eco·ease

PET

TECHNICAL HANDBOOK

INTRODUCTION

PET IS AN AMORPHOUS, SOLID PLASTIC SHEET, WHICH CAN BE MANUFACTURED IN TRANSPARENT, TRANSLUCENT OR COLOURED FORM. IT IS MADE OF A PURE PET (POLYETHYLENE TEREPHTHALATE) WHICH IS A THERMOPLASTIC POLYESTER. THIS PLASTIC IS WIDELY KNOWN FROM ITS USE IN FOOD PACKAGING (PET-SOFT DRINK BOTTLES), AS FIBRES USED IN CLOTHING (®TREVIRA) AND AS VIDEOTAPE (®HOSTAPHAN).

Process innovation has made it possible to extrude this material into sheets of thickness between 1 to 6mm which combine good mechanical and optical properties. The unique combination of properties of PET are supplemented by good fire resistance, compliance with FDA/BGA requirements for contact with foodstuffs, and the ability of any waste sheet to be used in existing recycling facilities for PET.

This technical handbook describes the different properties of PET, details the test methods, and explains the results. In general, the tests are performed according to ISO methods. A reference to the corresponding DIN and/or ASTM method is made where appropriate.

PROPERTIES OF PET

- **Fire Rating**
  B1 (DIN), 1Y (BS), M2 (NF P) non burning drips without flame inhibiting additives.
  The product is hence suitable for indoor and outdoor applications.

- **Weathering Stability**
  Guarantee for 5 and years against yellowing and less of transparency and of stiffness.

- **Chemically Stable**

- **Meets FDA and BGA Regulations**

- **Recyclable**

- **Excellent Mechanical Properties:**
  - high impact toughness
  - high breaking resistance
  - no splintering upon breakage

- **Simple Fabrication**

  suitable for
  - routing
  - planing
  - grinding and polishing
  - sawing

- **Forming**
  - warm
  - cold
  - thermoforming

- **Optically Transparent**
  even after processing as outlined above

- **Extremely favourable bending radius**
  as low as 12 cm

PROPERTIES OF PET

Property	Method	Value	Units
General Properties			
Density	ISO 1183	1.335	$g.cm^{-3}$
Fire Rating (indoor use) (Report BAM,	DIN 4102	B1	
Aktenzeichen VII.23/24836)	BS 476 Part 7	1Y	
Mechanical Properties			
Tensile Strength (v = $5mm.min^{-1}$, -40^0C)	ISO 527-1,2	77	MPa
Tensile Strength (v = $5mm.min^{-1}$, 23^0C)	ISO 527-1,2	57	MPa
Tensile Strength (v = $5mm.min^{-1}$, 60^0C)	ISO 527-1,2	35.5	MPa
Tensile Modulus (v = $1mm.min^{-1}$, 23^0C)	ISO 527-1,2	2420	MPa
Strain at Break	ISO 527-1,2	No Break	%
Bending Stiffness (v = $2mm.min^{-1}$, 23^0C)	ISO 178	86	MPa
Bending Modulus (v = $2mm.min^{-1}$, 23^0C)	ISO 178	2400	MPa
Ultimate Bending Stress (v = $2mm.min^{-1}$, 23^0C)	ISO 178	No Break	MPa
Compression Strength (v = $5mm.min^{-1}$, 23^0C)	ISO 604	56	MPa
Ball Indentation Hardness	ISO 2039-1	117	$N.mm^{-2}$
Shore Hardness D (15s)	ISO 868	78	
Charpy Impact Toughness (23^0C)	ISO 179	No Break	$kJ.m^{-2}$
Charpy Notched Impact Toughness (23^0C)	ISO 179	4.4	$kJ.m^{-2}$
IZOD Notched Impact Toughness (23^0C)	ISO 180	3.54	$kJ.m^{-2}$
Multiaxial impact force at break (23^0C, 4mm sheet)	ISO 6603-2	8900	N
Multiaxial impact force at break (-30^0C, 4mm sheet)	ISO 6603-2	1600	N
Total Work (23^0C, 4mm sheet)	ISO 6603-2	195	J
Thermal Properties			
Softening Point HDT A (1.8MPa)	ISO 75-1,2	69.3	^0C
Softening Point HDT B (0.45MPa)	ISO 75-1,2	72.7	^0C
Vicat A Softening Temperature (10N)	ISO 306	79	^0C
Vicat B Softening Temperature (50N)	ISO 306	75	^0C
Recommended Maximum Continuous Use Temperature		60	^0C
Coefficient of Linear Expansion (-40^0C to $+60^0C$)	DIN 53752	$<60x10^{-6}$	$^0K^{-1}$
Glass Transition Temperature (DSC; $20^0C.min^{-1}$)	IEC 1006, A	82	^0C
Crystalline Melting Point (DSC)	ISO 3146	ca. 245	^0C
Optical Properties			
Refractive Index n_D at 589nm (3mm sheet)	DIN 53491	1.576	
Light Transmission (4mm sheet)	DIN 5036	89	%
Light Dispersion (4mm sheet)	ASTM 1003	0.6	%

DENSITY: ISO 1183

The density of materials is of interest when the weight of finished and semi-finished products have to be established. Density also provides information on technical properties such as stiffness, or it can be used for quality control of foamed or crystallised plastics.

Since the physical properties of a material are also directly connected to the density, it is possible to measure material changes (such as crystallinity) indirectly. The crystallinity influences the stiffness mentioned above, and it also influences the temperature stability.

The **Density ρ** of a material is the quotient of the weight m and the volume V:

$$\rho = \frac{m}{V}$$

The density of transparent (amorphous) ®Hostaglas is given in following table:

Density: ISO 1183	Value	Unit
Density	1.335	g/cm^3

The subject matter of this Standard is similar to DIN 53 479 and ASTM D 1895, and so the values from the tests are comparable.

FLAMMABILITY: DIN 4102-1

Information on the flammability of plastics is often required if they are used in building construction. Normally, materials must comply with country-specific tests, for instance, in Germany, France, Great-Britain and the United States. Sometimes one country will accept the results of a test mandated by another: Ireland, for example, accepts and uses the British tests.

In Germany, the flammability of construction materials is tested according to the Standard **DIN 4102-1**. Materials are then categorised into non-flammable materials (building material classes A1 and A2), and flammable materials (building material classes B1, B2 and B3). Since all plastics are ignitable, they all fall into the categories B1 to B3, whose requirements are described in the following sections:

- **Building material class B1,** fire-resistant:
  The average of the remaining sample length must be greater than 15cm, and none of the samples are permitted to have a length of 0cm. The exhaust temperature must be not greater than 200°C, and the B2 requirements of the small-burner-test have to be met.

- **Building material classes B2,** moderately-flammable:
  Five samples have to meet the requirements of the small-burner-test. The tip of the flame must not reach the mark within 20 seconds for any of the samples.

- **Building material classes B3,** flammable:
  All materials fall in category class B3 when they do not comply with the requirements of class B1 or B2.

In Great Britain plastic sheet is tested according to **BS 476 Part 7**. This method is used to rate the speed of the fire propagation on the surface of the sample. The sample is held vertically. The classification of the test material is made according to the flame size and the propagation.

The fire rating in France is performed according to **NF P92-501**. Aside from the fire rating there is a Standard **NF X10-702** which tests smoke and fume behaviour. The M classification for fire, and the F classification for smoke can then be determined.

The fire rating in the Netherlands is performed according to **NEN 6065**. Materials are divided into classes 1 to 5, with 1 being the best, for the surface flame spread and the contribution to flash-over.

The different national fire rating classifications of PET are given in the following table:

Flammability classification	**Sheet thickness**	**class**
Fire rating: DIN 4102-1 (inside use) Prüfungszeugnis BAM, Aktenzeichen VII.23/24836	1 - 6 mm	B 1
Fire rating: BS 476 part 7 Test Reports Warrington Fire Research, Warres No. 65685, 65686 and 66087	3 - 6 mm	1 Y *
Fire rating: NF P92-501 Process-verbal No. 943/95	1 - 5.5 mm	M 2
Smoke and fume rating: NF X10-702, Process-verbal No. 943/96	1 - 3 mm	F 1
Surface flame spread: NEN 6065	1 - 5 mm	1
Contribution to flash-over through: NEN 6065	1 - 5 mm	1

* The supplementary Y means that the sample softened and/or an influence on the flame propagation within allowable tolerances was observed.

BARRIER BEHAVIOUR

Testing the barrier behaviour gives information on the gas and water vapour permeability through plastics and characterises the barrier properties. The packaging and container industries which make film, sheet or containers (e.g. bottles) are the prime industries most interested in these tests.

Gas permeability: ISO 2556

The **gas permeability** is defined by the gas volume which diffuses through a sample of one square meter and thickness d, during 24 hours at a specific temperature and pressure difference.

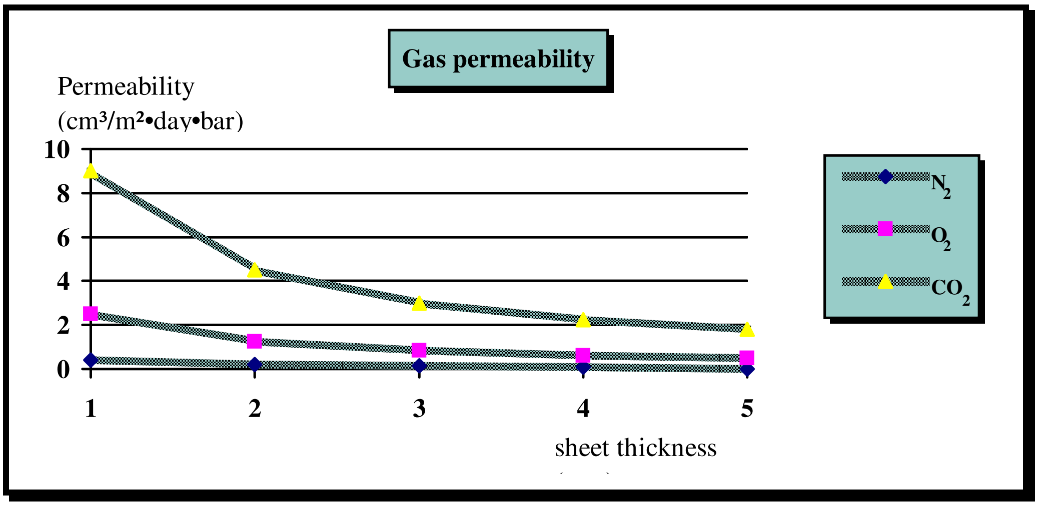
The test is performed with a variety of gasses, depending on the application. The permeability behaviour of N_2, O_2 and CO_2 are the most common. The temperature and humidity can be varied, but are usually fixed at 23°C and 0% respectively.

The relationship is defined by:

$$P = \frac{V}{F \times d \times D}$$

where **P** is the Permeability, **V** is the gas volume, **F** is the surface area, **d** is the sample thickness and **D** is the pressure difference.

The Standard ISO 2556 is identical to DIN 53 380.



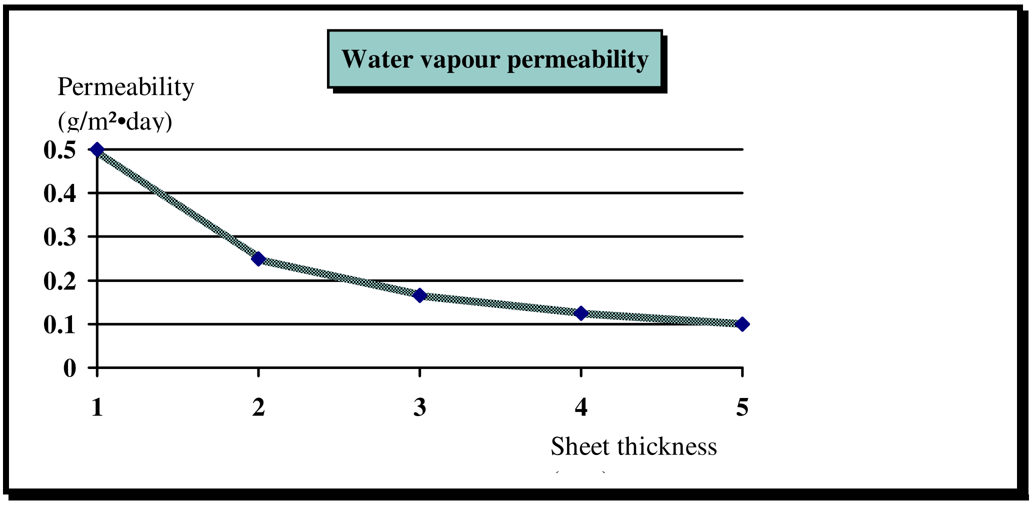
Water vapour permeability: DIN 53 122

The **water vapour permeability** is defined by the amount in grams of water volume which diffuses through a sample of one square meter and thickness d, during 24 hours at a specific temperature and humidity difference. The temperature and humidity can be varied, but are usually fixed at 23°C and 0% respectively.

The relationship is defined by:

$$WDD = \frac{G}{F \times d}$$

where **G** is the amount by weight, **F** the surface area and **d** is the sample thickness



MECHANICAL PROPERTIES

For the design engineer, the converter, and the end user of plastics, the most important mechanical properties are determined by stress-, bend- and pressure experiments. These properties will allow comparison between different materials and material qualities. It has to be kept in mind that a detailed comparison of the behaviour of plastics is only possible when the mechanical property data are determined under a variety of temperatures and test conditions (e.g. test speeds, temperatures, sample preparation and preconditioning of the sample).

