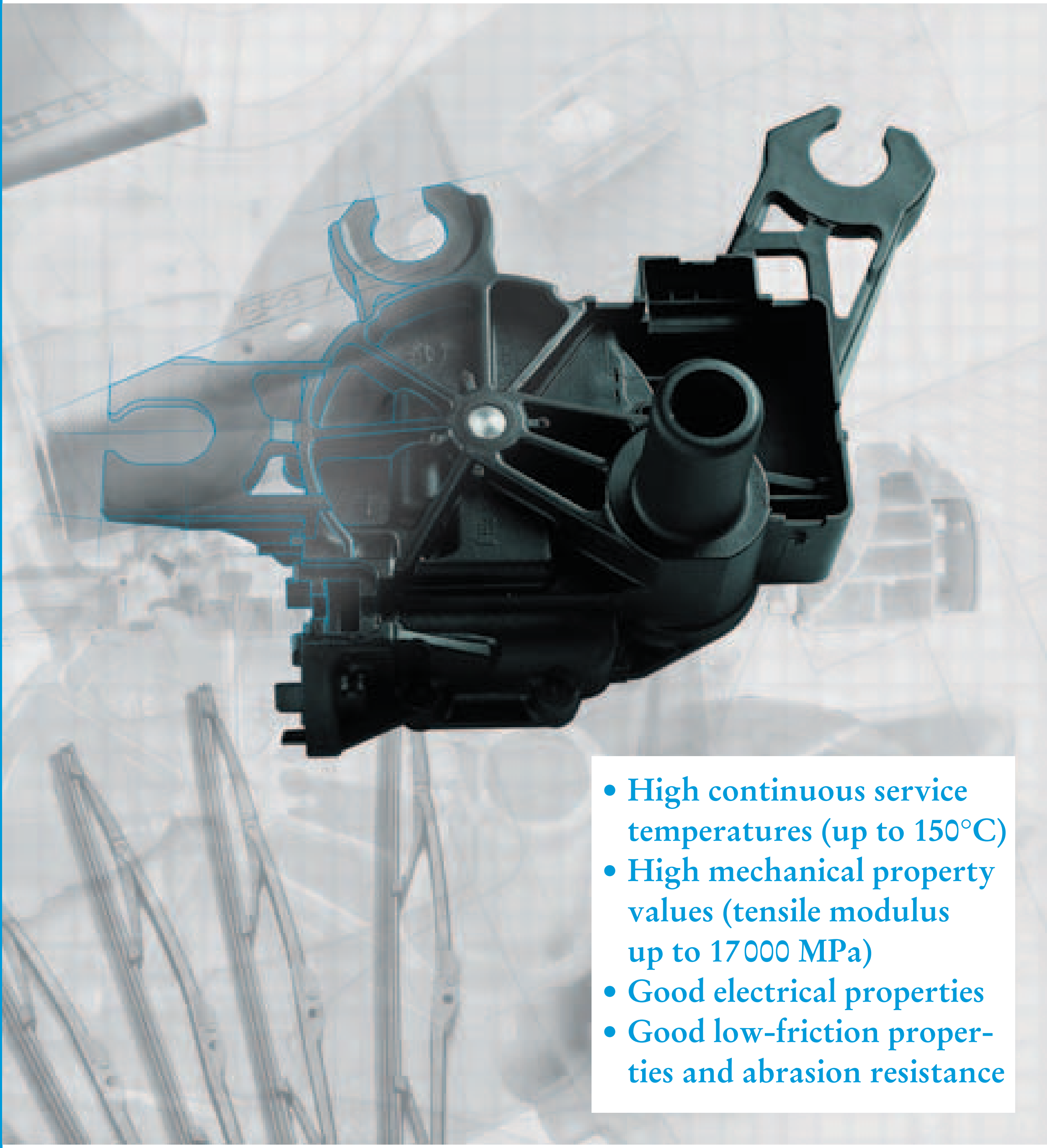
Europe

Celanex® Impet® Vandar® *Thermoplastic polyesters*

Celanex® Impet® Vandar®

Thermoplastic polyesters



- High continuous service temperatures (up to 150°C)
- High mechanical property values (tensile modulus up to 17000 MPa)
- Good electrical properties
- Good low-friction properties and abrasion resistance

Ticona

Contents

1. Introduction

Ticona offers a wide range of thermoplastic polyesters that are used mainly in injection moulding for engineering applications.

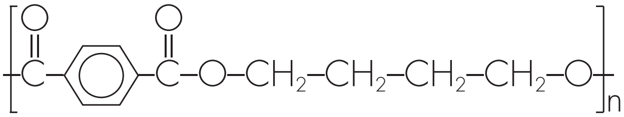
These materials are marked under the trade names Celanex®, Impet®, Vandar®.

1.1 Structure and properties

1.1.1 Celanex (PBT)

Celanex is the Ticona trade name for partially crystalline thermoplastic polyesters based on polybutylene terephthalate.

Polybutylene terephthalate (PBT) is produced by melt polycondensation of terephthalic acid dimethyl ester with 1,4-butanediol and has the following chemical structure:



Celanex has a combination of excellent properties:

- high strength,
- good creep properties,
- high heat deflection temperature, particularly the glass-fibre-reinforced grades,
- high rigidity,
- high hardness,
- good low-friction properties and abrasion resistance,
- high dimensional stability (low thermal expansion coefficient, low water absorption),
- good electrical properties,
- good chemical resistance,
- good weathering resistance,
- no environmetal stress cracking,
- paintability,
- flame-retardant grades available (UL 94: V-0, in some cases 5 VA),
- rapid crystallisation and fast cycle times.

Celanex is supplied in many different formulations, providing a wide range of properties:

- Melt viscosity:
  formulations with different viscosities (flow properties) and molecular weights make both injection moulding and extrusion possible.

- Reinforcing materials such as glass fibres:
  reinforcement with chopped glass strands increases rigidity and heat resistance; glass fibre content and hence property formulations can be widely varied.

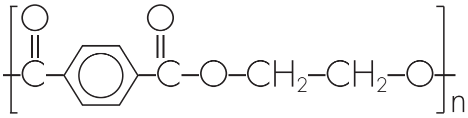
- Additives such as glass microspheres and mineral fillers:
  for low-warpage engineering parts, may also be used in combination with glass fibres.

- Polymer modifiers:
  with suitable modifiers surface gloss, impact strength and flexibility can be increased, the melting point and warpage can be reduced.

1.1.2 Impet (PET)

Impet is the Ticona trade name for injection mouldable thermoplastic polyesters based on polyethylene terephthalate.

Polyethylene terephthalate (PET) is produced by melt polycondensation of terephthalic acid or terephthalic acid dimethyl ester with ethylene glycol and has the following chemical structure:



Because of the shorter diol with two methylene groups compared with the butanediol having four methylene groups in PBT polyesters (e. g. Celanex®),

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® = registered trademark

Impet has some important advantages over polybutylene terephthalate:

- higher mechanical strength values at room temperature and elevated temperatures,
- higher heat deflection temperature,
- higher continuous service temperature.

All Impet grades contain glass fibre reinforcement.

Impet has the following properties:

- high rigidty and hardness,
- very good creep strength,
- paintable surface,
- high heat deflection temperature,
- good low-friction and wear properties,
- very good electrical, good dielectric properties,
- high chemical resistance and weathering resistance.

1.1.3 Vandar (Thermoplastic polyester-blends)

Vandar is the Ticona trade name for a range of elastomer-modified polybutylene terephthalate grades; it is characterised by the following properties:

- high impact and notched impact strength, even at low temperatures,
- high heat deflection temperature, particularly the glass-fibre-reinforced grades,
- high resistance to organic solvents, fuels, lubricants and brake fluids,
- high abrasion resistance,
- good processability,
- paintability.

Despite the elastomer modification, even unreinforced grades have relatively good rigidity. Higher rigidity requirements can be met by, for example, suitable glass fibre reinforcement.

2. Supply form, coloration, quality management, grades

A table of the Celanex, Vandar and Impet grades you find in the leaflet, which is inserted at the rear side.

Product groups – typical characteristics

Figures 1 to 4 show the tensile modulus of the three product groups as a function of the parameters tensile stress at break, elongation at break, notched impact strength and heat deflection temperature.

Supply form

Ticona polyester grades are supplied as ready-to-process, natural or coloured, cylindrical pellets with a particle size of about 3 mm. The normal packaging unit is a 25 kg container (plastic film bag or multilayer paper bag). By prior arrangement, Ticona polyester grades may also be supplied in other types of packaging.

Coloration

Most grades are available in black as well as natural color; some grades can at present be supplied only in black. Special colors e.g. for laser marking or laser welding are also available on request. A number of grades can be supplied color-matched to a sample on request. In-plant coloration by customers with color masterbatches is possible and in many cases an advantage.

Quality Management System

Meeting the quality requirements of our customers, both locally and globally, is a critical activity for Ticona. We constantly pursue and update the certifications needed for this purpose – indeed our quality management system has been certified to ISO 9000 standards since the early 1990s. In 2003, we built on this foundation by implementing the Global Ticona Integrated Management System (TIMS) for quality, environmental and risk management.

Important certifications include ISO 9001:2000, ISO/TS 16949:2002, ISO 14001 and ISO/IEC 17025. Quality Management System Certifications under ISO 9001:2000 and ISO/TS 16949:2002 have now been achieved for all production sites and supporting remote locations of Ticona worldwide. The ISO/TS 16949:2002 standard combines the automotive regulations in Europe of VDA 6.1, EAQF and AVSQ with the requirements of QS-9000 in North America and supersedes all of these. Ticona received the certification for this standard 2003.

Ticona facilities in the Americas and at Oberhausen, Germany achieved certification under ISO 14001, the Environmental Management System Standard, prior to the end of 2002. At Kelsterbach, Germany, completion of registration is scheduled mid 2005. The appropriate Ticona laboratories are certified to meet general requirements according to ISO/IEC 17025 for testing and calibration laboratories.

On our website www.ticona.com further information showing the details of products and facilities covered and PDF files of all actual certificates of registration are available.

Fig. 1: Tensile modulus of unreinforced and reinforced polyester grades as a function of tensile stress at break

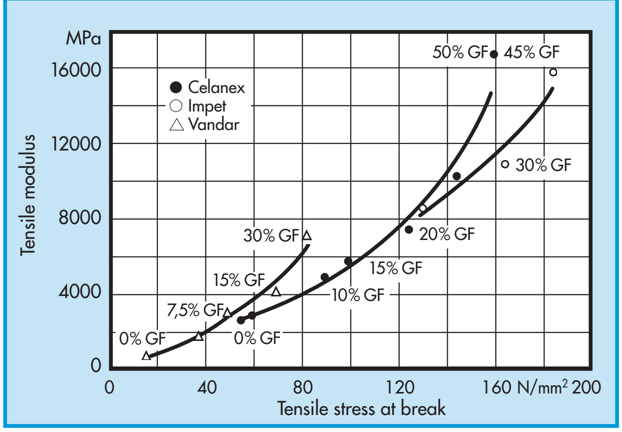


Fig. 2: Tensile modulus of unreinforced and reinforced polyester grades as a function of elongation at break

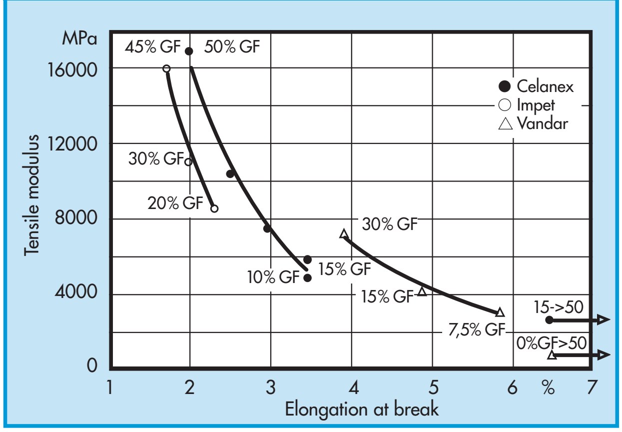


Fig. 3: Tensile modulus of unreinforced and reinforced polyester grades as a function of notched impact strength (Charpy)

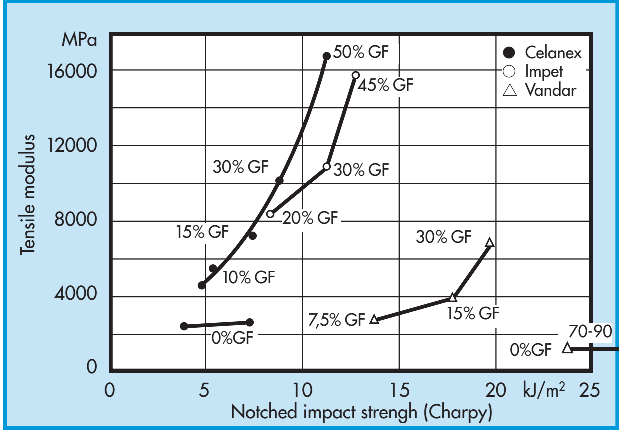
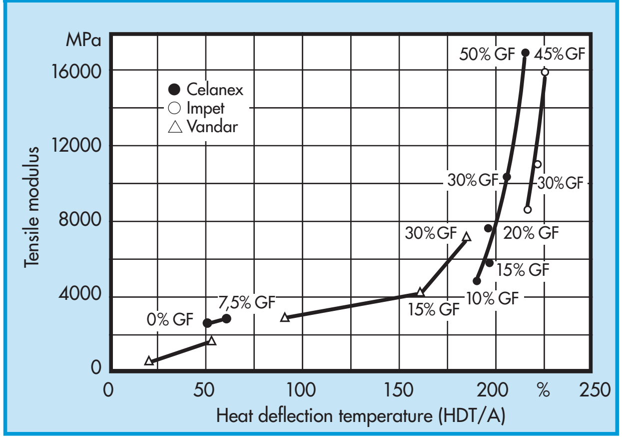


Fig. 4: Tensile modulus of unreinforced and reinforced polyester grades as a function of heat deflection temperature (HDT/A)



3. Physical properties

This section discusses the important characteristic properties of Celanex, Vandar and Impet and their dependence on temperature and time. The properties were determined largely by standard test methods.

