fiber	55.0	90.0
PET - Polyethylene Terephthalate	140.0	140.0
PET, 30% Glass Fiber-reinforced	70.0	130.0
PET, 30/35% Glass Fiber-reinforced, Impact Modified	100.0	230.0
PETG - Polyethylene Terephthalate Glycol	50.00	50.00
PFA - Perfluoroalkoxy	10.0	35.0

PI - Polyimide	60.0	112.0
PMMA - Polymethylmethacrylate/Acrylic	10.0	25.0
PMMA (Acrylic) High Heat	10.0	25.0
PMMA (Acrylic) Impact Modified	20.0	130.0
PMP - Polymethylpentene	100.0	150.0
PMP 30% Glass Fiber-reinforced	30.0	80.0
PMP Mineral Filled	30.0	80.0
POM - Polyoxymethylene (Acetal)	60.0	120.0
POM (Acetal) Impact Modified	90.0	250.0
POM (Acetal) Low Friction	10.00	70.00
POM (Acetal) Mineral Filled	25.0	60.0
PP - Polypropylene 10-20% Glass Fiber	50.0	145.0
PP, 10-40% Mineral Filled	38.0	110.0
PP, 10-40% Talc Filled	30.0	200.0
PP, 30-40% Glass Fiber-reinforced	45.0	160.0
PP (Polypropylene) Copolymer	60.0	500.0
PP (Polypropylene) Homopolymer	20.0	60.0
PP, Impact Modified	110.0	999.0
PPA - Polyphthalamide	960.0	1065.0
PPE - Polyphenylene Ether	130.0	300.0
PPE, 30% Glass Fiber-reinforced	90.0	130.0
PPE, Flame Retardant	200.0	300.0
PPE, Impact Modified	150.0	400.0
PPE, Mineral Filled	150.0	200.0
PPS - Polyphenylene Sulfide	5.0	25.0

PPS, 20-30% Glass Fiber-reinforced	35.0	100.0
PPS, 40% Glass Fiber-reinforced	60.0	100.0
PPS, Conductive	40.0	80.0
PPS, Glass fiber & Mineral-filled	25.0	70.0
PPSU - Polyphenylene Sulfone	133.0	690.0
PS (Polystyrene) 30% glass fiber	11.0	150.0
PS (Polystyrene) Crystal	20.0	25.0
PS, High Heat	20.0	25.0
PSU - Polysulfone	60.0	100.0
PSU, 30% Glass fiber-reinforced	55.0	90.0
PSU Mineral Filled	35.0	55.0
PTFE - Polytetrafluoroethylene	160.0	200.0
PTFE, 25% Glass Fiber-reinforced	150.0	150.0
PVC (Polyvinyl Chloride), 20% Glass Fiber-reinforced	50.0	100.0
PVC Rigid	20.0	110.0
PVDC - Polyvinylidene Chloride	20.0	50.0
PVDF - Polyvinylidene Fluoride	130.0	400.0
SAN - Styrene Acrylonitrile	20.0	30.0
SAN, 20% Glass Fiber-reinforced	50.0	150.0
SMA - Styrene Maleic Anhydride	20.0	100.0
SMA, 20% Glass Fiber-reinforced	100.0	140.0
SMA, Flame Retardant V0	40.0	70.0
SMMA - Styrene Methyl Methacrylate	18.0	160.0
SRP - Self-reinforced Polyphenylene	43.0	59.0
UHMWPE - Ultra High Molecular Weight Polyethylene	999.0	999.0

XLPE - Crosslinked Polyethylene	10.0	220.0

Toughness at Low Temperature

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» Toughness at Low Temperature Values of Several Plastics
» How to Measure the Toughness at Low Temperature of plastic

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The **two methods** are based on common principle of applying the load at high rate and measuring the amount of energy absorbed (Kg/m or Joule) in breaking the sample due to impact. However, there are some difference also in these two methods in terms of:

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Toughness Values of Several Plastics at Low Temperature

Among numerous impact tests available, we have selected Notched Izod Impact test performed at low temperature (-40°F or -40°C). It measures the energy to be applied to a notched standardized sample to break it at low temperature.

Since many materials (especially thermoplastics) exhibit lower impact strength at reduced temperatures, this test is often conducted at lower temperatures to simulate the intended end-use environment of the material. To conduct this test at low temperatures, the specimens are conditioned at the specified temperature in a freezer, quickly removed, and impacted one at a time. (*Neither ASTM or ISO specify a conditioning time or elapsed time from freezer to impact - typical values from* *other specifications are 6 hours of conditioning and 5 seconds from freezer to impact.*)

The result of the Izod test is reported in energy lost during the impact per unit of specimen thickness (such as ft-lb/in or J/cm) at the notch. Tests results, especially in Europe, may be reported as energy lost per unit cross-sectional area at the notch (J/m^2 or $ft\text{-}lb/in^2$).

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ABS Flame Retardant	30.00	90.00
ABS High Heat	40.00	90.00
ABS High Impact	70.00	250.00
ABS/PC Blend - Acrylonitrile Butadiene Styrene/Polycarbonate Blend	74.70	534.00
ABS/PC Blend 20% Glass Fiber	80.00	160.00
ASA - Acrylonitrile Styrene Acrylate	21.00	48.00
ASA/PC Blend - Acrylonitrile Styrene Acrylate/Polycarbonate Blend	70.00	70.00
CA - Cellulose Acetate	53.00	69.00
ECTFE - Ethylene Tetrafluoroethylene	48.00	122.00
FEP - Fluorinated Ethylene Propylene	999.00	999.00
HIPS - High Impact Polystyrene	69.00	69.00
LCP - Liquid Crystal Polymer - Glass Fiber-reinforced	110.00	185.00
LDPE - Low Density Polyethylene	240.00	694.00
LLDPE - Linear Low Density Polyethylene	294.00	970.00
PA 6 - Polyamide 6	16.00	210.00

PA 66 - Polyamide 6-6	27.00	35.00
PA 66, 30% Glass Fiber	90.00	110.00
PA 66, Impact Modified	64.00	220.00
PBT - Polybutylene Terephthalate	27.00	120.00
PBT, 30% Glass Fiber	86.00	112.00
PC/PBT Blend - Polycarbonate/Polybutylene Terephthalate Blend	170.00	640.00
PET - Polyethylene Terephtalate - 30% Glass Fiber-reinforced	96.00	101.00
PMMA - Polymethylmethacrylate/Acrylic	19.00	59.00
POM - Polyoxymethylene (Acetal)	53.00	250.00
POM (Acetal) Low Friction	32.00	53.00
PP - Polypropylene 10-20% Glass Fiber	48.00	48.00
PP, 30-40% Glass Fiber-reinforced	64.00	64.00
PP (Polypropylene) Copolymer	32.00	32.00
PP (Polypropylene) Homopolymer	27.00	107.00
PP, Impact Modified	25.00	135.00
PPE - Polyphenylene Ether	54.00	54.00
PTFE - Polytetrafluoroethylene	80.00	80.00