The experiments are performed as short term measurements on standardised test specimens under predetermined conditions. For example, the sample pre-treatment (preconditioning), the test climatisation (e.g. temperature, humidity) and the test speed are standardised. The test results are dependent on the way samples are generated, for example, by extrusion or by injection moulding. All the properties discussed in the following sections are based on samples prepared out of PET sheet from production.

The mechanical properties of plastics are a variable of time and temperature, since plastics show a visco-elastic behaviour. These properties are needed for static stability and deformation calculations of parts which have to withstand long-term loads and stresses. Therefore the results of the short term measurements discussed in following sections cannot be used for long term static considerations.

The visco-elastic behaviour can be described with the help of the modulus of elasticity (or Young's modulus), which can be determined from standardized measurements. For instance, the modulus of elasticity is dependent on stress time or the oscillation frequency during vibration experiments. Plastics show a different elasticity behaviour compared to natural materials. Holding a sample in place after applying an abrupt stress for example, shows that the tension will decrease over time. This decrease is based on molecular relaxation processes, which means that the molecules will adapt to the new sample shape. The elasticity modulus will therefore also decrease over time.

The modulus of elasticity and the flexural modulus of PET measured with the stress and the bend test, show almost identical values between -40 °C to 70 °C. It is interesting to note that only amorphous plastics with a Tg considerably higher than room temperature behave like this.

TENSILE STRESS BEHAVIOUR - ISO 527-1,2

This test provides some insight to the dependence between longitudinal applied stress and the deformation behaviour of plastics. Tensions are calculated from their force and length changes. Plotting the data into a stress-strain curve visualises this dependence.

Some properties which can be determined are tensile strength, tensile stress at rupture, yield stress, modulus of elasticity and strain at tensile strength. These properties are defined as:

The **tensile strength** is the quotient of the measured maximum force at break (in N) and the initial cross-section of the sample (in mm^2).

The **tensile stress at rupture** is quotient of the measured force (in N) and the initial cross-section of the sample (in mm^2).

The **yield stress** is the tensile strength at which the gradient angle of the stress-strain curve becomes zero for the first time.

The **strain** is the change in length related to the initial measured length during any time of the experiment. Usually the **strain at rupture** and the **strain at tensile strength** are specified.

The **modulus of elasticity** or **Young's modulus** is a measure for the stiffness of the material. It is an important measure for static calculations and can be described as:

$$S = E \times d^3$$

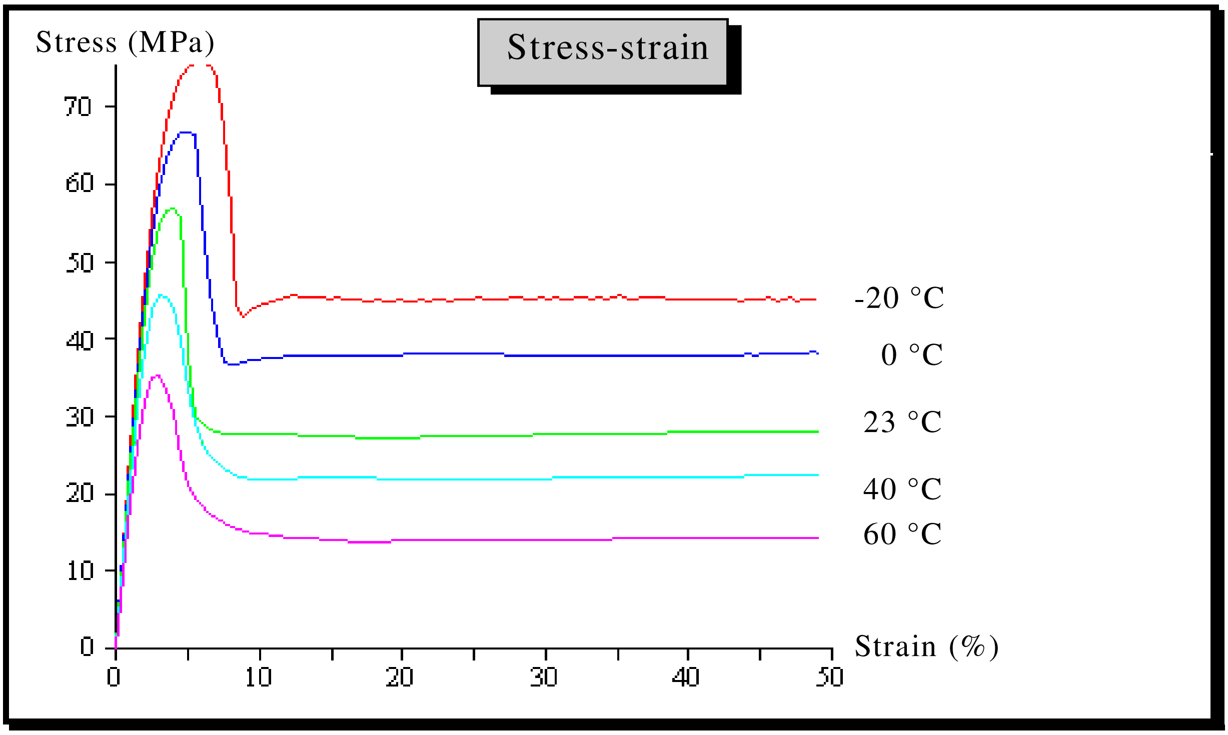
Of which **S** is the stiffness, **E** is the modulus of elasticity and **d** is the thickness of the sample.

The modulus of elasticity is usually measured at the very beginning of the tensile stress experiment. In this part of the stress-strain curve, it is assumed that plastic materials still show a fully elastic behaviour. PET has a high modulus of elasticity. The material shows a distinct stretch range with a high elongation, is not brittle but behaves in a ductile manner. To give a simple understanding of the relationship it can be said that a material with a high modulus of elasticity only needs to be thin to achieve a certain stiffness.

For example, one advantage of a high stretch range is that the material can easily be thermoformed with good detail and high deformation. On the other hand, a high modulus of elasticity allows for the use of thinner sheet when only regular deformation is required, which results in a lower material cost.

The tensile strength and the yield stress are the same for PET. The material also does not show any rupture between -40 to 70°C at a draw speed of 5mm/min. This means that PET is very tough.

Stress-strain curves from PET at different temperatures and at a draw speed of 5mm/min.

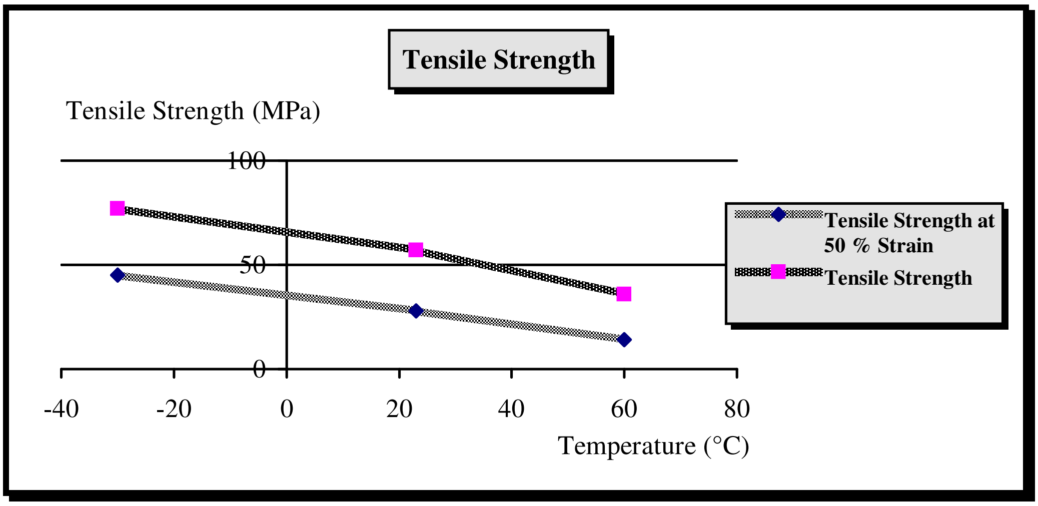


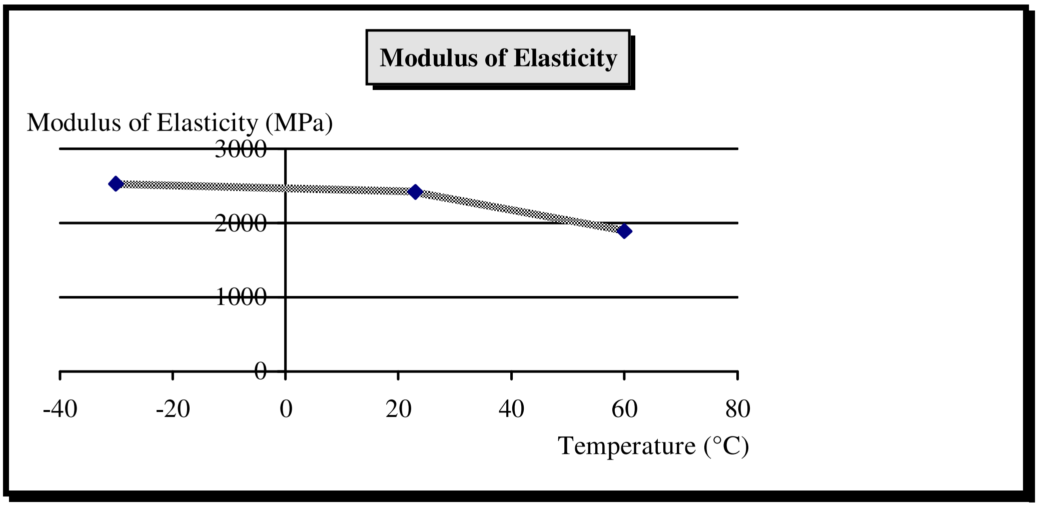
The following table gives typical values of PET. The subject matter of this test standard is similar to DIN 53 455 and DIN 53 457 (for the modulus of elasticity), so the values obtained from the tests are comparable.

Tensile stress behaviour: ISO 527-1,2	**Value**	**Unit**
Tensile bar type 1A, Temperature = 23°C, Draw speed (v) = 50 mm/min		
Tensile strength	61	MPa
Tensile strength at 50 % strain	22	MPa
Strain at tensile strength	4,3	%
Modulus of elasticity (v = 1 mm/min)	2250	MPa
Tensile stress at rupture	3,5	MPa
Strain at rupture [1]	44	%
Tensile bar type 1A, Temperature = -30°C, draw speed (v) = 5 mm/min		
Tensile strength	77	MPa
Tensile strength at 50 % strain	45	MPa
Strain at tensile strength	6,1	%
Modulus of elasticity (v = 1 mm/min)	2530	MPa
Strain at rupture	no break	%
Temperature = 23°C		
Tensile strength	57	MPa
Tensile strength at 50 % strain	28	MPa
Strain at tensile strength	3,8	%
Modulus of elasticity (v = 1 mm/min)	2420	MPa
Strain at rupture	no break	%
Temperature = 60°C		
Tensile strength	36	MPa
Tensile strength at 50 % strain	14	MPa
Strain at tensile strength	2,8	%
Modulus of elasticity (v = 1 mm/min)	1890	MPa
Strain at rupture	no break	%

[1] Some of the samples ruptured

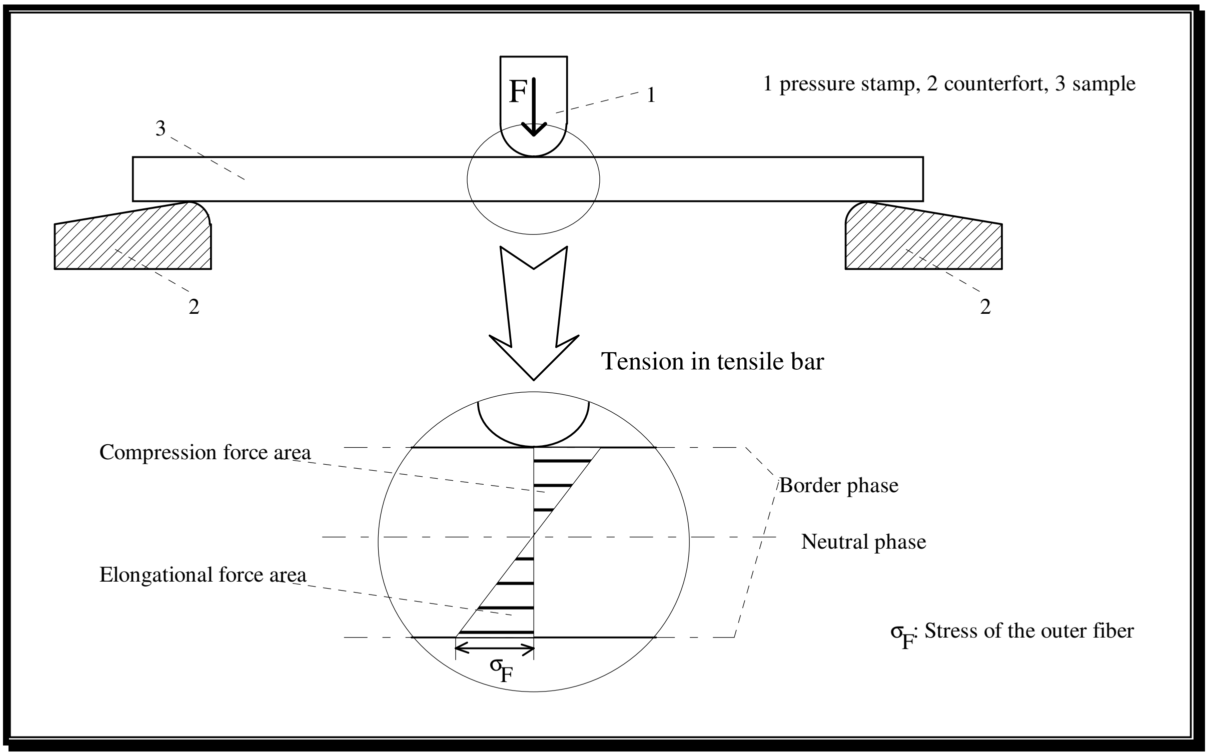
The following graphs show the tensile strength, modulus of elasticity, of PET with regard to temperature.