The physical property values of Celanex, Vandar and Impet are given in the leaflet, which is inserted at the rear side.

Descriptions of the polyester grades and their properties are available in the CAMPUS® database.

Results determined on test specimens by standard methods are guide values and can be used as a basis for comparing different materials. However, they have only limited applicability to finished parts. The strength of a component depends to a great extent on design and so design strength is the criterion used to assess load-bearing capacity [1, 2].

3.1 Mechanical properties

Thermoplastics are viscoelastic materials. They exhibit the property known as creep, i. e. they tend to undergo permanent deformation with time, depending on temperature and stress. After stress removal, depending on the level and duration of stress, a moulded part returns partially or completely to ist original shape. The reversible deformation corresponds to the elastic portion and the permanent deformation to the plastic portion. This viscoelastic behavior must be taken into account when designing moulded parts.

From the above, it follows that the mechanical properties of a plastic are primarily dependent on the important basic parameters of time, temperature and stress. Further important influences are design, manufacturing parameters and environmental conditions.

One crucial factor which characterizes a plastic is the dependence of the shear modulus G on temperature.

The temperature dependency of the shear modulus G and mechanical loss factor d is shown in fig. 5 for unreinforced and glass-fibre-reinforced Celanex and in fig. 6 for unreinforced and reinforced Vandar.

Both materials have high rigidity up to shortly below their glass transition temperature. Above the glass transition temperature, the shear modulus curves drop up to the melting temperature; in glass-fibre-reinforced grades, the curve is flatter.

CAMPUS® = registered trademark of CWFG, Frankfurt am Main

Fig. 5: Shear modulus G and mechanical loss factor d of reinforced and unreinforced Celanex, measured in the torsion pendulum test (DIN 53 445)

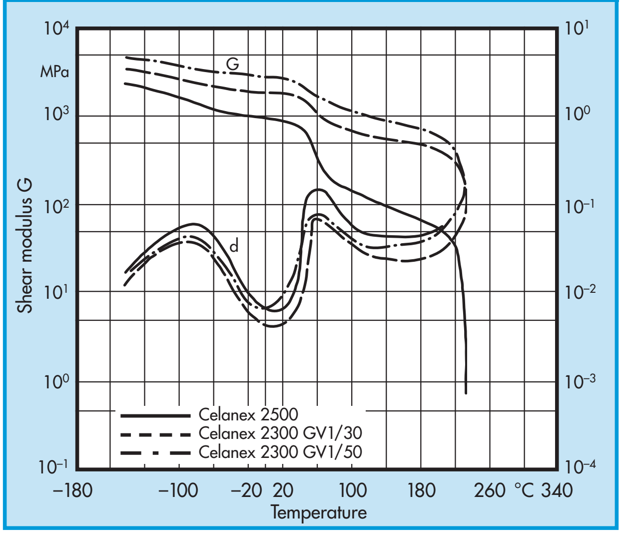
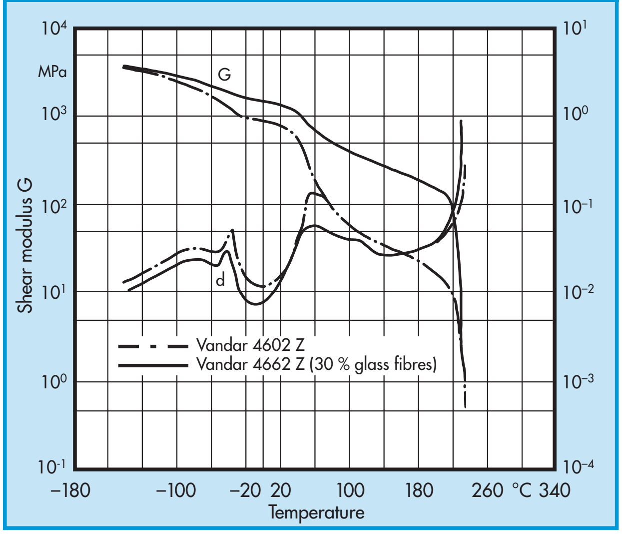


Fig. 6: Shear modulus G and mechanical loss factor d of reinforced and unreinforced Vandar, measured in the torsion pendulum test (DIN 53 445)



3.1.1 Behaviour under short-term stress

The behaviour of materials under dynamic, short-term stress can be studied in the tensile test according to ISO 527. This test enables yield stress, elongation at yield, tensile stress at break, tensile strength and elongation at break to be determined.

Celanex and Impet as engineering thermoplastics have far higher values than those of standard plastics.

Characteristic stress-strain graphs for unreinforced and reinforced Celanex at different temperatures are shown in figs. 7 and 8.

Fig. 9 shows the tensile stress at break values of Celanex general-purpose grades as a function of glass fibre content and temperature.

Glass-fibre-reinforced polyester grades have particularly high strength and rigidity. These good material properties can, however, be fully exploited only if optimum processing conditions are used.

Fig. 7: Stress/strain graph for Celanex 2500; measured according to ISO 527, test temperatures 23, 60 and 120 °C, testing rate 50 mm/min

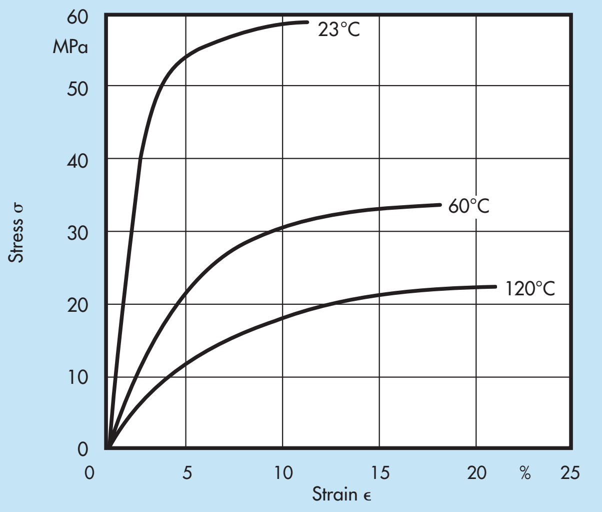


Fig. 8: Stress/strain graph for Celanex 2300 GV 1/30; measured according to ISO 527, test temperatures 23, 60 and 120 °C, testing rate 50 mm/min

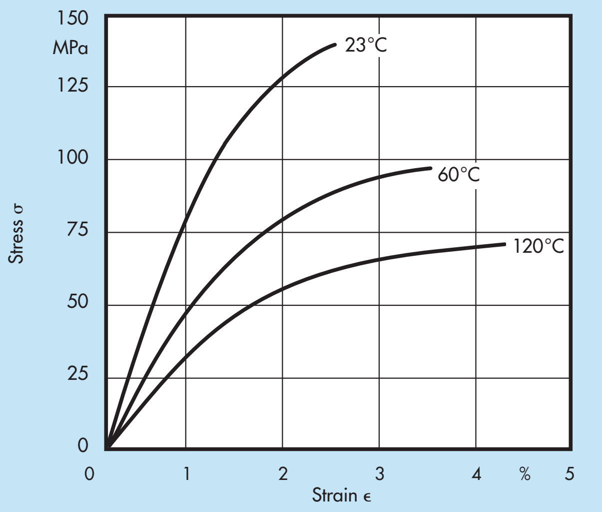
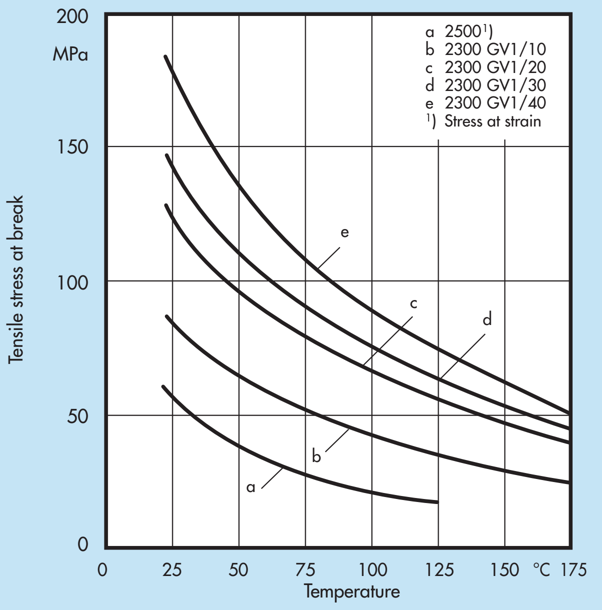


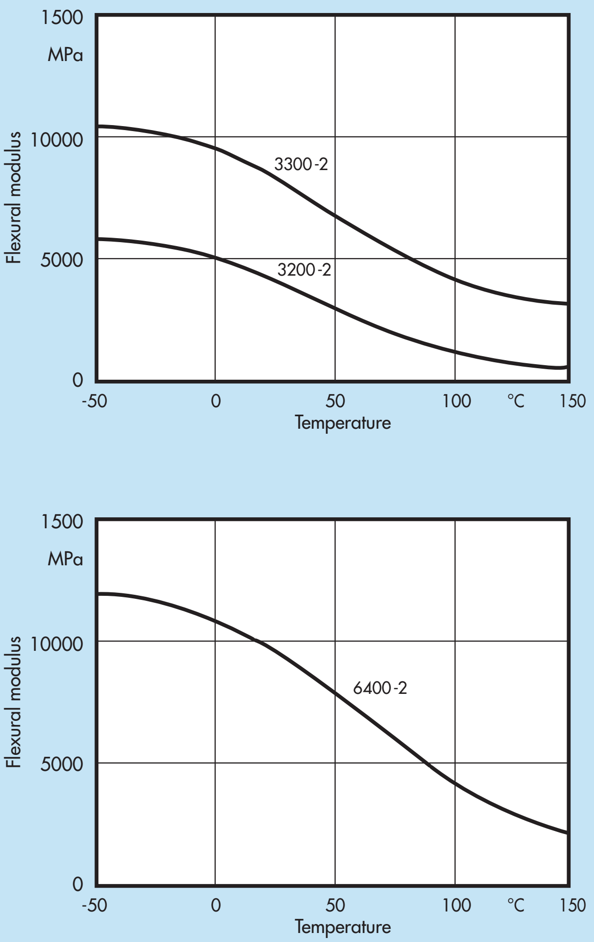
Fig. 9: Tensile stress at break (yield stress) of reinforced and unreinforced Celanex as a function of test temperature, based on ISO 527 (testing rate 50 mm/min)



Other properties determined under short-term-stress include the different elastic moduli, i. e. the tensile modulus and flexural modulus, measured according to ISO 527 and ISO 178, as well as the initial values for the flexural creep modulus (ISO 899, part 2). These values provide an indication of rigidity and are used not only to characterise plastics but also for strength calculation and the design of moulded parts.

Fig. 10 shows the flexural modulus of different Celanex grades between – 50 and + 150 °C.