BENDING STRESS BEHAVIOUR: ISO 178

Bending stress experiments give information on the behaviour of plastics under a 3-point bending pressure. It is important to know that in this test both compressive and elongation forces occur simultaneously in the sample. In order to obtain accurate measurements which then can be used to compare different materials with one another it is important to be in the linear pressure range. Therefore, a standardised point of measure, the flexural stress at 3.5% strain, has been chosen as a reference point. It is also important to have symmetrical test samples. With all the bending stress tests, pressure variation throughout the sample cross-section will occur. A pressureless condition will take place in the centre. This is called the neutral phase. The top and the bottom of the sample will encounter the maximum pressures. These are called the border phases.



The properties which can be determined with this test are:

The **flexural strength,** which is the maximum force, when the maximum takes place before 3.5% strain, measured in MPa.

The **flexural stress at 3.5% strain,** which is the force when the border phase strain equals 3.5%.

The **flexural stress at rupture,** which is the maximum flexural stress, when the sample breaks before the border phase strain equals 3.5%.

The **strain,** which is the change of the bend related to the initial position during any time of the experiment. Usually the **strain at flexural strength** is specified.

The **flexural modulus,** which is the a measure for the stiffness of the material. It is important measure for static calculations and can be described as:

$$S = E \times d^3$$

Whereas **S** is the stiffness, **E** is the flexural modulus and **d** is the sample thickness.

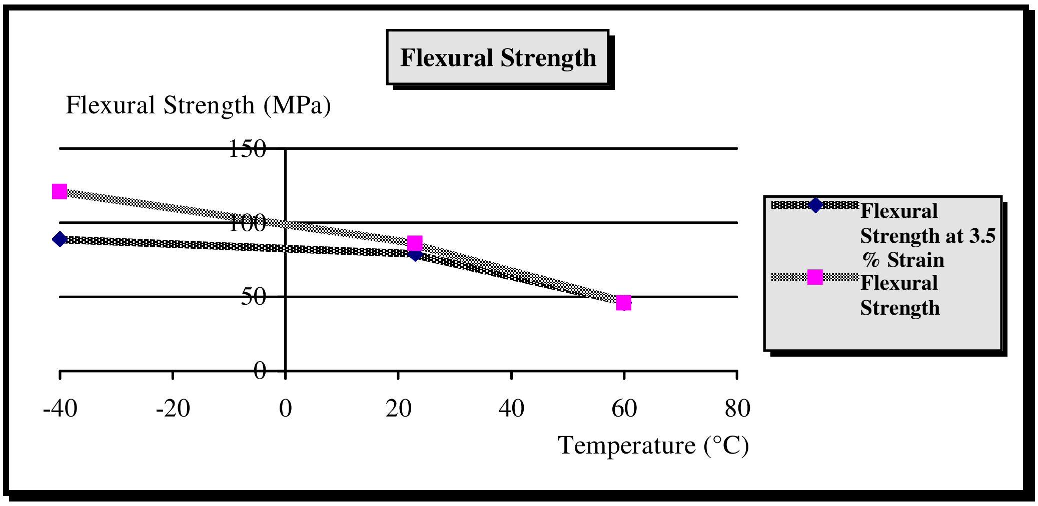
With a material with a high flexural modulus, only a small thickness is needed to achieve a certain stiffness.

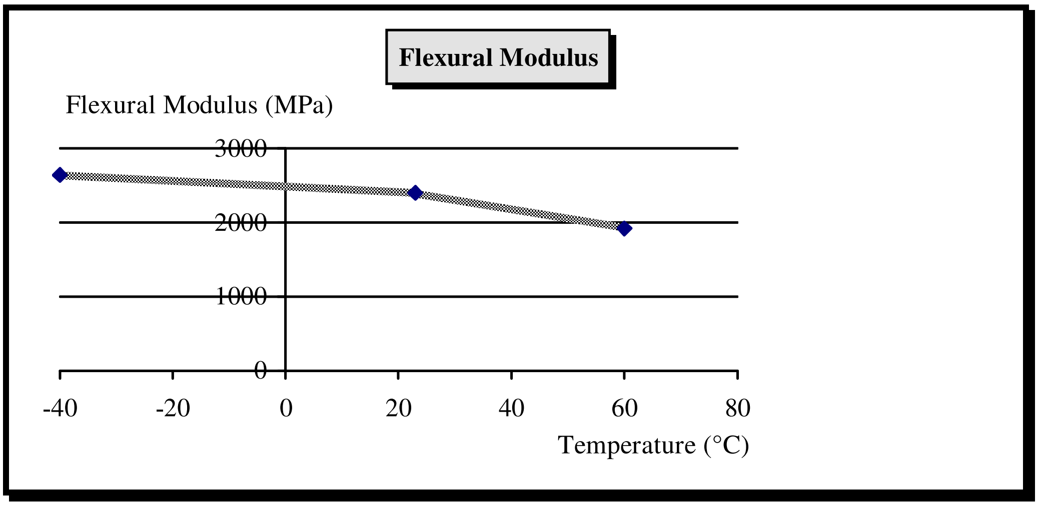
The **stress of the outer fibre** is the force which occurs in the border phase.

The following table gives typical values of PET. The subject matter of ISO 178 is similar to DIN 53 452 and DIN 53 457 (for the flexural modulus). Therefore the values obtained from the tests are comparable.

Bending stress behaviour: ISO 178 (Bending speed = 1.1% per min; v = 2mm/min)	**Value**	**Unit**
Temperature = -40°C		
Flexural strength	121	MPa
Flexural stress at 3.5% strain	89	MPa
Strain at flexural strength	7	%
Flexural modulus	2640	MPa
Flexural stress at rupture	no break	MPa
Temperature = 23°C		
Flexural strength	86	MPa
Flexural stress at 3.5% strain	79	MPa
Strain at flexural strength	4.5	%
Flexural modulus	2400	MPa
Flexural stress at rupture	no break	MPa
Temperature = 60°C		
Flexural strength	46	MPa
Flexural stress at 3.5% strain	46	MPa
Strain at flexural strength	4	%
Flexural modulus	1920	MPa
Flexural stress at rupture	no break	MPa

The following graphs show the flexural strength and flexural modulus of PET with regard to temperature:





COMPRESSIVE STRESS BEHAVIOUR: ISO 604

This test provides some insight on the behaviour of plastics when they are compressed in one direction. Properties which can be determined with this test method are: compressive strength, compressive yield stress, compressive stress at x% strain, and strain at compressive yield stress.

The **compressive strength** is the quotient of the measured force (in N) and the pressurised area (in mm^2) at the time of break.

The **compressive yield stress** is the compressive strength at which the gradient angle of the stress-strain curve becomes zero for the first time.

The **compressive stress at x% strain** is the stress which occurs at a certain strain x.

The **strain at compressive yield stress** is the change in thickness related to the initial measured thickness during any time of the experiment.

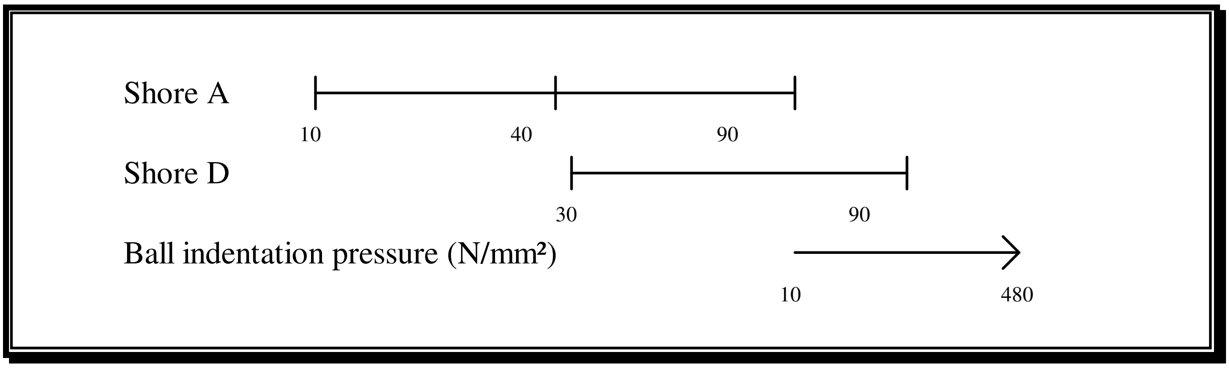
Following table gives typical values of PET. The subject matter of ISO 604 is the same as DIN 53 454, therefore the values obtained from the tests are comparable.

Compressive Stress behaviour: ISO 604 Pressure speed (v) = 5 mm/min; Temperature = 23°C	**Value**	**Unit**
Compressive stress at 1% strain	22	MPa
Compressive yield stress	56	MPa
Strain at compressive yield stress	4.4	%
Compressive strength	no break	MPa

HARDNESS: ISO 868 AND ISO 2039-1

The hardness of a material provides information about the force needed for an irreversible deformation of the surface. The hardness tests discussed here are called impression methods. The penetrating resistance to the intruding tip (ball or cone) into a surface is measured. The penetrating resistance related to the surface area is determined in the ball-indentation hardness test. The shore method test uses a spring-loaded tip. Penetrating depth and resistance are both dependent upon the hardness of the material. The hardness and the modulus of elasticity of plastics have a certain correlation.

It is important to know that there is no linear correlation between the different test methods, also the units of measure are not the same. Following graph shows the different methods in comparison to each other.



The **ball indentation hardness** is the quotient of the applied pressure and the contact area of the surface with a 5mm diameter ball, measured after 10, 30, or 60 seconds.

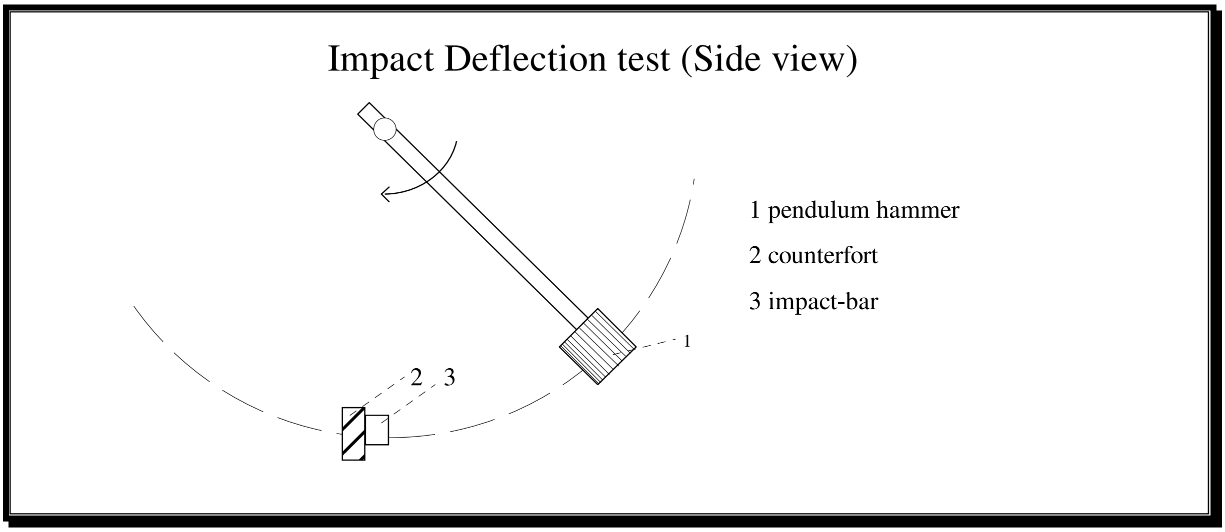
The **Shore hardness** is the resistance of intrusion under a defined spring-loaded force of a cone tip (Shore A) or rounded cone tip (Shore D). The received values have no unit.

The following table gives typical values of PET. ISO 2039-1 is the same as DIN 53 456, therefore the values obtained from the tests are comparable. There is no equivalent DIN standard to ISO 868.