Fig. 10: Flexural modulus of different Celanex grades as a function of temperature, measured according to ISO 178



3.1.2 Behaviour under long-term stress

The results of long-term tests carried out under various conditions provide design engineers with a basis for calculation when designing components subjected to prolonged stress.

The properties of plastics under long-term tensile stress are tested by two basic methods:

- creep rupture test according to ISO 899 (deformation increase in specimen held under constant stress),
- stress relaxation test according to DIN 53 441 (stress decay in specimen held under constant strain).

The first test gives the creep strength, i. e. the time to rupture of a test bar loaded with a specified stress under defined environmental conditions. These tests are carried out on tensile test bars (unaxial stress condition) or on pipes (multiaxial stress condition) in air or another medium.

A clear indication of stress-strain behavior as a function of time is provided by so-called isochronous stress-strain curves. With Celanex 2300 GV 1/30 (fig. 12) the beneficial effect of glass fibre reinforcement as compared with unreinforced Celanex 2500 (fig. 11) is apparent.

The strain values and creep moduli determined in the creep rupture test under tensile stress also serve as a good approximation for the values to be expected under flexural and compressive stress. To provide a sufficient safety margin against failure, a strain of 0.5 to 1% is usually allowed for in design calculations.

The results of creep tests under uniaxial stress have only limited applicability to the multiaxial stress condition.

Fig. 11: Isochronous stress-strain curves for Celanex 2500 at 23 °C; the parameter is the time in hours.

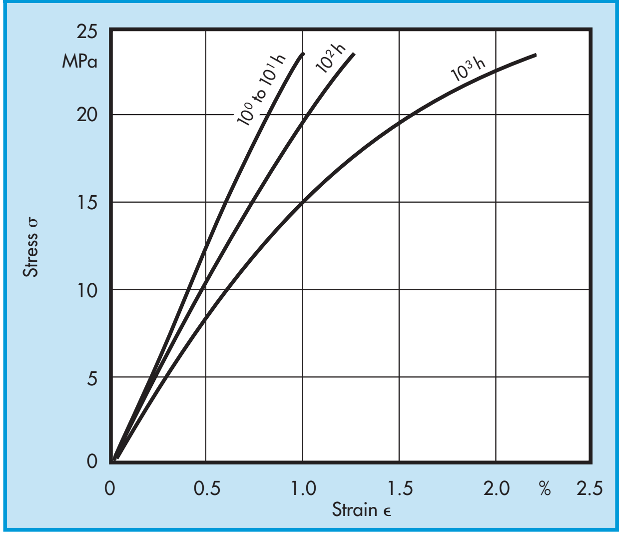
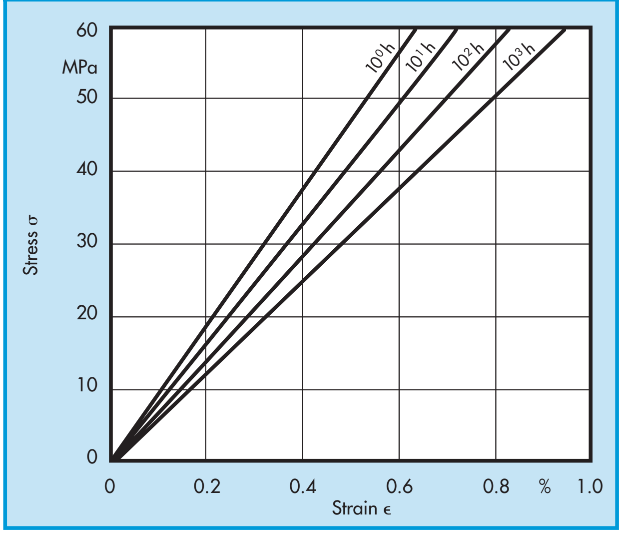


Fig. 12: Isochronous stress-strain curves for Celanex 2300 GV 1/30 at 23 °C; the parameter is the time in hours.



Celanex exhibits low creep under flexural stress, even at high temperatures (180 °C) and under high stress (14 MPa). Figs 13 and 14 show the creep curves for different test specimen loads.

Fig. 13: Flexural creep curves for Celanex 3300-2, outer fiber stress 3.5 MPa, at different temperatures

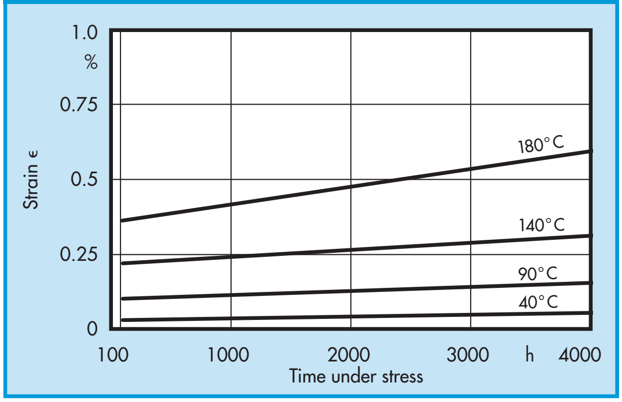
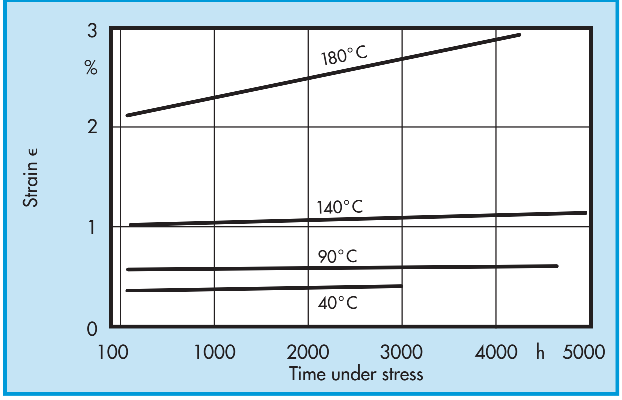


Fig. 14: Flexural creep curves for Celanex 3300-2, outer fiber stress 14 MPa, at different temperatures



The flexural creep modulus decreases slightly under long-term stress as figs. 15 and 16 show for an unreinforced Celanex grade and Celanex grades reinforced with different glass fibre levels at room temperature and 80 °C.

Tensile creep tests with unreinforced and reinforced Celanex also show a slight decrease in tensile creep modulus and only very slight increase in strain (figs. 17 and 18).

Fig. 15: Flexural creep modulus of unreinforced and reinforced Celanex, flexural stress σ_b = 10 MPa, test temperature 23 °C

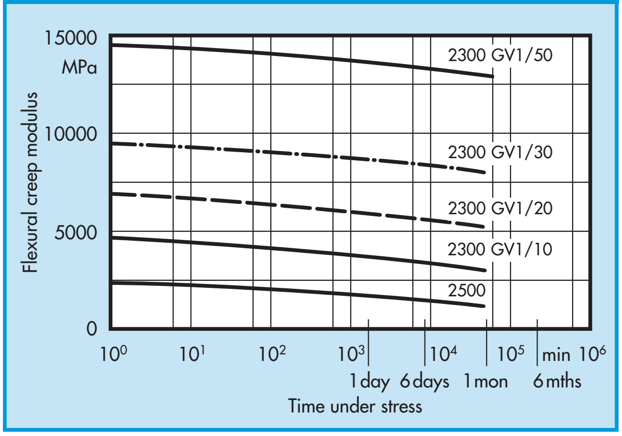


Fig. 16: Flexural creep modulus of unreinforced and reinforced Celanex, flexural stress σ_b = 5 MPa, test temperature 80 °C

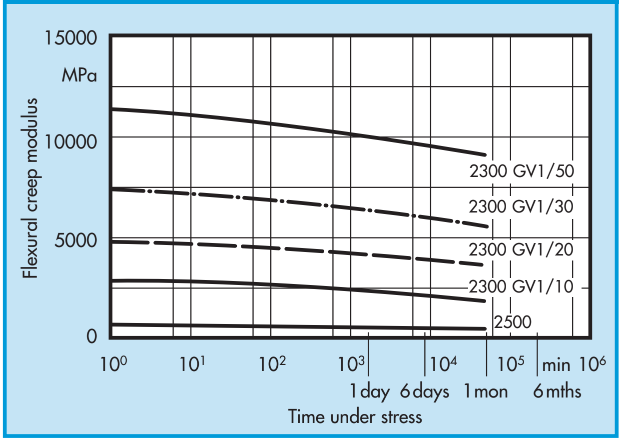


Fig. 17: Tensile creep modulus of different Celanex grades, measured in the tensile creep test (ISO 899), test temperature 23 °C, stress a = 40 MPa, b = 35 Mpa, c = 7 MPa.

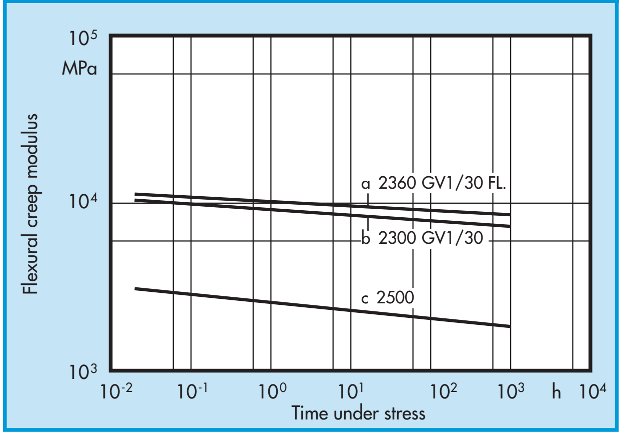
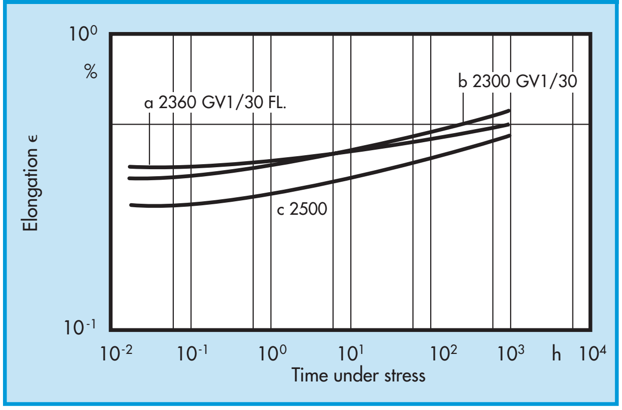


Fig. 18: Tensile creep curves for different Celanex grades, measured in the tensile creep test (ISO 899), test temperature 23 °C, stress a = 40 MPa, b = 35 Mpa, c = 7 MPa.



3.1.3 Behaviour under impact stress

Impact tests serve to determine the toughness characteristics of unnotched and notched standard test specimens at high deformation rates. The impact and notched impact strength values thus determined are used solely for comparative assessment of material properties and are not directly applicable to moulded parts. They are not therefore suitable for engineering calculations for stressed components.

For such purposes, component testing under simulated service stresses is recommended.

Impact testing under standard climatic conditions leads in the case of virtually all unreinforced Celanex general-purpose grades to a "no failure" result. Measurement of notched impact strength shows an increase in toughness with higher molecular weight (molar mass).

All Vandar grades are suitable for the production of moulded parts with increased impact strength. But the higher-molecular-weight, stiff-flowing Celanex general-purpose grades 3100, 1600 A and 1700 A can be used for the production of impact-resistant mouldings, provided these parts are designed with medium to high wall thickness.

If such parts have low wall thickness, the use of higher-molecular-weight Celanex grades can lead to orientation of the molecular chains in the flow direction, resulting in anisotropy of mechanical properties. Easier-flowing Celanex grades give rise to less oriented, low-stress mouldings; their toughness may therefore be greater than is the case with parts produced from high-molecular-weight grades.

Modification of Celanex and Vandar general-purpose grades with reinforcing materials has an effect on toughness properties. For example, glass fibre reinforcement reduces impact strength, even in the case of Vandar. Mineral reinforcement has a slightly less crucial effect.

The notched impact strength value, which is much lower than the impact strength, is improved by addition of reinforcing materials and impact modification. In the design of moulded parts, notches should be avoided as fas as possible.

Toughness properties are considerably influenced by processing conditions.

3.1.4 Behaviour under cyclic stress

Structural components subject to periodic stress must be designed on the basis of fatigue strength, i. e. the cyclic stress amplitude σ_a obtained in the fatigue test – at a given mean stress σ_m – which a test specimen withstands without failure over a given number of stress cycles, e. g. 10^7, ("Wöhler curve"). The various stress ranges in which tests of this nature are conducted are shown in fig. 19.

For most plastics, the fatigue strength after 10^7 stress cycles is about 20 to 30 % of the tensile stress at break determined in a tensile test. It decreases with increasing temperature and stress cycle frequency, and with the presence of stress concentration peaks in notched components.

Fig. 19: Stress range in the fatigue test

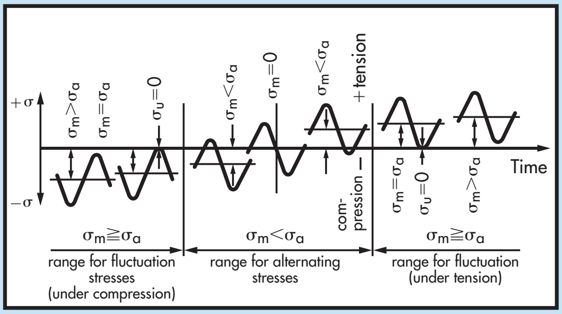


Fig. 20: Wöhler curve for Celanex 2300 GV 1/30, determined in the alternating flexural stress range

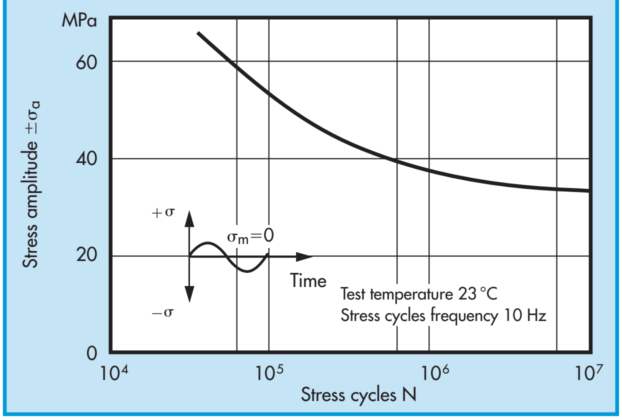


Fig. 20 shows the Wöhler curve for Celanex 2300 GV 1/30 in the alternating flexural stress range. According to the graph, the fatigue strength under alternating flexural stress for N = 10^7 stress cycles amounts to $\sigma_W = \pm 32$ MPa.

3.1.5 Surface properties

Celanex and Impet offer particularly good surface properties, such as hardness, abrasion resistance and low friction, which are important for many technical applications.

Hardness

For thermoplastics, it is customary to determine ball indentation hardness in accordance with ISO 2039, part 1. Ball indentation hardness is temperature-dependent and for the Celanex general-purpose grades lies between 122 and 145 N/mm² at 23 °C and 358 N test load.

Glass-fibre-reinforced Celanex 2300 GV 1/50 attains 235 N/mm² and Impet 2700 GV 1/45 even reaches 300 N/mm².

Low-friction properties

Celanex and Impet both have good low-friction properties similar to those of the acetal copolymer Hostaform®.

The dynamic friction coefficient of unreinforced Celanex 2500 in sliding contact with steel lies between 0.2 and 0.45, depending on surface pressure loading p and sliding speed v (figs. 21 and 22). However, because the softening range of Celanex starts at 50 °C, the p · v value used in the design of slide bearings is lower than for Hostaform. For this reason, the glass-fibre-reinforced products are normally used if relatively high operating temperatures – due to frictional heat or the ambient temperature – are expected. This is possible because in injection moulding – assuming high mould cavity temperatures – a surface layer with low glass fibre content and good friction properties is formed. Fig. 23 gives an indication of the high wear resistance of Celanex, even of the glass-fibre-reinforced grades.

If – after prolonged periods of service – glass fibres are exposed in the sliding surface, stick slip and noisy operation must be expected with Celanex in sliding contact with steel. Glass-sphere-filled products behave in a similar way to the glass-fibre-reinforced grades and offer no advantages in terms of noise development.

Fig. 21: Dynamic friction coefficient μ of Celanex 2500 as a function of surface pressure loading, determined under simulated bearing conditions in sliding contact with steel (RZ = 2 μm bearing play 1%, test duration 45 min)

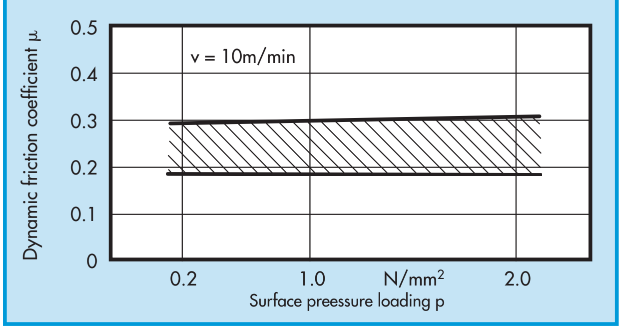


Fig. 22: Dynamic friction coefficient μ of Celanex 2500 as a function of sliding speed, determined under simulated bearing conditions in sliding contact with steel (RZ = 2 μm, bearing play 1%, test duration 45 min)

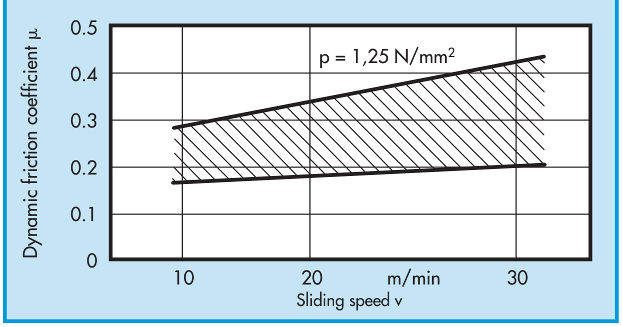
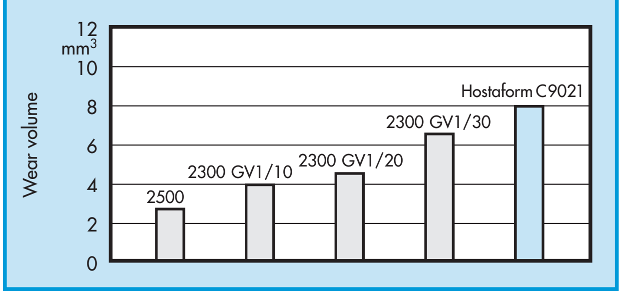
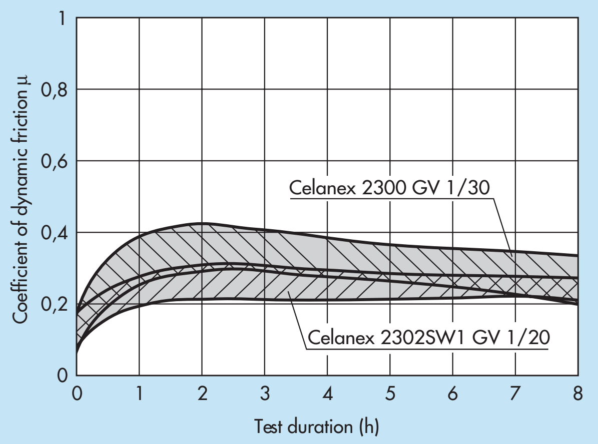


Fig. 23: Wear behaviour of various Celanex grades compared with POM in dry sliding contact with a polished steel shaft (RZ = 0.8 μm, v = 136 m/min, F = 3.1 N, test duration 60 h)



Apart from the principally low level of the coefficient of dynamic friction of all grades a special wear resistant modification exists. Celanex 2302SW1 (unreinforced) and Celanex 2302SW1 GV 1/20 (glass fiber reinforced) are specially used for tribological applications.

Fig. 24 · Curve of the coefficients of friction plotted against time for reinforced Celanex under oscillating motion in contact with smooth steel 100 Cr 6 (R_z = 0,1 µm)



If the surface pressure loading p and sliding speed v are restricted to values which preclude a marked increase in sliding surface temperature, unfilled and glass-fibre-reinforced polyesters are good sliding partners for Hostaform, polyamide, polycarbonate and ABS, even in unlubricated operation. Once-only lubrication with grease or oil significantly increases sliding performance under load and should be carried out whenever possible.

Further information to the tribological characteristics of Celanex you find in the broschure B.2.3 – Plain bearings made from engineering plastics.

3.2 Thermal properties

The most important thermal properties of a plastic include:

- melting point, transition temperatures or phase change regions, specific heat, enthalpy, thermal conductivity, coefficient of expansion
- thermal stability (stability of the melt at processing temperature)
- heat deflection temperature
- continuous service temperatures in air.

Phase change regions

The thermal behaviour of the polyester grades depends on the polymer matrix and on the nature and content of possible reinforcing materials.

Glass-fibre-reinforced formulations attain very high rigidity and strength because of the good adhesion between the polar matrix and fibres. The effect of glass transition diminishes with increasing glass fibre content so that, above the glass transition temperature, glass fibre reinforcement not only brings a significant improvement in modulus but also substantially increases heat deflection temperature under load.

Linear thermal expansion coefficient

The addition of reinforcing materials to the general-purpose grades reduces thermal expansion. It should be remembered however that thermal expansion depends to a large extent on the orientation, amount and type of reinforcing material.

With fibrous reinforcing materials, in particular, expansion is different in the orientation and transverse directions. These differences are negligible with spherical or laminar reinforcing materials such as glass microspheres and mineral fillers. The thermal expansion coefficient α for the polyester grades in the 23 – 80 °C temperature range is given in table "Physical properties" inserted at the rear side.

Heat deflection temperature

The heat deflection temperature under load (HDT) determined by standard test methods (A, B and C, each with different test stresses) provides designers with initial guidance on the continuous service temperatures of a material. Through the addition of reinforcing materials, the heat deflection temperature of the polyester grades is increased up to the vicinity of the crystalline melting range – a property also known with other polymers (e. g. polyamide).

The reinforced Celanex grades achieve a heat deflection temperature of 215 °C, reinforced Vandar 185 °C and reinforced Impet 228 °C (HDT/A, 1.8 MPa). These are top-of-the-range values for engineering plastics and are only exceeded by the high-performance thermoplastics.

Continuous service temperatures in air

The progress of heat aging is influenced by many different factors in the service environment in various ways. Terms such as “heat resistance”, “continuous service temperature”, etc, do not therefore characterise specific material properties but should be seen only in the context of a requirement profile for a given application.

Many Celanex grades have been checked on the basis of the UL 746 B standards. The temperature indices are given in the fold-out leaflet, ref. B 263 FB E. Depending on the grade, values of up to 140 °C are attained.

Figs. 25 and 26 show the results of heat aging trials at 180 °C for various Celanex general-purpose grades and flame-retardant grades.

Fig. 25: Decrease in tensile stress at break of reinforced and unreinforced Celanex in heat aging trial at 180 °C, based on ISO 527 (testing rate 50 mm/min)

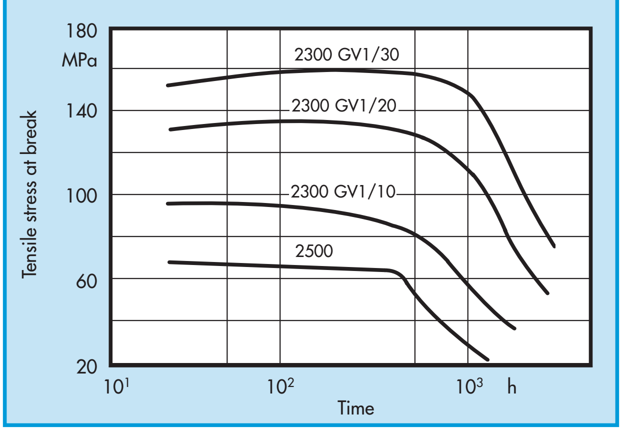
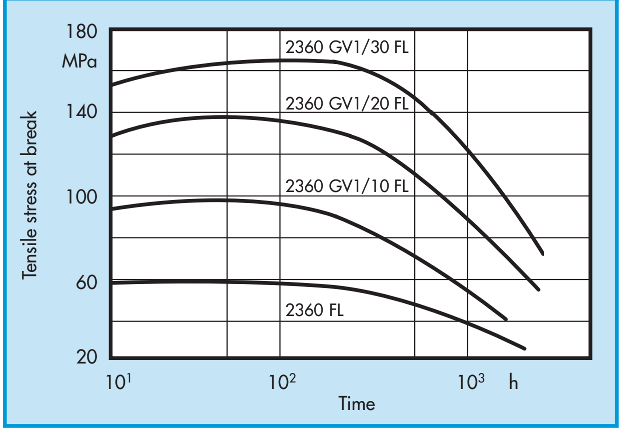


Fig. 26: Decrease in tensile stress at break of flame-retardant Celanex in heat aging trial at 180 °C, based on ISO 527 (testing rate 50 mm/min)



UL listings

The status of the UL listings for the Celanex, Vandar and Impet grades is listed in the leaflet, which is inserted at the rear side.