Hardness: ISO 868 and ISO 2039-1	Method	Value	Unit
Shore hardness D (15 s)	ISO 868	78	N/mm^2
Ball indentation hardness (Pressure: 358 N, 30 s)	ISO 2039-1	117	N/mm^2

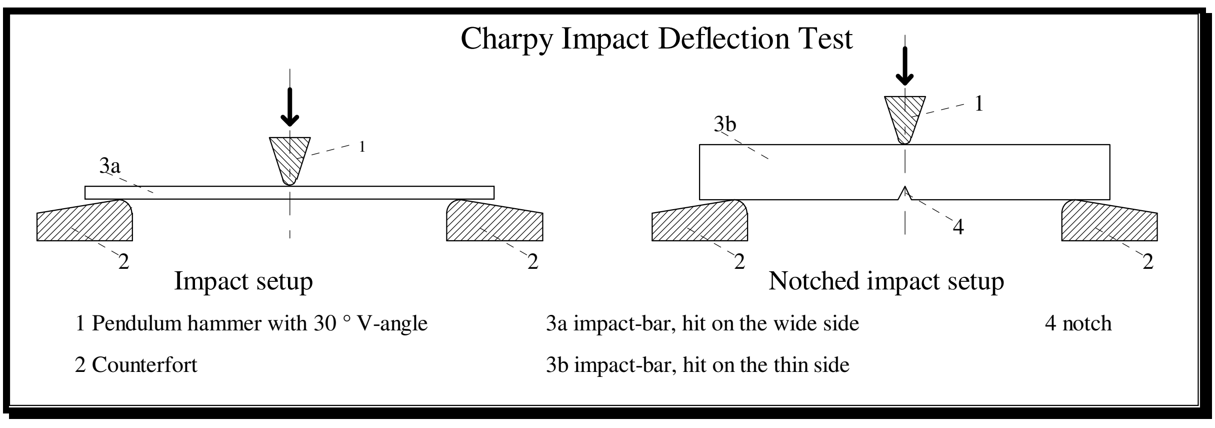
IMPACT DEFLECTION BEHAVIOUR: ISO 179 / ISO 180 (CHARPY & IZOD)

The Charpy and Izod impact deflection tests give additional information on the bending tests with regard to break resistance after applying a load on impact (e.g. hail or vandalism). Notched-bar impact tests simulate the influence of deep surface marks on the surface. In general, the description of a notch is any cross-section transition which influences the homogeneous tension distribution of a material. Specifically, a technical notch is a notch with a circular base and straight sides which have a certain angle to the surface.

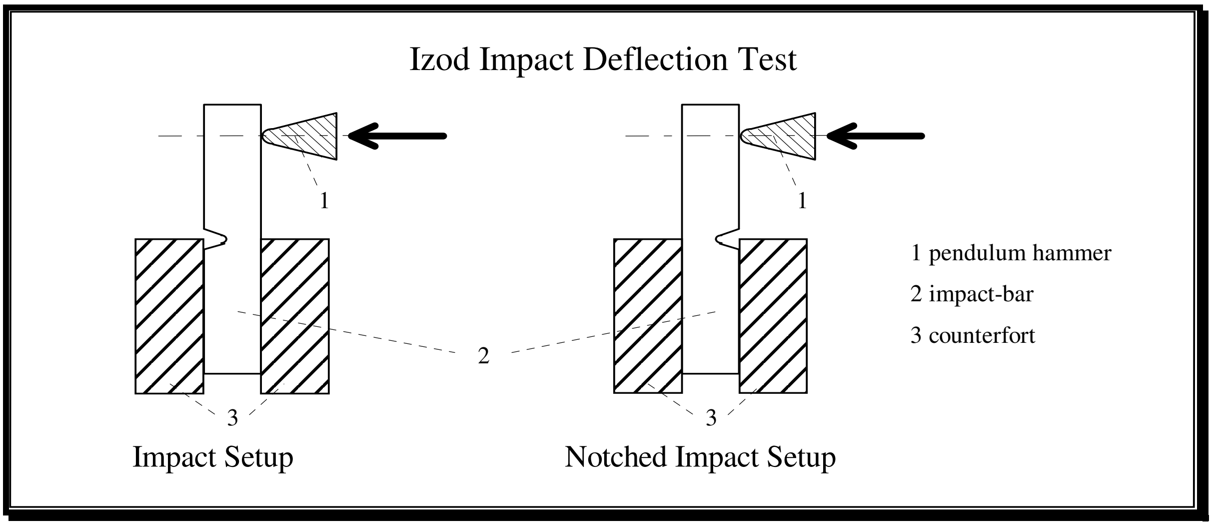


The test according to ISO 179, also called the Charpy-test, consists of two parts: the impact and the notched-bar impact deflection test. Both tests are performed with the same equipment, set-up and tensile bars. The impact-bar has a notch on one of the thin sides.

The test set-up is similar to the 3-point bending stress test but a pendulum hammer hits the bar once on impact. The sample will break if the material is brittle enough. In case of breakage, the used energy is determined by the comparison of the height of the hammer before and after impact.



The test according to ISO 180, called the Izod-test, also consists of two parts, the impact and the notched-bar impact deflection test. Both tests are performed with the same equipment and notched-bars, but with a different set-up. The impact-bar has a notch on one thin side, is held in place between two supports, and is once hit with a pendulum hammer on impact. The used energy is determined by the comparison of the height of the hammer before and after impact.



The **Charpy impact strength** is the energy used after breakage of the impact-bar, related to the initial cross-section.

The **notched Charpy impact strength** is the energy used after breakage of the notched impact-bar, related to the initial cross-section at the notch.

The **Izod impact strength** is the energy used after breakage of the notched impact-bar, related to the initial cross-section at the notch. The notch is directed away from the pendulum hammer.

The **notched Izod impact strength** is the energy used after breakage of the notched impact-bar, related to the initial cross-section at the notch. The notch is directed into the direction of the pendulum hammer.

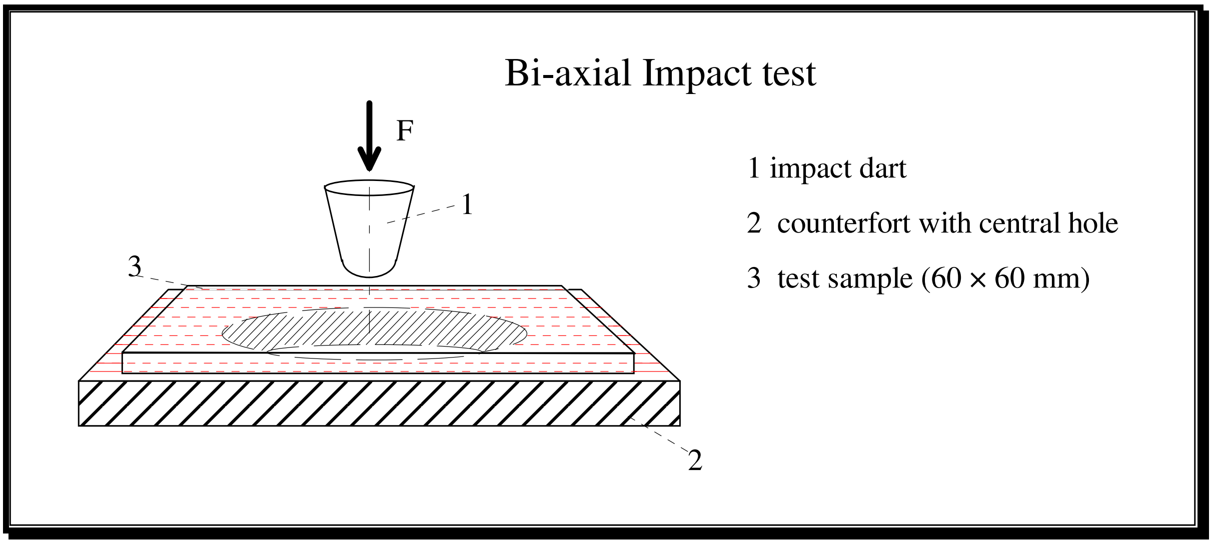
The following table gives typical values for ®Hostaglas. The subject matter of ISO 179 is the same as DIN 53 453, so the values obtained from the tests are comparable. There is no comparable standard for ISO 180.

Impact deflection behaviour: ISO 179 and ISO 180	Method	Value	Unit
Charpy impact strength at 23°C	ISO 179	no break	kJ/m²
Charpy impact strength at -30°C	ISO 179	73	kJ/m²
Charpy notched impact strength at 23°C	ISO 179	4.4	kJ/m²
Charpy notched impact strength at -30°C	ISO 179	2.4	kJ/m²
Izod notched impact strength at 23°C	ISO 180	3.5	kJ/m²

BI-AXIAL IMPACT BEHAVIOUR: ISO 6603-2

A bi-axial impact test is the dart-impact test according to ISO 6603-2. The test is distinguished by impact in two directions, compared to the impact tests in one direction (Charpy and Izod). This test is more appropriate for sheet products, since bi-axial loads occur more often in real life than do one-directional loads. Brittle or ductile breaks, ruptures or bumps can occur depending on the material and the test conditions. This defined behaviour can give information on the actual behaviour of the material during practical applications.

The forces within the test samples show very complex distributions. This behaviour makes it very difficult to compare the impact energy of samples of different thickness. Measuring only one thickness is not enough, as with most other tests.



The **damaging energy** is the total energy absorbed by the sheet up to the pre-defined damaging point.

The **pre-defined damaging point** is the point of the stress-strain curve at which the gradient angle becomes zero for the first time and is followed by a force drop of more than 10%.

The **damaging force** is the total force used by the impact-dart up to the pre-defined damaging point.

The **damaging deformation** is the deformation of the sheet up to the pre-defined damaging point.

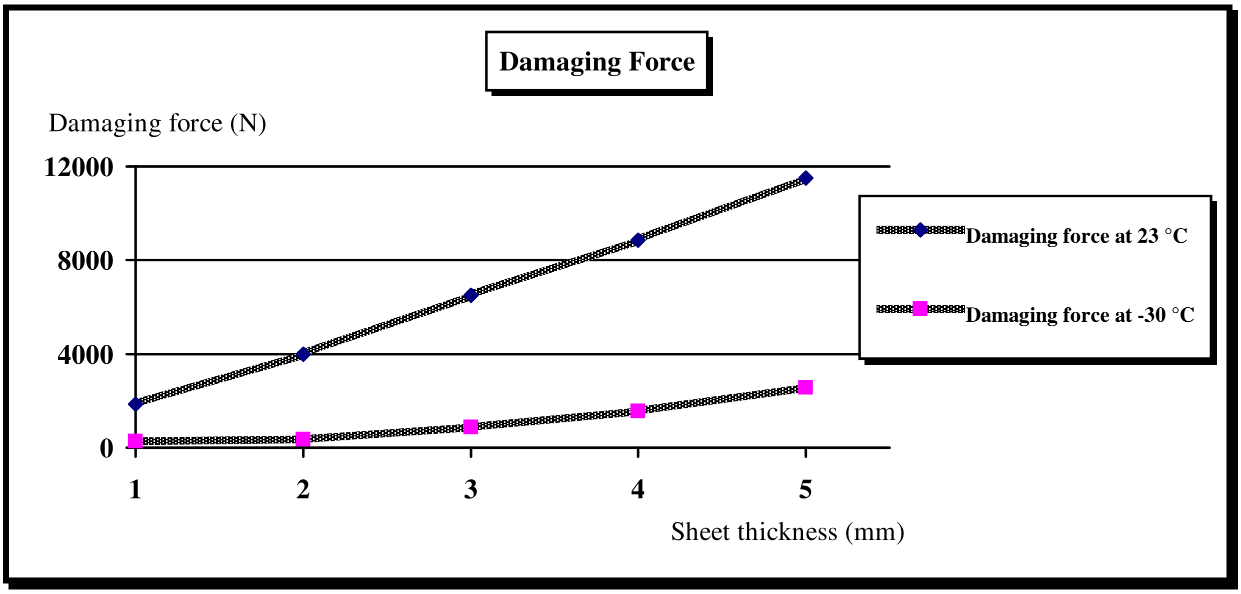
The **total energy** is the total energy used until the point of puncture.

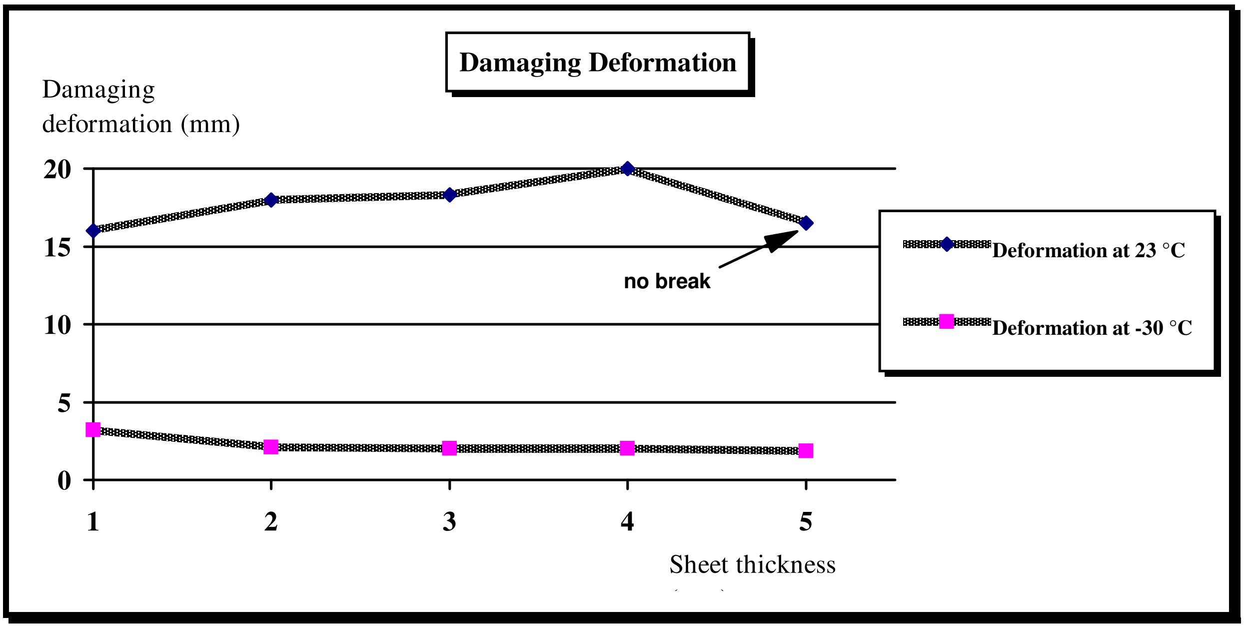
The following table gives typical values for PET. The subject matter of ISO 6603-2 is the same as DIN 53 443, so the values obtained from the tests are comparable.