3.3 Electrical properties

The Ticona polyester grades have very good electrical properties. As a result of these properties, Celanex is specified and approved for many different applications in the electrical, electronics and telecommunications industries.

Insulation properties

The volume resistivity of the polyester grades is high. Data on the change in volume resistivity on prolonged heat exposure of the insulating material in air, water or oil is important for designers. Fig. 27 shows this change for Celanex 3300-2.

Fig. 27: Volume resistivity of Celanex 3300-2 as a function of exposure time at 70 °C and 100 % relative humidity

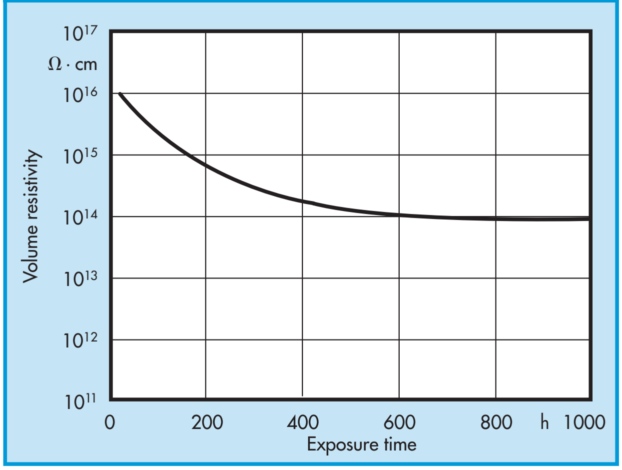
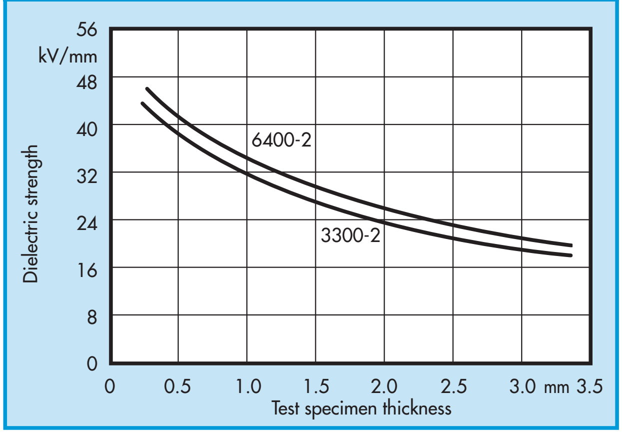


Fig. 28 shows the effect of test specimen thickness on the dielectric strength of two Celanex grades. A higher dielectric strength is obtained with thin test specimens than with thicker sheets. This is also the reason why insulating films in capacitors can be relatively thin.

Fig. 28: Dielectric strength of Celanex as a function of test specimen thickness



Dielectric constant, dissipation factor

The dielectric constant ε_r of the Celanex grades ranges between 3.5 and 5.1; for Vandar, it is between 3.6 and 4.9 and for Impet between 4.0 and 5.2. ε_r decreases slightly with increasing frequency.

The dissipation factor tan δ is a measure of the energy loss in the dielectric by conversion into heat. The dissipation factor values of the polyester grades are relatively low, amounting to about 0.022 for Celanex, 0.029 for Vandar and 0.019 for Impet at a frequency of 1 MHz.

The low dissipation factor precludes the use of high-frequency heating and welding for this material.

4. Resistance to environmental effects

In this section, the properties of the polyester grades in the presence of certain media and their dependence in some cases on temperature and time of exposure are described.

4.1 Water absorption

Celanex and Impet have very low water absorption. The value when tested based on ISO 62 at 23°C is between 0.35 and 0.45%. Vandar has slightly higher values of between 0.45 and 0.5%.

This low water absorption accounts for the excellent dimensional stability of mouldings produced from these materials.

Water absorption by the polyester grades is a reversible process, i.e. on subsequent storage in air the absorbed water is given up again until equilibrium is reached.

4.2 Service temperatures in hot water

Celanex and Vandar have good long-term resistance to water at temperatures of up to 40°C. If continuous exposure to hot water is expected, the use of Hostaform acetal copolymer is recommended (see the relevant notes in the Hostaform brochure). Celanex withstands short-term exposure to steam and water under pressure at temperatures of up to 150°C.

Impet is not resistant to prolonged exposure to hot water. It should not therefore be used in water or aqueous solutions at increased temperatures higher then 50°C or in steam.

4.3. Resistance to hydrolysis

Thermal shock tests at 80% relative humidity are specified particularly by the automotive industry. For this purpose, increasing use is being made of the USCAR (United States Council for Automotive Research) test. In this test, finished components are exposed to temperature and humidity cycling as shown in Fig. 29. After 40 cycles, the component is subjected to mechanical, electrical and optical tests.

Components made from standard PBT usually meet the requirements for low temperature classes (up to 80°C; up to 100°C). For the higher temperature classes (125°C; 155°C), hydrolytically stabilized Celanex grades are available. Celanex 3300HR retains 90% of its initial tensile strength, even after 40 temperature/humidity cycles (see Fig. 30).

Fig. 29: Curve for temperature and humidity testing according to USCAR section 5.6.2, class II

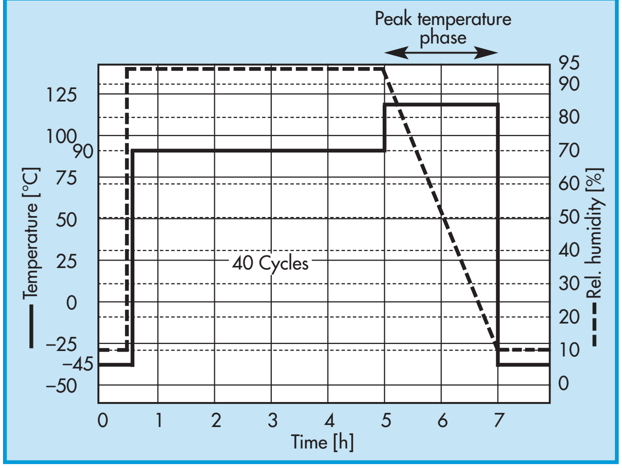
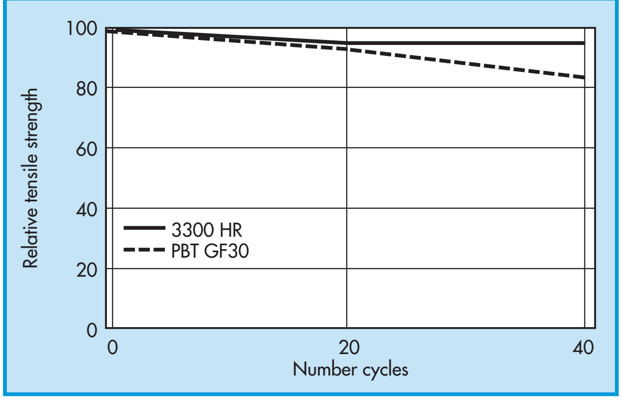


Fig. 30: Change in the tensile strength at break of Celanex specimens tested according USCAR class III



4.4 Chemical resistance

Before a material can be approved, particularly for more highly stressed parts in aggressive media, its suitability in terms of chemical resistance must be demonstrated in practical tests, e. g. on prototypes.

Celanex has high resistance to many organic and inorganic chemicals. Table 2 shows the behaviour of Celanex on exposure to a wide variety of chemicals.

The tensile strength and dimensions of injection moulded test specimens made from Celanex change only slightly in dilute acids at room temperature. However, prolonged exposure at high temperatures leads to gradual polymer degradation.

Celanex has excellent resistance to many organic solvents and chemicals at room temperature. Even on prolonged contact, only minimal property and dimensional changes generally take place. On contact at higher temperatures, the properties of Celanex can change. For any application in which Celanex mouldings are to be in prolonged contact with organic chemicals at elevated temperatures, prototypes must be tested.

Celanex has outstanding long-term resistance to the substances normally encountered in the automotive sector such as gear oil, brake fluid, engine oil and lubricating grease.

A frequently asked question concerns the resistance of Celanex PBT to liquid media used in the automotive sector. Underhood components, in particular, can be contaminated with a wide variety of substances, such as gasoline, engine oil, transmission oil, brake fluid, coolant, windshield wash fluid and cold cleaner, if these media are incorrectly handled. When components made from Celanex are wetted with these liquids, no damage to the surface is observed (except in the case of battery acid), even after several days' exposure at elevated temperature (the usual test conditions are 5 cycles: wetting + 48 h storage at 80°C). This also applies to liquids, such as coolants (ethylene glycol/water mixture), to which Celanex PBT has limited or zero resistance when in direct contact at elevated temperature.

With some chemicals, the glass fibre reinforcement of Celanex can cause deviations in resistance. To check suitability, a long-term test is highly advisable.

Because of its crystalline structure, Celanex polyester is not susceptible to environmental stress cracking which is sometimes a problem with amorphous engineering polymers under certain conditions. In immersion trials for 5 hours in different test media at room temperature, Celanex test specimens subjected to different outer fibre stresses in a bending device exhibited no stress cracking, table 1.

Electrical engineering components are in some cases exposed to the action of ozone. Trials have shown that Celanex 3300-2 retains 70 % of ist original tensile strength after 50 hours at 120°C in an atmosphere containing 1.7% ozone.

Table 1:
Stress cracking resistance of Celanex 3300-2

Immersion time 5 hours Stress 82.8 Mpa	Temperature °C	Effect[3]
Test fuel C (ASTM D 471) (50 % v/v isooctane, 50 % v/v toluene)	60	none
Ethylene glycol	93	none
Gear oil A	93	none
Lockheed brake fluid (heavy duty)	60	none
Uniflo oil	93	none
BTX[1]	23	none
Skydrol[2]	23	none

[1] 50 % benzene, 37.5 % toluene, 12.5 % xylene
[2] Hydraulic fluid (Monsanto)
[3] Under a microscope at 30 x magnification, no environmental stress cracking was observed

Solvents for Celanex include the phenolic compounds well known as solvents for polyester or halogenated aliphatic acids.

Table 2 gives chemical resistance data for unreinforced Vandar. Glass-fibre-reinforced grades may show deviations from the resistance shown in the case of some chemicals. Before practical operation, it is definitely necessary to test suitability in a long-term test.

Impet generally possesses good chemical resistance, table 2. It is resistant to weak acids, salt solutions, oils, fuels, solvents and surfactants but not to strong acids, alkalis and chlorinated hydrocarbons.

Glass fibre reinforcement of Impet can cause deviations in resistance to some chemicals. It is definitely necessary here again to check suitability in a long-term test.

4.5 Resistance to UV and weathering

Even without additional stabilisation, the polyester grades have very good resistance to the effects of ultraviolet radiation and outdoor weathering.

In laboratory Weatherometer trials, unpigmented and pigmented injection moulded test specimens made from Celanex 3300-2 exhibited only a relatively slight loss in tensile strength. Fig. 31 plots the retention of tensile strength (as a percentage of original strength) against time of exposure in a Weatherometer test lasting 12 000 hours (500 days).

Although there is no exact correlation between accelerated weathering in the laboratory and natural outdoor weathering, tests carried out under standardised laboratory conditions yield results which can be used to assess outdoor weathering behaviour. This has also to be prooved by tests under practical conditions.

Values measured over three years' outdoor weathering show that the physical properties of Celanex do not fundamentally alter. As expected, the weathering resistance of black Celanex is higher than that of the natural-coloured material. For applications involving long-term outdoor exposure, the use of black Celanex grades is recommended. Figs. 32 and 33 show the tensile stress at break and Izod notched impact strength values after 12 months' natural outdoor weathering.

4.6 Flammability

Many different standards and test methods are used to characterise the behaviour of polymers on exposure to flame or incandescent objects.

The results of hot wire tests on Celanex, Vandar and Impet grades are shown in table "physical properties", which is inserted at the rear side.