Dart impact test with electronic data acquisition: ISO 6603-2 Impact speed = 4.4 m/s; Fall height = 1m; Fall weight = 20kg	**Value**	**Unit**
1mm thick Sample		
Damaging force at 23°C	1,900	N
Damaging force at -30°C	260	N
Damaging energy at 23°C	21	J
Damaging energy at -30°C	0.4	J
Damaging deformation at 23°C	16	mm
Damaging deformation at -30°C	3.2	mm
Puncture energy at 23°C	29	J
Puncture energy at -30°C	1	J
2mm thick Sample		
Damaging force at 23°C	4,000	N
Damaging force at -30°C	370	N
Damaging energy at 23°C	51	J
Damaging energy at -30°C	0.5	J
Damaging deformation at 23°C	18	mm
Damaging deformation at -30°C	2	mm
Puncture energy at 23°C	73	J
Puncture energy at -30°C	1.2	J

Dart impact test with electronic data acquisition: ISO 6603-2 Impact speed = 4.4m/s; Fall height = 1m; Fall weight = 20kg	**Value**	**Unit**
3mm thick Sample		
Damaging force at 23°C	6,500	N
Damaging force at -30°C	890	N
Damaging energy at 23°C	86	J
Damaging energy at -30°C	1	J
Damaging deformation at 23°C	18	mm
Damaging deformation at -30°C	2	mm
Puncture energy at 23°C	130	J
Puncture energy at -30°C	4	J
4mm thick Sample		
Damaging force at 23°C	8,900	N
Damaging force at -30°C	1,600	N
Damaging energy at 23°C	130	J
Damaging energy at -30°C	2	J
Damaging deformation at 23°C	20	mm
Damaging deformation at -30°C	2	mm
Puncture energy at 23°C	195	J
Puncture energy at -30°C	8	J
5mm thick Sample		
Damaging force at 23°C	11,500	N
Damaging force at -30°C	2,600	N
Damaging energy at 23°C	130	J
Damaging energy at -30°C	3	J
Damaging deformation at 23°C	172	mm
Damaging deformation at -30°C	17	mm
Puncture energy at 23°C	200	J
Puncture energy at -30°C	9	J

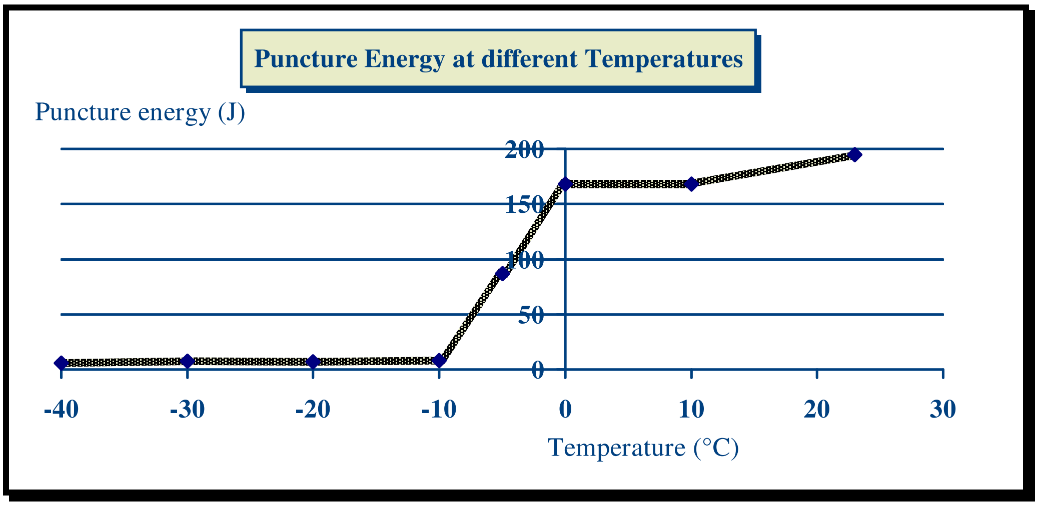
The following graphs show the correlation between the sheet thickness and the damaging force, damaging energy, damaging deformation and the puncture energy respectively of PET at different temperatures.





The following table and graphic show the mechanical behaviour of 4mm PET sheet with regards to the damaging energy and the temperature.

Dart impact test with electronic data acquisition: ISO 6603-2 Impact speed = 4.4m/s; Fall height = 1m; Fall weight = 20kg	**Value**	**Unit**
4mm thick Sample		
Puncture energy at -40°C	6	J
Puncture energy at -10°C	8	J
Puncture energy at -5°C	87	J
Puncture energy at 0°C	168	J
Puncture energy at 10°C	168	J
Puncture energy at 23°C	195	J



OPTICAL PROPERTIES

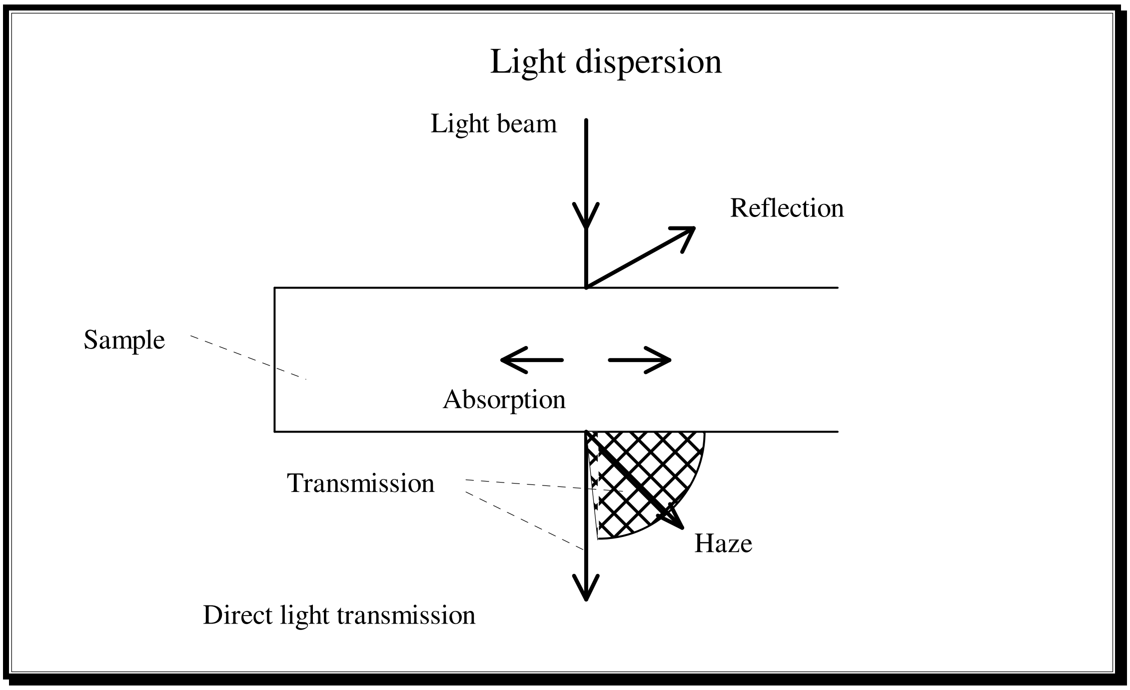
LIGHT TRANSMISSION AND HAZE: ASTM D 1003

Light transmission, haze and clarity are related terms which can be grouped under the collective term “transparency.” Incident light is either reflected, absorbed, or deflected from a material or else is transmitted through the material without distortion.

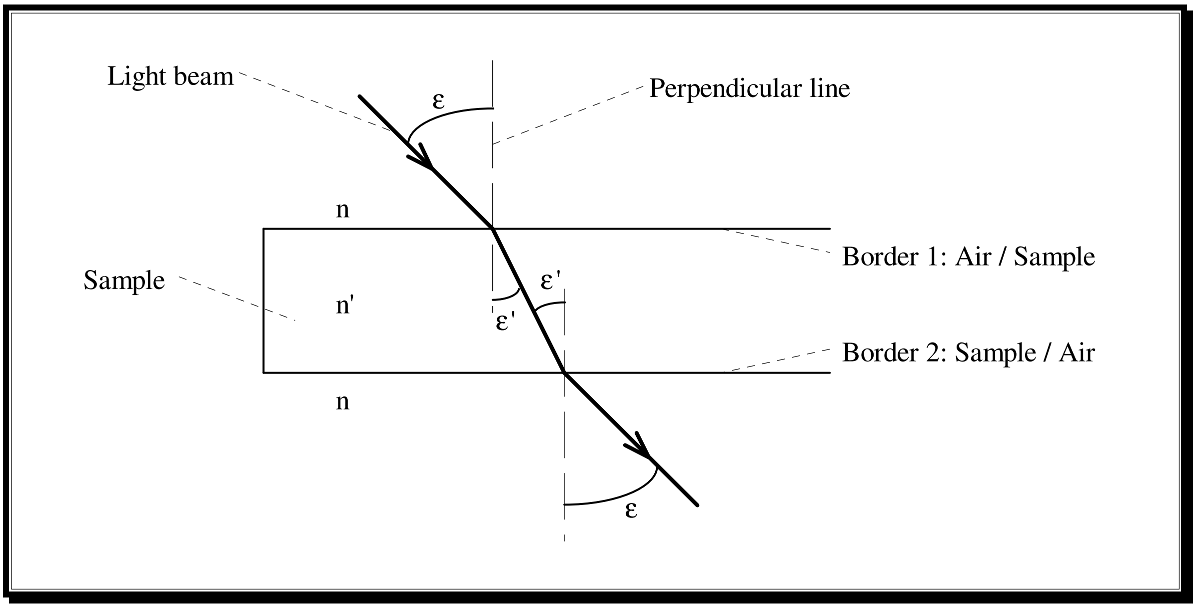
The total transmission is the part of the light which is emitted on the back side of a sample. It can be separated into light transmission and haze.

The **total light transmission** is the relationship between the total amount of the exiting light and the incoming light. It is reduced by absorption and reflection.

The **haze** is the percentage of the exiting light which is deflected more than 2.5° of the incoming light beam.



The **refractive index** n is the relation between the incoming light angle (ε) and outgoing light angle (ε′). It is defined by following formula: $n = \sin \varepsilon / \sin \varepsilon'$. The value n is the refractive index of a sample material compared to vacuum, which is very close to the refractive index of air. A light beam is broken towards the perpendicular line, when the refractive index is smaller from the medium it leaves compared to the medium it enters. The refractive index is also dependent on temperature and wave length.



The typical values for 4 mm transparent ®Hostaglas are:

Optical according to ASTM 1003	Value	Unit
Transmission	89	%
Haze	0.6	%

GLOSS: ISO 2813

Gloss plays an important role with transparent materials. A low gloss means that the reflected light is dispersed strongly, and the depth-sharpness will be reduced significantly. This is the case with matte surfaces (anti-reflection). The gloss is usually measured with a reflectrometer. The reflectometer value, measured according to DIN 67 530, is based on a black glass standard with a defined refractive index. The value for this standard is defined as 100 units.

In this measurement, light is directed at the sheet at three different angles: 20°, 60° and 85°. The 60 degree light angle is preferably used with medium gloss surfaces. The measured values should be between 10 and 70 gloss units. High gloss surfaces, which have a higher value at the 60° light angle, should be measured at 20°. Matte surfaces, on the other hand, should be measured with 85° light. In order to obtain good results, the surface to be measured should be flat. Special care should be taken with transparent samples, because the background can influence the measurements. For these samples a matte, black background is usually used.

Gloss is defined as the ratio of the reflective light intensity of the sample and the intensity of a high quality optical mirror used as the reference.

The typical values for 4 mm transparent PET are:

Gloss: ASTM 2813	Value	Unit
Gloss 20°	170	-
Gloss 60°	140	-

ISO 2813 is comparable to DIN 67 530 and ASTM D 2457.

SCRATCH RESISTANCE: DIN 52 348 (SAND ABRASION TEST)

The sand abrasion test is used to measure the sensitivity to abrasion of transparent materials used in glazing applications. The unit of measure for the amount of abrasion is the haze.

In this test, 3kg of sand abrades the sheet surface. A defined amount of sand flows through a pipe from a height of 1.6m onto a sample which is rotating at 250rpm. In addition, the sample is fixed at a 45° angle, so that the sand can flow away easily without interfering. The haze is measured after the test, and is compared with standards. The increase in haze is the unit of measure for the surface deformations caused by the abrasion test. The light density coefficient Δl (cd/m^{2}lx), or the measured increase in haze $\Delta\tau$ (%), is stated.

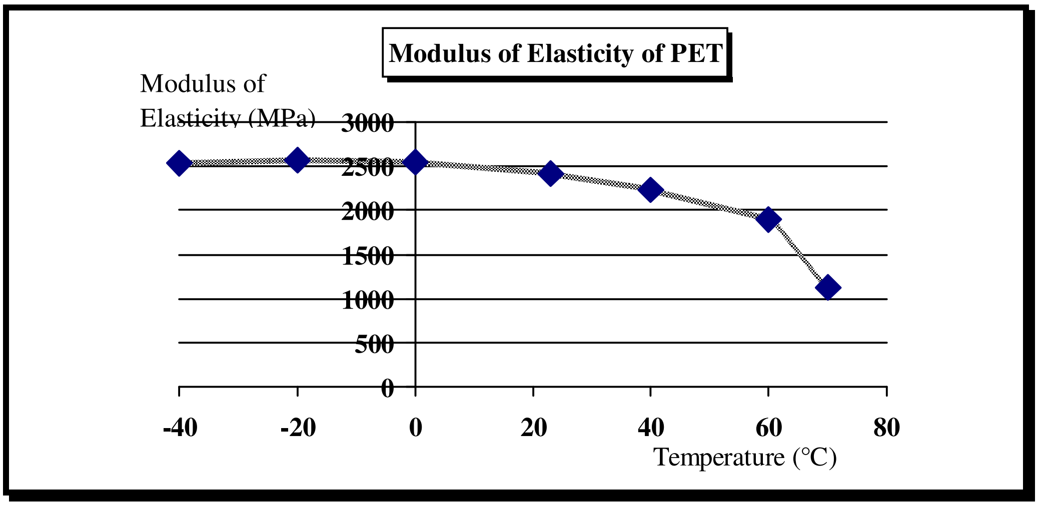
The typical value for 4 mm transparent PET is:

Scratch resistance: DIN 52 348, measured on the relative light density coefficient Λl	**Value**	**Unit**
Scratch resistance	48	cd/m^{2}lx

TEMPERATURE BEHAVIOUR

®Hostaglas is a transparent amorphous thermoplastic. The molecules of amorphous thermoplastics are not arranged in a structure but are randomly distributed. The molecules can therefore move easily when the material is heated. The flat PET sheet can be reformed with heat and pressure into another shape, e.g., by pressure or vacuum forming, or hot-bending, to produce a three-dimensional part.

The material stiffness is a function of the modulus of elasticity. The following graph shows the modulus of elasticity in relation to the temperature. The material is rigid below 60°C, showing a fairly constant modulus of elasticity, and begins to soften above 65°C. The material starts melting at the glass-transition temperature (Tg), which is 84°C for PET. The vicat-softening temperature, the heat deflection temperature, and the coefficient of linear thermal expansion give additional information about the temperature behaviour of thermoplastic materials.

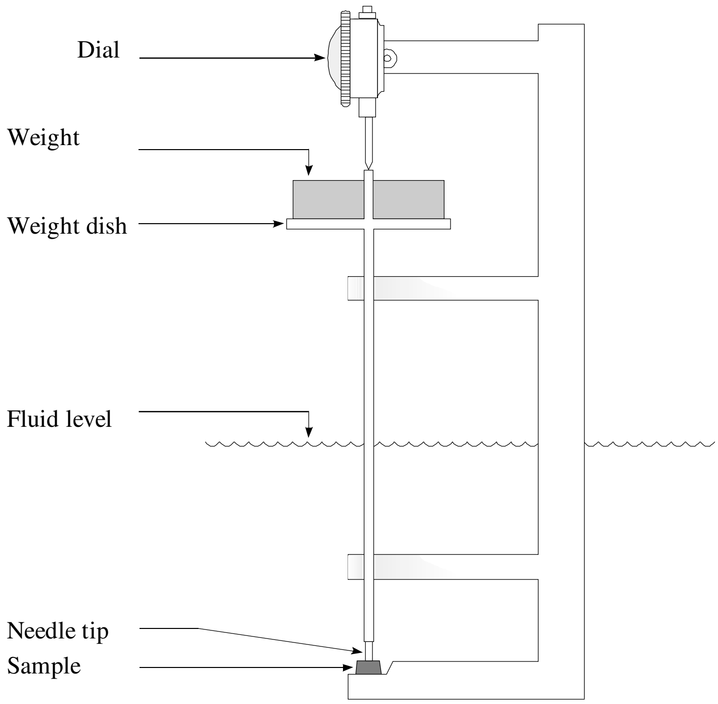


VICAT-SOFTENING TEMPERATURE: DIN/ISO 306

The **vicat-softening temperature** (VST) is determined by placing the sample in a heated, thermally-controlled water bath, and applying a load of either 10N for Vicat A or 50N for Vicat B. The load is applied on a needle tip with a surface area of $1mm^2$. The temperature is continuously raised until the penetration of the needle is 1mm; this is then the VST.

The typical values for 4mm PET are:

Thermal Properties of PET	Value	Unit
Vicat A softening temperature (10N)	79	°C
Vicat B softening temperature (50N)	75	°C



Test setup for Vicat-measurement

HEAT DEFLECTION TEMPERATURE (HDT): ISO 75-1,2

The test set-up is similar to the set-up of the vicat-softening temperature. In this case, the sample rests on two supports while a load is applied in the centre of either 1.8MPa for HDT A, or 0.5MPa for HDT B.

The **Heat Deflection Temperature** is the temperature where the strain in the border face equals 0.2%.

Thermal Properties of PET	Value	Unit
HDT A (1.8MPa)	69.3	°C
HDT B (0.45MPa)	72.7	°C

ISO 75-1,2 is the same as DIN 53 461, so the values obtained from the tests are comparable.

COEFFICIENT OF LINEAR THERMAL EXPANSION α: DIN 53752

The coefficient of linear thermal expansion α is used to determine changes in length or dimension which occur as a result of heat expansion. This material property is especially important for large size sheets, used as part of outside construction, which are subject to wide temperature differences.

The way the sheets are mounted is also important, since different levels of thermal expansion in the materials used can produce tension. For example, metal has a lower thermal coefficient of expansion than plastic does. If metal frames are used to mount the plastic sheet, it is important to leave enough room for expansion. Without this extra room, tension could result.

The **coefficient of linear thermal expansion** α can be described by following formula:

$$\alpha = \frac{\Delta l}{l_0} \times \frac{1}{T_1 - T_0}$$

where $\mathbf{l_0}$ is the sample length at starting temperature $\mathbf{T_0}$ and $\mathbf{\Delta l}$ is the change in length at temperature $\mathbf{T_1}$.

The change in dimension can be calculated based on the thermal expansion:

$$\Delta l = \alpha \times l_0 \times (T_1 - T_0)$$

The coefficient of linear thermal expansion of PET is comparable with other non-reinforced plastics.

The typical values for PET are:

Linear coefficient of thermal expansion: DIN 53 752	**Value range**	**Unit**
Coefficient of thermal expansion from -40 to +60°C	$50 - 60 \times 10^{-6}$	K^{-1}

TEMPERATURE RANGE

Because of its chemical structure, PET has good mechanical behaviour over a wide temperature range. The temperature range is from below -70°C up to 60°C. The modulus of elasticity (Young's modulus) decreases significantly above this temperature range and the material softens quite rapidly. The functional life time of PET is reduced, however, when this temperature is exceeded for a longer period of time. PET can be used in very low temperatures, but the material becomes brittle in these environments.

Stable mechanical properties over a large temperature range are important for the user. The impact resistance and stiffness of PET show only minimal changes between -70 °C to +60 °C, even over a longer period. The modulus of elasticity for instance, still has 80% of its value at 60°C, compared to room temperature. The vicat softening temperature (Type B, 50 N) according to DIN/ISO 306 is 75°C. The heat deflection temperature HDT B (ISO 75-1,2) is 73°C.

The properties described here apply to tests of relatively short duration. However PET retains its good properties even over long periods.

Other thermal properties of PET are:

Thermal Properties	Standard	Value	Unit
Recommended Maximum use Temperature		60	°C
Glass Transition Temperature (DSC; 20°C/min)	IEC 1006, A	82	°C
Crystalline Melting Point (DSC)	ISO 3146	approx. 245	°C

ELECTRICAL BEHAVIOUR

In the electric and electronic industries, the electrical properties of plastics are of great importance. Plastics are most often used in these industries because of their excellent insulation properties. Determining the electrical behaviour of plastics is very complex because there are so many variables. Only a selection of the most important measurements and properties are explained here.

The methods introduced here are in general according to IEC-standards (**I**nternational **E**lectrotechnical **C**ommission Standards), and the corresponding DIN standards.

Volume Resistivity: DIN / IEC 93

An important property of insulating materials is the volume resistivity. It can be described as the inner resistance measured with flat electrodes placed on two parallel outer surfaces. The value is the ratio of the electrical power on the two electrodes after a current flows through the material for a pre-defined time. The unit is Ohm (or Ω).

The **specific volume resistivity δ_D** is obtained when the volume resistivity is related to a cube with sides equal to 1cm. The unit of measure is Ω×cm or when related to an area Ω×cm².

The typical values for PET at 23°C and 50% humidity are:

Volume Resistivity: DIN / IEC 93		Value	Unit
Specific Volume Resistivity	100 V	1×10^{17}	Ohm×cm
	500 V	9×10^{16}	Ohm×cm
	1000 V	8×10^{16}	Ohm×cm

Surface Resistivity: DIN/IEC 93

Another electrical property which can be determined is the electrical condition of the surface of a material.

The **surface resistivity** is the ratio of the DC-voltage and the current, applied between two electrodes across the surface of a material. For comparing test data between materials it is important to use the same conditions (sample thickness, electrode shape and position), since a part of the current always flows through the sample. The surface resistivity is also dependent of the test environment; variables in the test such as like humidity and particles on the surface. The unit is Ohm (or Ω).

The typical values for PET at 23°C and 50% humidity are:

Surface Resistivity: DIN IEC 93		Value	Unit
Specific Surface Resistivity R/Square	100 V 500 V	2×10^{14} 6×10^{14}	Ohm Ohm

Dielectric Constant: DIN 53 483

An important insulation property is the dielectric constant. The dielectric constant is dependent on the frequency of the applied AC-voltage and the temperature of the test material.

The **dielectric constant ε_τ** is the quotient of the capacity C_x of a capacitor, of which the test material fills the space between the electrodes and the capacity C_o measured in vacuum.

The typical values for PET at 23°C and 50% humidity are:

Dielectric Constant: DIN 53 483		Value	Unit
Dielectric constant	at 50 Hz at 0.1 MHz	3.8 3.6	- -

Dissipation Factor: DIN 53 483

In general, all plastics have similar insulating properties, but they differ in their dipole moment. A material has a dipole moment if the molecules have negative and positive areas. The effects of the dipole moments are revealed in electrical alternating current fields. The dipoles are re-oriented with the AC-frequency, which results in the loss of active power within the dielectric field.

The dissipation factor δ is a measure for the loss of power. The value does not have a unit of measure.

Typical values for PET at 23°C and 50% humidity are:

Dissipation factor: DIN 53 483		Value	Unit
Dissipation factor	at 50 Hz at 0.1 MHz	0.003 0.03	- -

Dielectric Strength: DIN 53 481

In contrast to the other electrical measurements, the measurement of the dielectric strength is not a material constant, but depends heavily on outside factors. The measurement depends on the shape of the electrodes, the time and the AC-frequency of the applied voltage, the temperature, the sample thickness and the sample preparation.

The measurement of the **dielectric strength E_d** is done under increasing frequency, with the sample fixed between two electrodes which are placed either in air or in a standard oil. The voltage applied at the moment the spark penetrates the material is called the break down voltage. This voltage related to the sample thickness gives the dielectric strength in kV/mm.

The typical value for PET at 23°C and 50% humidity is:

Dielectric strength: DIN 53 481	Value	Unit
Dielectric strength	> 23	kV/mm

Comparative Tracking Index: DIN/IEC 112

The Comparative Tracking Index (CTI) is a characteristic value of resistance to electrical leakage. The resistance to electrical leakage is the resistance of an insulating material against a build-up of a creeping current over a distance.

The test is performed by placing two electrodes which have a electrical potential difference on the surface of a sample. A certain number of drops of a salt solution are then placed on the surface in between the electrodes. The **Comparative Tracking Index** is defined as the highest voltage which the material can withstand without showing any creeping current between the electrodes under exposure to 50 drops of a standardized salt solution.

The typical value for PET at 23°C and 50% humidity is:

Comparative Tracking Index: DIN/IEC 112	Value	Unit
Comparative Tracking Index (CTI)	225	-

THERMOFORMING

Thermoforming is a technique commonly employed in the plastics industry. It was originally regarded as a simple process for producing relatively unsophisticated components, but a host of innovative modifications have been developed to enable the manufacture of increasingly more complex mouldings. PET is excellently suited for thermoforming. As with traditional materials, the moulding process involves heating the sheet to above the glass transition temperature, forming the sheet to the desired shape, cooling to below the T_G and finally demoulding. PET does not require drying or annealing.

PET sheets can be crystallised during the thermoforming process. Hence, depending upon the extent of the thermal conditioning treatment following the forming process, it is possible to retain the favourable property profile of the transparent amorphous sheet, or alternatively produce crystalline components with increased thermal stability and outstanding resistance to chemicals.

Some comments valid for the stages in the thermoforming process are given below.

Heating

Unlike sheet materials such as ABS or Polycarbonate, PET requires no drying or other preparation prior to the thermoforming process.

Radiation heating and circulating air ovens are both suitable for use with ®Hostaglas. In the case of radiation heating, it is recommended to have heating panels arranged on both sides of the sheet especially when forming sheets in excess of 2.5mm.