Fig. 31: Effect of accelerated weathering in the Weatherometer on the change in tensile stress at break of Celanex 3300-2 black and natural

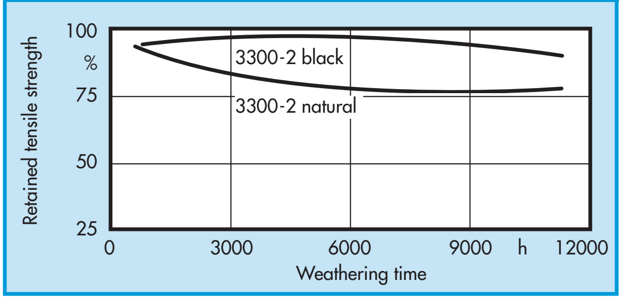


Fig. 32: Tensile stress at break of Celanex 3300-2 black and natural as a function of outdoor weathering time, measured in Florida and Arizona

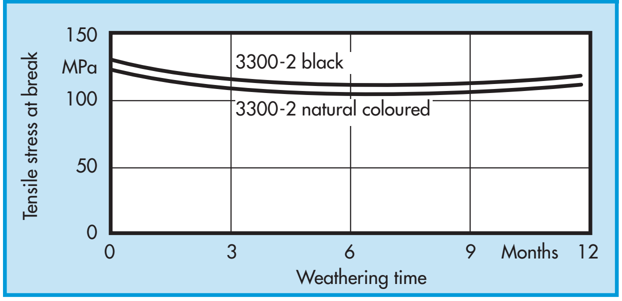
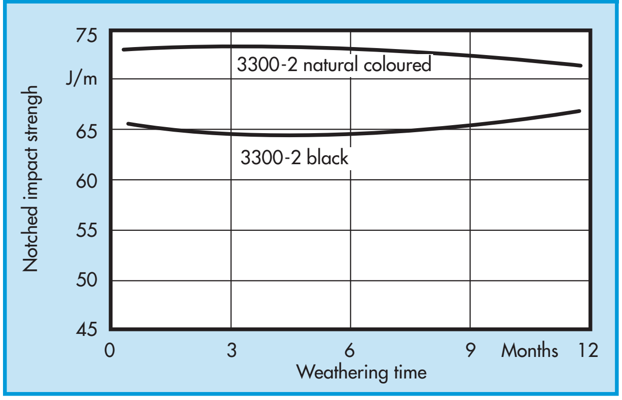


Fig. 33: Notched impact strength (Izod) of Celanex 3300-2 black and natural as a function of outdoor weathering time, measured in Florida and Arizona



Most Celanex and some Vandar grades have been tested by Underwriters Laboratories. The table of UL listings is included in the leaflet, which is inserted at the rear side.

Flame-retardant Celanex grades achieve class V-0, in some cases at wall thicknesses of only 0.4 mm and with up to 50 % regrind. Some grades also attain class UL 94-5 VA.

4.7 Resistance to high-energy radiation

These polyester grades have relatively good resistance to high-energy radiation. Degradation of a more serious nature does not take place until the absorbed energy level reaches 100 kJ/kg. This has also to be prooved by tests under practical conditions.

4.8 Pharmaceutical / medical applications

In order to meet the particularly high standards for materials used in medical engineering, and to be able to comply with legal requirements varying from one country to another, Ticona has specially tailored a number of engineering polymers for healthcare applications.

The special suitability of the Celanex base polymer for medical engineering applications is demonstrated by favourable results from extensive biocompatibility testing. Celanex is included in FDA's Drug Master Files and Device Master Files. The polymer's characteristics include high creep resistance combined with good dimensional stability, high toughness and good flowability. Improved flow grades of Celanex are particularly suited for fine-structured, precision-moulded parts.

Grade	description
2401MT	unreinforced standard grade
2402MT	unreinforced, improved flowability
2403MT	unreinforced, high-speed crystallisation, faster cycle times
2404MT	PTFE-modified, improved abrasion and friction properties

Ticona does not support the use of its plastics for implant applications. Irrespective of the positions as regards responsibility, Celanex should not be used for permanent implants because of the risk involved.

For further information please ask for our brochure ”New Polymer Grades for Medical and Laboratory Engineering“ (B 281 E) or contact us directly.

Table 2: Chemical resistance of unreinforced and glass-fibre-reinforced Celanex, unreinforced Vandar and glass-fibre-reinforced Impet – continued

These data have been determined on laboratory specimens and can only serve as guideline values.
The resistance of a moulding to a specific medium must be checked under practical conditions.

Key:
+ = resistant (little or no weight change)
/ = limited resistance (short-term contact with the medium possible)
– = not resistant (weight change exceeding 5%, sharp decline in mechanical properties)

Test duration: 30 days
The values in brackets refer to the different chemical resistance behaviour of reinforced Celanex.

	Celanex		**Vandar**		**Impet**	
Medium1)	**23 °C**	**60 °C**	**23 °C**	**60 °C**	**23 °C**	**60 °C**
Acetic acid (5%)	+	/				
Acetic acid (10%)	+	/	/	/	+	/
Acetic acid (100%)	–	–	–	–	/	
Acetone	+ (/)	–	+	–	/	
Allyl alcohol	+					
Ammonia (10%)	/	–	/	–	+	
Amyl acetate	+	–				
Benzene	+	–	+	–	+	
Brake fluid	+	+	+	+	+	+
Butane	+		+			
Butanediol-1,4	+	/				
Butanol	+	/	+	/		
Butyl acetate	+	+	+	+		
n-Butyl ether	+					
Calcium chloride (10%)	+	+ (/)	+	+		
Calcium hypochlorite	+	+				
Carbon disulphide	+		+			
Carbon tetrachloride	+		+			
Chlorobenzene	–	–	–	–		
Chloroform	–	–	–	–		
Citric acid (10%)	+	/	+	/		
Cresol	–	–	–	–		
Detergent, synthetic	+	+ (/)	+	+		
Dibutyl phthalate	+	/	+	/		
1,2-Dichloroethane	–		–			
Diesel oil	+	+	+	+	+	
Diethyl ether	+		+		+	
Dioxane	+	–	+	–		
Engine oils	+	+	+	+	+	+

Table 2: Chemical resistance of unreinforced and glass-fibre-reinforced Celanex, unreinforced Vandar and glass-fibre-reinforced Impet – continued

These data have been determined on laboratory specimens and can only serve as guideline values.
The resistance of a moulding to a specific medium must be checked under practical conditions.

Test duration: 30 days
The values in brackets refer to the different chemical resistance behaviour of reinforced Celanex.

	Celanex		Vandar		Impet	
Medium1)	**23 °C**	**60 °C**	**23 °C**	**60 °C**	**23 °C**	**60 °C**
Ethanol	+	/	+	/	+	
Ethyl acetate	+ (/)	–	/	–	/	
Ethylene glycol	+	/	+	/	+	/
Fluorocarbons	+		+	+		
Fluorocarbons – HFA 134 a – HFA 227	 + +	 / +				
Formic acid (10%)	+	/	+	/	+	
Glycerol	+	+ (/)	+	+	+	
Heptane	+	+	+	+		
Hexane	+	+	+	+	+	
Hydraulic oil	+	+	+	+	+	+
Hydrochloric acid conc.	–	–	–	–		
Hydrochloric acid (10%)	+	/	+	–	+	
Hydrofluoric acid (10%)	/ (–)	/ (–)	/	/		
Hydrofluoric acid (5%)	+ (–)	/ (–)				
Hydrogen peroxide (35%)	+	/				
Hydrogen peroxide (5%)	+	/				
Isopropanol	+	/	+	/	+	
Kerosene	+	+	+	+		
Linseed oil	+	+	+	+		
Lubricating greases	+	+	+	+	+	+
Methanol	+	/	+	/	+	/
Methyl ethyl ketone	+ (–)	/	+	/		
Methylene chloride	–		–		–	
Mineral oils	+	+	+	+		
Nitric acid (10%)	+	/	+	/		
Nitric acid conc.	–	–	–	–		
Octane	+	+	+	+		
Olive oil	+	+	+	+		
Paraffin oil	+	+	+	+		
Perchloroethylene	+	/	/	–		

Table 2: Chemical resistance of unreinforced and glass-fibre-reinforced Celanex, unreinforced Vandar and glass-fibre-reinforced Impet – continued

These data have been determined on laboratory specimens and can only serve as guideline values.
The resistance of a moulding to a specific medium must be checked under practical conditions.

Test duration: 30 days
The values in brackets refer to the different chemical resistance behaviour of reinforced Celanex.

	Celanex		Vandar		Impet	
Medium1)	**23 °C**	**60 °C**	**23 °C**	**60 °C**	**23 °C**	**60 °C**
Petrol, premium	+	/	*	/	+	/
Petrol, regular and unleaded	+	/	+	/	+	/
Petroleum	+	+	+	+		
Phenol (10 %)	–	–	–	–		
Phosphoric acid (20 %)	+	/	+	/		
Potassium chloride (10 %)	+	+ (/)	+	+		
Potassium dichromate (10 %)	+	+	+	+		
Potassium hydroxide (1 %)	+ (–)	/ (–)				
Potassium hydroxide (10 %)	/ (–)	–	–	–	–	
Potassium permanganate (10 %)	+	/	+	/		
Silicone oils	+	+	+	+		
Soap solution (10 %)	+	+ (–)	+	/		
Sodium bisulphite (10 %)	+	+	+	+		
Sodium carbonate (10 %)	+	+	+	+	+	+
Sodium chloride (10 %)	+	+	+	+		
Sodium hydroxide (1 %)	+ (–)	/ (–)				
Sodium hydroxide (10 %)	/ (–)	–	–	–	–	
Sodium hypochlorite (10 %)	+	+ (/)				
Sulphuric acid conc.	–	–	–	–		
Sulphuric acid (10 %)	+	–	+	–	+	
Tetrahydrofuran	/		–			
Toluene	+	–	/	–	+	
Transformer oil	+	+	+	+		
Trichloroethylene	/	–	/	–		
Turpentine oil	+		+			
Vaseline	+	+	+	+		
Vegetables	+	+	+	+		
Washing soap	+	+	+	+		
Water	++				+	+
Xylene	+	–	/	–	+	

1) Percentages relate to aqueous solutions (% w/w)

5. Processing

5.1 Material preparation

Celanex, Vandar and Impet are supplied in plastic or multiwall bags. Before processing, the material should be dried to achieve optimum moulded-part properties. The moisture content of virgin material and regrind to be processed should not exceed 0.02% in the case of Celanex and Vandar and 0.01% with Impet. Higher moisture contents lead to hydrolytic degradation of the melt and to a deterioration in the mechanical properties, particularly toughness, of the mouldings.

The processing machine feed hopper should be closed during the processing operation; heating the hopper can be an advantage.

5.2 Regrind addition

Good-quality, dry, sorted regrind can be added in proportions of up to 20% of the original material. In the case of Celanex grades 2016, 3116, 3216 and 3316, UL permit a regrind addition of up to 50%. The properties of the mouldings so produced, particularly the mechanical properties, should however be checked.

5.3 Injection moulding parameters

The offered method of processing is injection moulding but extrusion is also possible. The shot volume and cylinder volume should be in a ratio such that the residence time of the melt in the plasticising unit does not exceed 5 – 10 min, depending on material composition. In the event of longer residence times resulting from interruptions to processing, the melt remaining in the plasticising unit should be pumped off before restart.

All these polyester grades have very good melt flowability. Processing conditiones for Celanex, Impet and Vandar are shown in figs. 34 to 37. For Celanex and Vandar temperatures higher than 270°C should be avoided because of the risk of melt degradation. With grades containing flame retardants, a maximum temperature of 265°C should not be exceeded (see fig. 35).

For Impet, melt temperatures of 270 – 290°C are recommended. Temperatures above 295°C can cause thermal degradation of the melt.

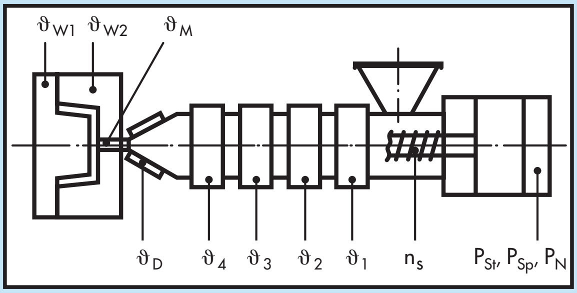
The injection rate and injection and holding pressures should be matched to the particular article geometry. Generally speaking, because of the high freezing and crystallisation rate, short production cycles should be achieved. Thin-walled parts, in particular, should be produced

- with high injection rates and
- high injection pressures

to prevent the melt freezing during the tool filling operation and so causing poor-quality surfaces.
A medium to high holding pressure is recommended to prevent sink marks. It is important to ensure good tool venting.

Fig. 38 shows the peripheral screw speed as a function of screw speed for various screw diameters. With standard screws, peripheral speeds of 0.1 to 0.3 (0.5) m/s should not be exceeded.