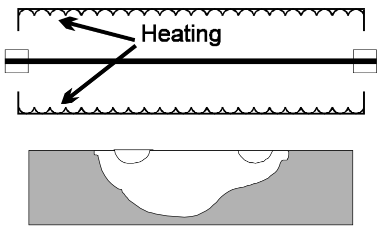


Fig. 2: Heating

Excellent results can be achieved by forming PET at temperatures as low as 130°C - 145°C. In comparison to other sheet materials, the outcome of this is a considerable reduction in cycle time and correspondingly, a significant increase in productivity. The heating times for ®Hostaglas are typically 1/3 of those necessary for PC or PMMA.

Sheet Forming

PET can be formed using all standard techniques e.g. vacuum forming, pressure forming, drape forming and mechanical forming. Combinations of these processes are also possible, as are specific process modifications including varying the temperature profile in the sheet or inflating to a dome prior to moulding both of which are occasionally employed to improve wall thickness in the final article.

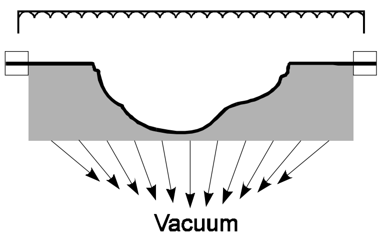


Fig. 3: Forming

To accommodate for the processing window for PET but more importantly in the interest of process efficiency, it is advisable to minimise the duration of the forming stage. For this reason moulds incorporating the maximum number of vent holes of maximum diameter (typically 1 mm)should be used.

Cooling

Once the sheet forming stage has been completed, the moulding should be rapidly cooled using air or air/water mist.

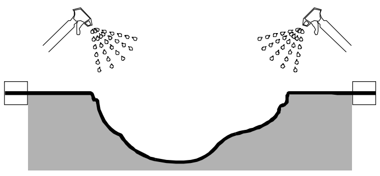


Fig. 4: Cooling

Demoulding is possible once the moulding temperature has reduced to below ca. 60 °C.

Demoulding

As a result of the low and uniform shrinkage characteristics of amorphous PET (approx. 0.5 %), removal of the moulding from the mould does not present a problem. The moulding is dimensionally stable as a further shrinkage over time does not occur.

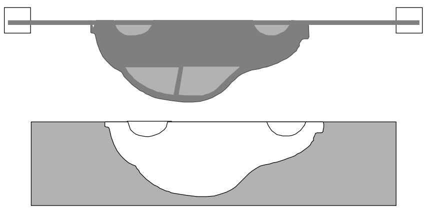


Fig. 5: Demoulding

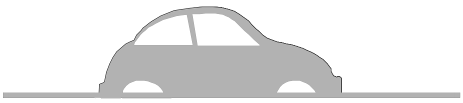


Fig. 6: Result, amorphous ®Hostaglas component

Crystallised Mouldings with PET

Mouldings from crystallised PET exhibit greater thermal stability and chemical resistance than the amorphous counterparts. Crystalline PET components are manufactured firstly by forming as described above. The crystallisation process begins following the actual forming stage, and involves heating the moulding whilst it is being held on the mould and maintaining it for a short period of time at ≥ 150 °C.

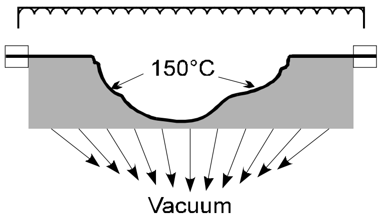


Fig. 7: Crystallisation

During crystallisation, the moulding shrinks by approximately 2 %. For this reason, it is advisable to employ negative (female) moulds. Vent holes of diameter ca. 0.5 mm are recommended. The mould should also be constructed to allow a surface temperature of in excess of 150 °C to be attained, i.e. they should be made of aluminium and incorporate oil or electrical heating.

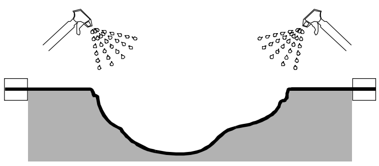


Fig. 8: Cooling

At the end of the crystallisation process, the moulding is still relatively flexible. Following surface cooling using an air/water mist spray, and demoulding, the component should be allowed to cool in a cooling jig to prevent distortion.

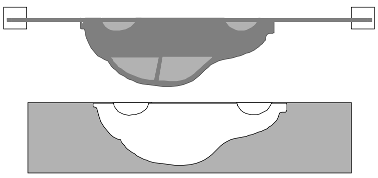


Fig. 9: Demoulding

Fig. 10: Result, crystalline PET components

Resistance to Chemicals and Solvents

Assessment of the Effects of Chemicals and Solvents

The influence of chemicals or solvents may cause selected properties of PET sheets to change:

Optical properties	Gloss Transmission Discolouring
Other physical properties	Stress cracking Impact toughness / fracture Hardness Softening point Shrinkage Swelling
Chemical aggression	Reaction of chemicals with polymer, for example dissolution or degradation

Factors Influencing Resistance

The behaviour of the material depends on the following factors:

- duration of contact with chemicals
- temperature during contact
- concentration of chemicals
- either stresses inherent to the material and/or stresses caused by external factors specific to the application or test conditions
- other environmental effects (e.g. damaged surface of sheet)

Resistance and Conditions of Assessment

PET is generally resistant to most acids, alcohols and salts as well as plasticisers. Moreover, PET is resistant to hydrocarbons such as toluene, xylene, mineral oil and petrol. The resistance to aliphatic hydrocarbons is limited.

Similarly, PET is also resistant to chemical attack by acid rain, diesel exhaust fumes and salinated air. Aromatic compounds show a variety of reactions.

All ketones attack PET to a certain extent, as do benzene and chlorobenzene.

Chemical degradation can be observed with phenols and o-chlorophenol as well as with aqueous alkali solutions. As with all polymers, contact with aggressive media should be avoided when possible.
The resistance of transparent PET sheets to water is good. However the continuous service temperature range of -40 °C to + 60 °C should be considered.

The tables contained in this bulletin list the stability of PET towards diverse substances, firstly in alphabetical order, and secondly where the chemicals are divided into groups.

The data was determined on unstressed samples by storing unloaded specimens for 4 weeks at room temperature in the respective solutions. A requirement for this, is a surface free of defects and damage.

Short term contact with many of the chemicals to which PET is classified as 'not resistant' is possible however without signs of chemical attack becoming apparent.

The classifications made for PET should be interpreted as indications. Actual resistance depends to a great extent on the ambient conditions during the application in question. It is therefore recommended, to examine resistance of PET under the specific circumstances of the intended use.

Contact with foodstuffs

PET is manufactured from the polymer raw material Polyethylene terephthalate which complies with FDA (American Food and Drug Administration) and BGA (Bundesgesundheitsamt) standards for contact with foodstuffs. The material is odourless and neutral in taste.
PET is suitable for usage with foodstuffs and medical applications.
PET can be sterilized with gamma rays or ethylene oxide.

Alphabetical Classification of Chemical Resistance

Acetic acid, 40 %	+
Acetone	-
Aliphatic hydrocarbons	•
Ammonium chloride	+
Ammonium hydroxide	-
Amyl alcohol	+
Benzyl alcohol	-
Butanol	+
Calcium hydroxide	•
Camphor	+
Camphorated oil	+
Carbon tetrachloride	•
Chloroform	-
Copper sulphate	+
Cyclohexanol	+
Dibutyl phtalate	+
Dinonyl phtalate	+
Dioctyl phtalate	+
Ethanol	+
Ethyl acetate	•
Ethylene oxide	+
Formaldehyde	+
Formic acid, 30 %ig	+
Glycerine	+
Glycol	+
Hydrochloric, 10 %	+
Hydrofluoric acid, 10 %	+
Hydrogen peroxide	+
Isopropanol	+
Linseed oil	+
Lubricating grease	+
Lubricating oil	+
Magnesium chloride	+
Maleic acid, 50 %	+
Mercuric chloride	+
Mercury	+
Methyl ethyl ketone	-
Mineral oil	+
Nitric acid, 10 %	+
Nitro benzene	-
Olive oil	+
Paraffin	+
Petrol	+
Petroleum ether	+
Phenol	-
Potassium bromide	+
Potassium chromate	+
Potassium cyanide	+
Potassium dichromate	+
Potassium hydroxide	-
Propionic acid, 20 %	+
Sodium carbonate	+
Sodium chloride	+
Sodium hydroxide	-
Sulphuric acid, 20 %	+
Tartaric acid, 10 %	+
Toluene	+
Transformer oil	+
Trichlorethylene	•
Water	+
Xylene	+

+ = resistant • = limited resistant - = not resistant

Chemical Resistance - Classification in Groups

Alcohols	
Amyl alcohol	+
Benzyl alcohol	-
Butanol	+
Cyclohexanol	+
Ethanol	+
Glycerin	+
Glycol	+
Isopropanol	+
Aldehydes	
Formaldehyde	+
Hydrocarbons	
Aliphatic hydrocarbons	•
Mineral oil	+
Petrol	+
Toluene	+
Xylene	+
Chlorinated Hydrocarbons	
Chloroform	-
Carbon tetrachloride	•
Trichlorethylene	•
Aqueous Alkaline Solutions	
Ammonium hydroxide	-
Calcium hydroxide	•
Potassium hydroxide	-
Sodium hydroxide	-
Platicisers	
Dibutyl phtalate	+
Dinonyl phtalate	+
Dioctyl phtalate	+

Salts	
Copper sulphate	+
Magnesium chloride	+
Mercuric chloride	+
Potassium bromide	+
Potassium chromate	+
Potassium cyanide	+
Potassium dichromate	+
Sodium carbonate	+
Sodium chloride	+
Ketone	
Methyl ethyl ketone	-
Esters	
Ethyl acetate	•
Acids	
Acetic acid, 40 %	+
Formic acid, 30 %	+
Hydrofluoric acid, 10 %	+
Maleic acid, 50 %	+
Nitric acid, 10 %	+
Propionic acid, 20 %	+
Sulphuric acid, 20 %	+
Tartaric acid, 10 %	+
Miscellaneous Organic Solvents	
Acetone	-
Nitro benzene	-
Petroleum ether	+
Phenol	-

+ = resistant • = limited resistant - = not resistant

PET - STORAGE AND TRANSPORTATION

- PET should be stored and transported on stable, flat pallets. The size should be equivalent to or slightly larger than the sheets.

- Sheets should be lifted and handled one at a time. To prevent scratching, sheets should not be allowed to slide over each other during handling.

- Sheets should be stored indoors and protected from direct sunlight (‘magnifying-glass effect’) and also from moisture.

- When storing in a vertical position, sheets should be supported to their full height.

PET Processing Guidelines - Bonding

The choice of adhesive for bonding PET to itself or other materials is largely governed by the environmental conditions expected during service, along with the type of joint to be employed.

This requires the user to test the glue for a given application, particularly with regard to the desired transparency and long-term adhesion. In principle, any epoxide, polyurethane, cyanoacrylate, silicone or UV curing adhesives should be suitable.

The following table lists the contact details of adhesives manufacturers, together with their product names, who have experience in the bonding of PET. The corresponding supplier is also included.

Manufacturer	Bonding System	Address
Polytec	Epotec 715	Promatech Ltd Unit 1, Elliot Centre 20 Elliot Road Cirencester Gloucestershire GK7 1YS Tel: 01285-644211
Panacol-Elosol	Penloc GTI Penloc GTI-S Vitralit 5634LV	Eurobond Adhesives Ltd Unit 4A, Smeed Dean Centre Eurolink Industrial Estate Sittingbourne Kent ME10 3RN Tel: 01795-427888 Fax: 01795-479685
Röhm	Acrifix 192 Acrifix 200	Röhm (Plastics Division) Ltd Bradbourne Drive Tilbrook Milton Keynes Bucks MK7 8AU Tel: 01908-274414 Fax: 01908-274588
Ciba	Araldite 2020	Ciba Additives Hulley Road Macclesfield Cheshire SK10 2LY Tel: 01625-665000
Dymax Europe	Dymax 3-20256	Intertronics Ltd Unit 9, Station Field Ind. Est. Banbury Road Kidlington Oxfordshire OX5 1JD Tel: 01865-842842 Fax: 01865-842172
Kleiberit	High Tack 851	Kleiberit Adhesives UK Ltd 11 Coopers Close Borrowash Derby DE7 3XW

Recommendations for adhesive bonding of PET

- The surface should be clean, dry and free from dust or loose particles.

- Degreasing: greatest adhesion is achieved by cleaning the surface with ethyl alcohol; good results can be obtained by cleaning with a detergent solution. Cleaning with acetone is not recommended.

- Follow manufacturer useful hints in bonding ®Hostaglas when using all adhesives.

- After the adhesive has been correctly applied, place the sheet substrates in contact and secure them firmly until the adhesive has cured.

- Depending upon the instructions given by the adhesive manufacturer, coat the sheet surface with the appropriate primer where necessary.

- Note that curing time can be as long as 24 hours in some cases.

- Use adhesives in a well ventilated room. Do not smoke in the area, and avoid skin contact.

Hoechst is not an adhesive manufacturer and is therefore unable to accept any responsibility for the performances of adhesives used to bond PET.

PROCESSING GUIDELINES - BUILDING & CONSTRUCTION

In general, follow standard technical construction regulations when installing the sheet. The choice of mounting technique depends upon the particular requirements of each situation. The available play which allows for adequate thermal expansion is an important factor, as with all other plastic sheets. When PET is mounted outside, the allowance should be 3 mm per meter of sheet length, due to seasonal variations in temperature.

The following table shows a comparison of the thermal expansion coefficients of some materials:

Material	**$*10^{-6}$ (m/m*°C)**
PET	60
acrylic	66
aluminum	22
steel	13
glass	0.8

Storage and Transportation

- To avoid damaging the surface, do not remove the protective film.
- Sheets should be picked up and laid down one at a time.
- To prevent scratches on the surface, sheets should not be allowed to slide over each other during handling.
- Store sheet indoors to prevent damage from sunlight ('magnifying-glass effect').
- Vertical storage is also possible, as long as the sheets are supported over their full height.

Sawing & Machining

PET can be cut quickly and easily with ordinary hand-held woodworking tools or with standard circular, band-, or scroll saws using normal sawblades. For best results the following guidelines should be followed:

- The protective film should not be removed to avoid damage to the surface.
- The sheet must be securely fastened to eliminate vibration which can result in chipping or rough edges.
- For best results, use low and medium cutting speeds.
- Cutting swarf and dust are best removed with pressurized air.

These additional guidelines should be considered, depending upon the type of saw used:

- Every second tooth of the circular saw blade should be beveled at 45° on both sides.
- Thin kerf-design blades which are carbide-tipped yield the best results.
- Either vertical or horizontal bandsaws can be used.
- Hand cross-cut saws should have taper-ground blades to resist binding and improve fast cutting action. The teeth should be bevel-filed for best performance.
- Sheets under 3 mm thick are best cut with band- or scroll saws.

The following table provides information for circular and bandsaws:

	Circular Saw	**Bandsaw**
Bottom tip angle (°)	5 - 15	30 - 40
Front tip angle (°)	0 - 10	0 - 5
Saw blade speed (m/min)	1500 - 2500	1000 - 1500
Teeth distance (mm)	2 - 5	2 - 3

Drilling

Holes can easily be drilled into ®Hostaglas with normal high-speed HSS drills. Excellent results can be achieved with special drill bits designed for use with plastic materials. These do not overheat the material due to excessive friction.

In general, the following recommendations apply:

- The sheet should be clamped tightly to minimize vibrations.
- The distance of the holes from the edge of the material should be 1.5 - 2.0 times the diameter of the hole.
- The holes should be at least 50 % larger than the diameter of the screw, nail, or rivet. This allows for thermal expansion of the sheet.
- While drilling, retract the drill several times to allow the material to cool, and to minimize the swarf.

Recommended drill angles and feed speeds:

Swarf angle (°)	3 - 5
Drill tip angle (°)	60 - 90
Pitch (°)	5 - 15
Cutting speed (m/min)	20 - 50
Feed (mm/rpm)	0.15 - 0.5

Mounting methods

Screw mounting

For internal installations, the drill hole should be a minimum of 1 mm larger than the circumference of the fixing screw to allow for thermal expansion. If the sheets are mounted flush together, a slight gap should remain between them. Large washers should be used to distribute the force on the sheet over a larger surface area.

In order to prevent tension it is important that the holes of the sheet are aligned with the holes in the structure onto which it will be mounted. It is best is to drill both holes at once. The distance of the holes to the edge of the sheet should as great as possible to reduce notch stress. The use of counter-sunk screws is not recommended, since they leave no play for expansion. Self-tapping screws should only be used with washers, spring-washers or clips.

Example:

- 0.8 x 1.5 m PET sheet with a 5 mm thickness
- Use 4 mm diameter screw at an interval of 40 cm
- The distance to the edges should be a minimum of 9 mm

Frame mounting

When PET is mounted in a wooden, metal or plastic frame, two other factors along with thermal expansion must be taken into account: the groove depth, and the correct sheet thickness. Once again, the thickness depends on the size and shape of the sheet and the maximum loads it will encounter (e.g., wind pressure).

Other mounting methods

PET can easily be mounted in standard industrial clamping systems. These clamping systems are very practical, especially when thermal expansion is a major factor. Clear adhesive tapes like Scotch™ 200 MP or 468 MP can be also used in some transparent applications or for colored sheets.

PET sheets may also be fastened with rivets. It is recommended that washers be used to reduce pressure during riveting. The hole in the sheet should be 1.5 to 2 times the diameter of the rivet to allow for expansion.

PROCESSING GUIDELINES - DRILLING

PET can easily be drilled using regular high-speed HSS drills. Excellent results can be achieved with special plastic drills, which are designed to reduce material heating caused by friction.

In general, the following recommendations apply:

- The sheet should be clamped tightly to minimize vibrations.
- The distance of a hole from the edge of the material should be 1.5 - 2.0 times the hole-diameter.
- The holes should be at least 50 % larger than the diameter of the screw, nail or rivet to allow for thermal expansion of the sheet.
- While drilling, the drill should be retracted several times to enable the material to cool and to minimize the build up of swarf.

Recommended drill angles and feed speeds:

Swarf angle (°)	3 - 5
Drill tip angle (°)	60 - 90
Pitch (°)	5 - 15
Cutting speed (m/min)	20 - 50
Feed (mm/rpm)	0.15 - 0.5

PROCESSING GUIDELINES - EDGE FINISHING

The edge of a sheet after cutting with a saw can be quite rough. For certain applications, a smooth and attractive edge is important. A smooth edge can also limit the risk of crack propagation during dynamic loading. A variety of methods for edge-finishing are described below. Common woodworking and plastic processing tools can be used.

Planing

Rapid and simple smoothing results can be obtained with a standard woodworking planes. Electric planers can also be used with particular caution to ensure that the rotation speed of the blade is low to prevent melting of the surface, which would otherwise affect the appearance of the edge. Best results are obtained by selecting a shallow planing depth. Following planing, the edge can be polished with a hard wooden block to obtain a matt finish.

Milling

Milling is suitable for a variety of purposes including grinding holes and cut-outs or for engraving. It can also be employed for edge-smoothing and finishing. With adequate cooling and low rotation speeds (5000 rpm), excellent results can be achieved even at high throughputs. The surface texture is matt and smooth. Adequate cooling is important to prevent melting of the material.

Disc-Grinding

Edges can be finished with disc grinders, even though these are generally employed for cutting. The results are equivalent to the finish obtained by milling. Also here it is recommended to maintain low rotation speeds to avoid melting the sheet.

Sanding

The edge finish obtained by sanding with 600 grade papers is similar to that obtained by milling. Finer papers will further improve the appearance. Transparent edges are possible employing 1200 grade paper or higher with outstanding clarity possible with 2400 grade paper. As with milling and grinding cooling during the sanding process is advisable.

Machine-polishing can also be employed for edge finishing. In this process, a prepared edge is polished using firstly a 6μm diamond suspension and finally a 3μm suspension.

Polishing with Steel Wool

Polishing with steel wool produces an edge comparable to a milled edge. Because this is a method carried out by hand, it is practical only for small areas.

Polishing using a Hot-Air Gun

Following milling or planing, edges can be polished very quickly and easily using a hot-air gun. The protective film should be peeled off to free about 1.5 - 2 cm from the edge. About 1 cm should then be carefully removed with a sharp knife. This prevents the film from melting onto the sheet during the polishing process. The gun should be moved slowly along the edge, maintaining a constant distance between the nozzle and the edge. The result depends on the temperature and the distance of the gun from the edge of the sheet. The edge becomes glossy and transparent. If the edge turns white, the material has been caused to crystallise. This can be avoided by increasing the distance of the gun, lowering the temperature, or a combination of both.

Gas Torch Polishing

Gas torch polishing is similar to polishing with a hot-air gun. The film should be removed as outlined above. Here too, the edge should be treated so as to avoid any signs of crystallisation. A standard butane torch with a small tip can be used. Since the temperature of the gas torch is higher than the temperature of the hot-air gun, the burner should be moved along the edge at a greater speed. High temperature H_2 or acetylene torches are not recommended.

Diamond Knife Planing

Standard cut edges can be smoothed and polished in one step by diamond knife planing. With this type of planing, high quality bevelled or plane edges can be obtained. In order to achieve these high quality surfaces, the material has to securely mounted and precisely guided to prevent vibration. This process yields a highly transparent and glossy surface with very good optical properties.

PROCESSING GUIDELINES - PRINTING

PET can be easily printed. Common methods such as silk screen or tampo printing can be used. Motives can be printed onto the flat sheet prior to forming into the final product.

A wide variety of suitable inks and thinner systems are commercially available. Not all inks however will demonstrate good adhesion, since PET has an excellent chemical resistance to many solvents. It is therefore very important to select a system which is suitable for use with polyester.

PET can be surface-treated during production to improve ink adhesion. If desired, it can also be subjected to corona treatment prior to the printing process. Plastics are generally not porous and inks are not absorbed. A clear lacquer can be applied to provide additional scratch resistance for the print.

The table below lists ink suppliers, together with their product names, who have experience in the printing of PET. Most common thinners have been found to be suitable with PET, with the exception of methyl ethyl ketone (MEK), acetone, or benzene, however, we strongly recommend you seek the advice of the ink supplier.

Manufacturer	Ink System	Address	
Ramp & Co. (RUCO-Farben)	988-UV 450-JK	Kaydee Ltd Stamford Street Newhall Road Trading Estate Sheffield S9 2TX	Tel. 01142-560222
Sericol	Polyplast PY (plus rigid vinyl thinner ZV541 and 10% additive ZV 560)	Sericol Limited Westwood Road Broadstairs Kent CT11 2PA	Tel. 01843-867071
Pröll GmbH & Co.	PUR-ZK Norilit K	VT Graphic & Display Ltd Unit 4, Block B Electra Park Industrial Estate Electric Avenue Witton Birmingham B6 7EB	Tel. 0121-328-7999 Fax 0121-328-8411

Useful hints for printing PET

- The protective film should be removed immediately before the printing process.
- To remove any dirt or particles without scratching the surface, only soft cloths or damp leather cloths should be used.
- Recommended ink systems and their thinners should be employed.
- A preliminary test with the inks to confirm the results should be performed.
- Ink systems should not be mixed.
- Methyl ethyl ketone, acetone, benzene, or similar solvents should be avoided. Thorough ventilation of the work area during the drying process should be provided.

PROCESSING GUIDELINES - SAWING

PET can be cut quickly and easily with conventional hand-held woodworking tools or with standard circular, band, or jig saws. For best results the following guidelines should be followed:

- The protective film should not be removed in order to avoid damage to the surface.
- The sheet must be adequately secured to prevent vibrations which could otherwise cause chipping and rough edges.
- For best results, use low and medium cutting speeds.
- Cutting swarf and dust are best removed with pressurized air.

Depending upon the type of saw used; further recommendations include:

- Alternate teeth of a circular saw blade should be beveled at 45°.
- Carbide-tipped blades yield best results.
- Vertical and horizontal bandsaws can be used. For curved cuts blades should be narrower and have more set.
- Hand cross-cut saws should have hollow ground blades to resist binding and improve fast cutting action. The teeth should be beveled for best performance.
- Sheets under 3mm thick are best cut with band or jig saws.

The following table provides information for circular and band saws:

	Circular Saw	**Band Saw**
Bottom tip angle (°)	5 - 15	30 - 40
Front tip angle (°)	0 - 10	0 - 5
Saw blade speed (m/min)	1500 - 2500	1000 - 1500
Teeth distance (mm)	2 - 5	2 - 3

PROPERTIES OF PET
COMPARED TO PC & PMMA

Property (1-4mm)	Unit	PET	PC	PMMA	
Density	$g.cm^{-3}$	1.34	1.2	1.2	
Light Transmission	%	89 - 91	88 - 91	92 - 94	
Haze	%	0.2 - 0.6	0.2 - 0.5	0.05 - 0.2	
Gloss (60^0)		150	140	120	
Visual Appearance		+	+	++	
Tensile Strength (RT and v = 5mm/min)	MPa	57	65	68 / Break	
Modulus of Elasticity	MPa	2400	2400	3300	
Flexural Strength	MPa	90	105	115	
Charpy Impact Strength	$kJ.m^{-2}$	no break	no break	19 / break	
2 Dimension Impact Energy	J	130	190	0.8	
Glass Transition Temperature	^oC	82	150	105	
Vicat B Softening Temperature	^oC	75	145	100	
Maximum Recommended Service Temperature	^oC	65	100	75	
Coefficient of Linear Thermal Expansion	$x10^{-6}.K^{-1}$	<60	<60	<66	
Fire Behaviour (DIN 4102)		B1, no burning drips	B2, burning drips*	B2, burning drips	
Public Rail (DIN 5510)					
Fire Rating		S4	No other transparent material complies to		
Smoke Classification		SR2	the requirements of the Deutsche Bahn		
Drip Classification		ST2	according to DIN 5510		

* Special grade gives B1, burning drips, cloudy appearance

Property (1-4mm)	Unit	PET	PC	PMMA	
Chemical Resistance		++	+/-	+/-	
Recycling		++	+/-	+/-	
FDA/BGA food contact		yes	in general: no 1 special type: yes	no	
Weather Stability	years	10	10	10	
Thermoforming		+	+	++	
Pre-Drying		no	yes	yes	
Forming Temperature	^{o}C	130	190	190	
Cycle Time	unit	0.3	1.0	1.0	
Draw Ratio		6	3 - 4	3 - 4	
Ability to Crystallise		yes**	no	no	
Cold Forming & Bending		++	+	not possible	
Diamond Edge Polishing		yes	no	yes	
Minimum Bending Radius		++	+	--	
Surface Decoration		++	+	+	
Ease of Converting		+	+	+	

** results in significantly different properties.