Fig. 34: Processing conditions for Celanex



	Basis grades	Reinforced grades	Celanex 2302/2303 GV1/xx
ϑ_1 =	240 – 250 °C	250 – 260 °C	250 – 260 °C
ϑ_2 =	240 – 250 °C	250 – 260 °C	250 – 260 °C
ϑ_3 =	245 – 255 °C	255 – 265 °C	260 – 270 °C
ϑ_4 =	245 – 255 °C	255 – 265 °C	260 – 270 °C
ϑ_D =	250 – 260 °C	260 – 270 °C	265 – 275 °C
ϑ_M =	250 – 260 °C	260 – 270 °C	265 – 275 °C
ϑ_{W1}, ϑ_{W2} =	75 – 85 °C	75 – 100 °C	90 – 120 °C

Maximum residence time in the cylinder: 5–10 min (see fig. 35).

P_{Sp} = 600 – 1000 bar
P_N = 400 – 800 bar
P_{St} = 10 – 30 bar

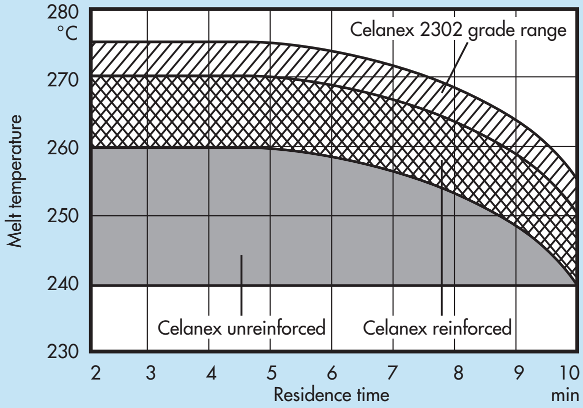
Injection rate: high

Nozzle design: preferably free-flow

Predrying
ϑ_{Dr} = 120 – 140°C, 2–4 h, res. humidity ≤ 0.02%
Predrying with dry-air drier

ϑ_1, ϑ_2-ϑ_D	°C	Cylinder temperatures, nozzle temperature
ϑ_M	°C	Melt temperature
ϑ_{W1}, ϑ_{W2}	°C	Tool temperatures
n_s	min^{-1}	Screw speed
P_{St}	bar	Back pressure
P_{Sp}	bar	Injection pressure
P_N	bar	Holding pressure

Fig. 35: Injection molding of Celanex
Reliable residence time of Celanex in a plasticizing cylinder of a injection molding machine



$$\text{Residence time} = \frac{\text{melt volume in cylinder x cycle time}}{\text{shot volume}}$$

Recommended machine utilization rate: 30 % – 70 %

Glass-fibre-reinforced polyester grades should be processed at low screw speed with very little or no back pressure in order to retain as far as possible the full length of the glass fibre used for reinforcement and the good mechanical properties associated with these.

For parts requiring very high dimensional stability, a tool wall temperature of 80 – 110 °C is recommended for Celanex, depending on the grade.

5.4 Flowability

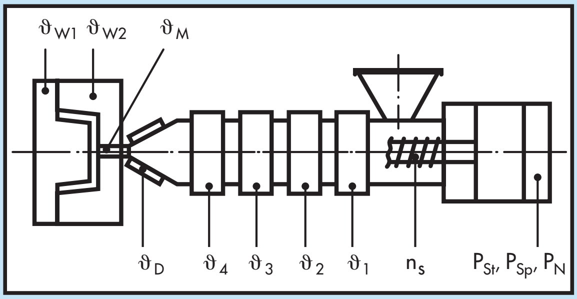
Melt flowability is determined in a spiral flow test which closely simulates practical conditions.

Unreinforced Celanex and Vandar grades achieve a longer flow path than the reinforced products and so have better flowability. The effect of wall thickness and injection pressure is shown in

Figs. 39 – 50 for Celanex
and figs. 51 – 53 for Vandar.

In tool design, calculations should be based on only 0.7 – 0.8 x the experimentally determined flow path in order to ensure sufficiently high cavity pressures.

Fig. 36: Processing conditions for Impet



ϑ_1 = 260 – 270 °C
ϑ_2 = 270 – 280 °C
ϑ_3 = 280 – 290 °C
ϑ_4 = 280 – 290 °C
ϑ_D = 270 – 290 °C
ϑ_M = 270 – 290 °C
ϑ_{W1}, ϑ_{W2} = 135 – 145 °C
Maximum residence time in the cylinder: 5 – 10 min
P_{Sp} = 600 – 900 bar
P_N = 300 – 500 bar
P_{St} = 10 – 20 bar

Injection rate: high

Nozzle design: preferably free-flow

Predrying
ϑ_{Dr} = 120 – 140°C, 2–4 h, res. humidity ≤ 0.01 %
Predrying with dry-air drier

ϑ_1, ϑ_2-ϑ_D	°C	Cylinder temperatures, nozzle temperature
ϑ_M	°C	Melt temperature
ϑ_{W1}, ϑ_{W2}	°C	Tool temperatures
n_s	min^{-1}	Screw speed
P_{St}	bar	Back pressure
P_{Sp}	bar	Injection pressure
P_N	bar	Holding pressure

Fig. 37: Processing conditions for Vandar

	unreinforced	reinforced	Vandar 9116
ϑ_1 =	190 – 200 °C	190 – 200 °C	190 – 200 °C
ϑ_2 =	210 – 220 °C	220 – 230 °C	200 – 210 °C
ϑ_3 =	220 – 230 °C	230 – 240 °C	220 – 230 °C
ϑ_4 =	230 – 240 °C	240 – 250 °C	220 – 230 °C
ϑ_D =	240 – 250 °C	250 – 265 °C	240 – 250 °C
ϑ_M =	240 – 250 °C	250 – 265 °C	240 – 260 °C
ϑ_{W1}, ϑ_{W2} =	70 – 85 °C	75 – 85 °C	30 – 50 °C

Maximum residence time in the cylinder: 5 – 10 min
P_{Sp} = 600 – 900 bar
P_N = 300 – 500 bar
P_{St} = 10 – 20 bar

Injection rate: high

Nozzle design: preferably free-flow

Predrying
ϑ_{Dr} = 120 – 140°C, 2–4 h, res. humidity ≤ 0.02 %
Predrying with dry-air drier

ϑ_1, ϑ_2-ϑ_D	°C	Cylinder temperatures, nozzle temperature
ϑ_M	°C	Melt temperature
ϑ_{W1}, ϑ_{W2}	°C	Tool temperatures
n_s	min^{-1}	Screw speed
P_{St}	bar	Back pressure
P_{Sp}	bar	Injection pressure
P_N	bar	Holding pressure

Fig. 38 · Peripheral screw speed v_s as a function of screw speed n_s and screw diameter D

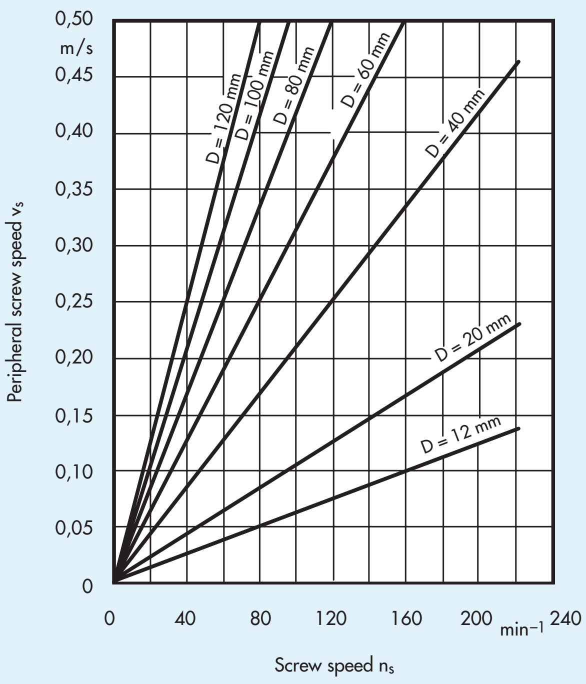


Fig. 39: Flow path length of Celanex 2500 as a function of the wall thickness of the test spiral at different injection pressures

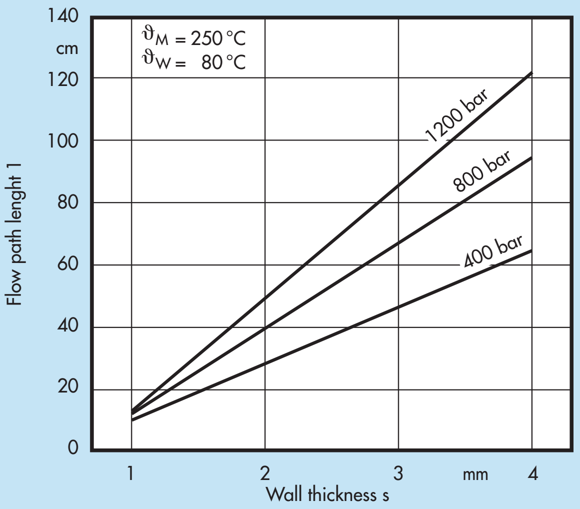


Fig. 40: Flow path length of Celanex 1600 A as a function of the wall thickness of the test spiral at different injection pressures

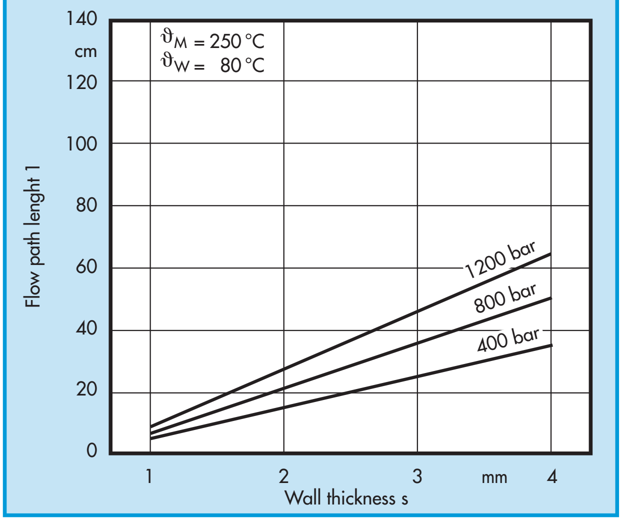


Fig. 41: Flow path length of Celanex 2300 GV 1/10 as a function of the wall thickness of the test spiral at different injection pressures.

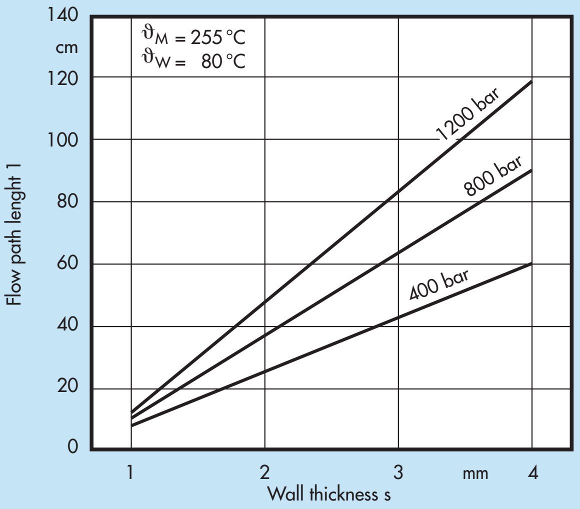


Fig. 42: Flow path length of Celanex 2300 GV 1/20 as a function of the wall thickness of the test spiral at different injection pressures

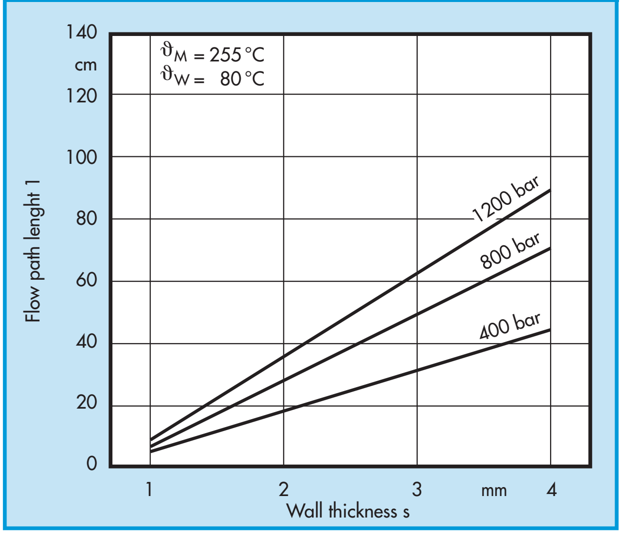


Fig. 43: Flow path length of Celanex 3300-2 as a function of the wall thickness of the test spiral at different injection pressures

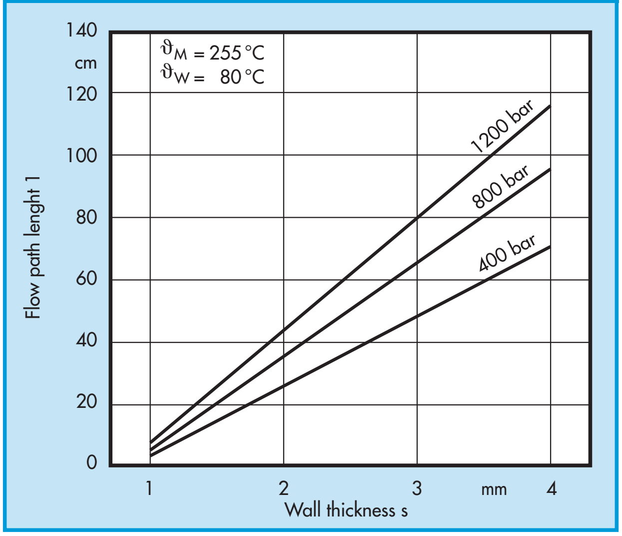


Fig. 44: Flow path length of Celanex 2300 GV 1/50 as a function of the wall thickness of the test spiral at different injection pressures

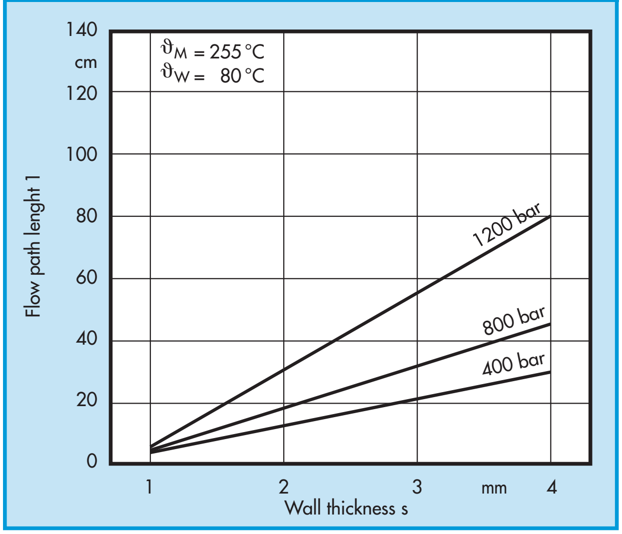


Fig. 45: Flow path length of Celanex 2302 GV 1/15 as a function of the wall thickness of the test spiral at different injection pressures

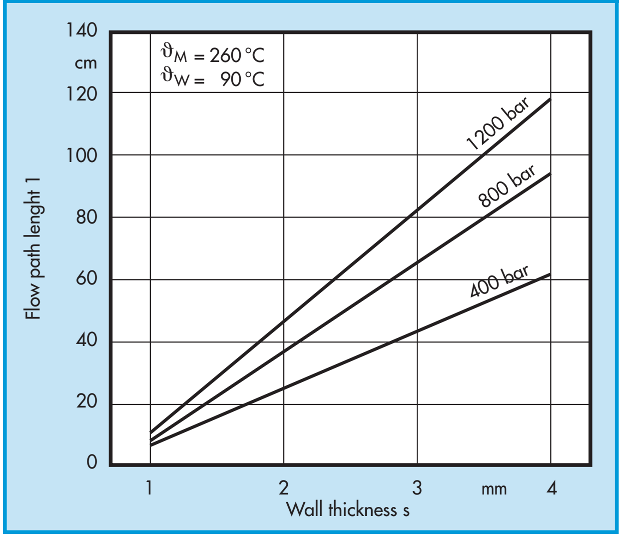


Fig. 46: Flow path length of Celanex 2302 GV 1/30 as a function of the wall thickness of the test spiral at different injection pressures

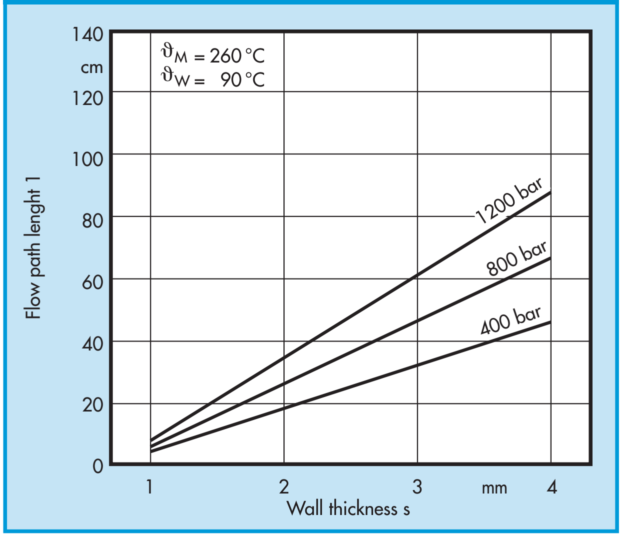


Fig. 47: Flow path length of Celanex 2300 GV 3/20 as a function of the wall thickness of the test spiral at different injection pressures

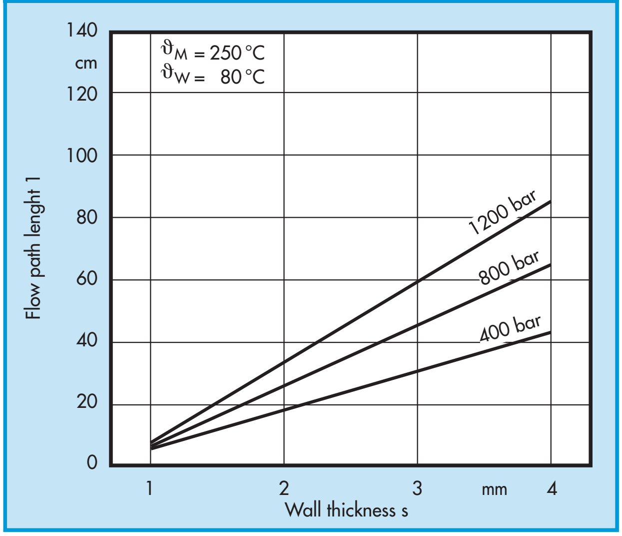


Fig. 48: Flow path length of Celanex 3314 as a function of the wall thickness of the test spiral different injection pressures

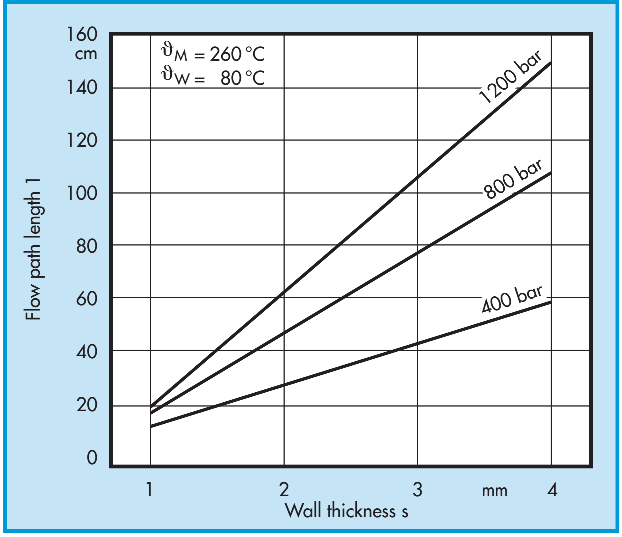


Fig. 49: Flow path length of Celanex 3316 as a function of the wall thickness of the test spiral different injection pressures

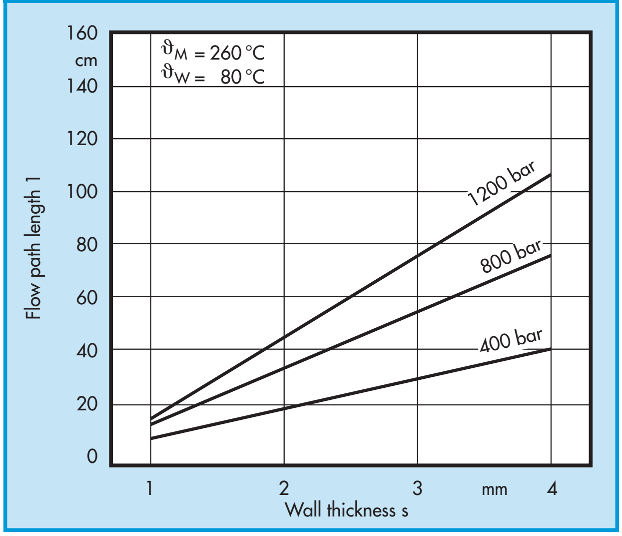


Fig. 50: Flow path length of Celanex J 600 and 6400-2 as a function of the wall thickness of the test spiral at different injection pressures

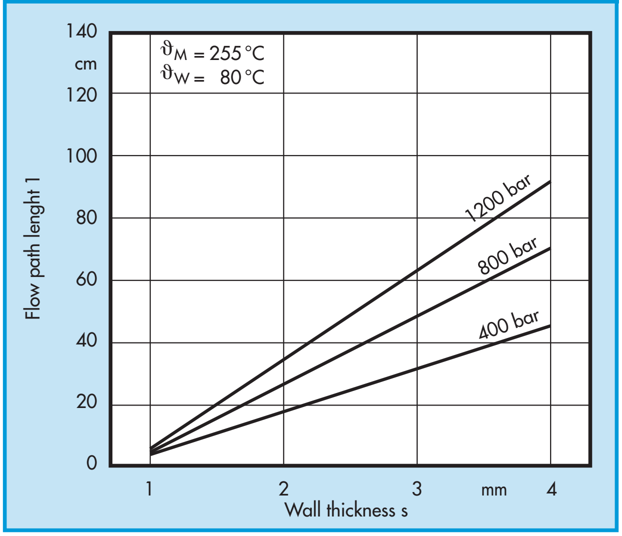


Fig. 51: Flow path length of Vandar 4602 Z and 8000 as a function of the wall thickness of the test spiral at different injection pressures

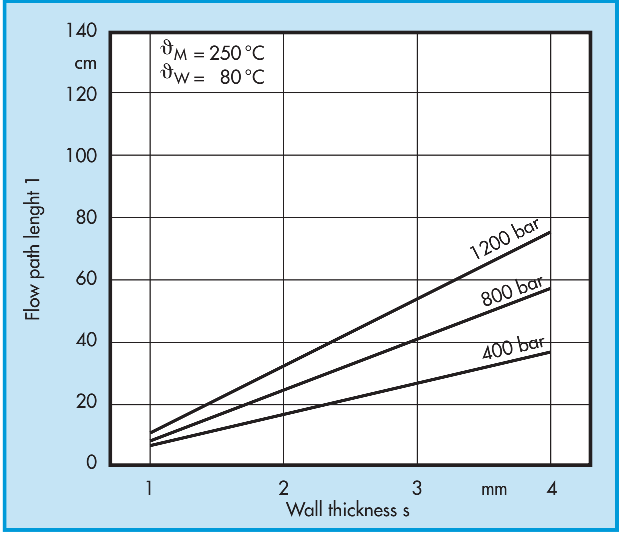


Fig. 52: Flow path length of Vandar 4612 R as a function of the wall thickness of the test spiral at different injection pressures

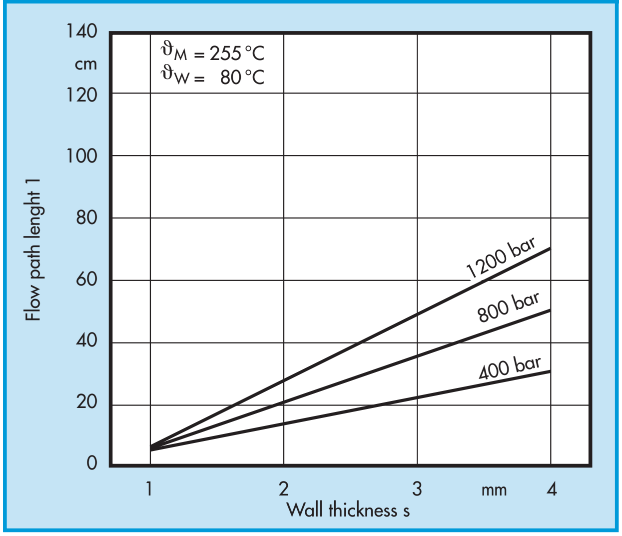
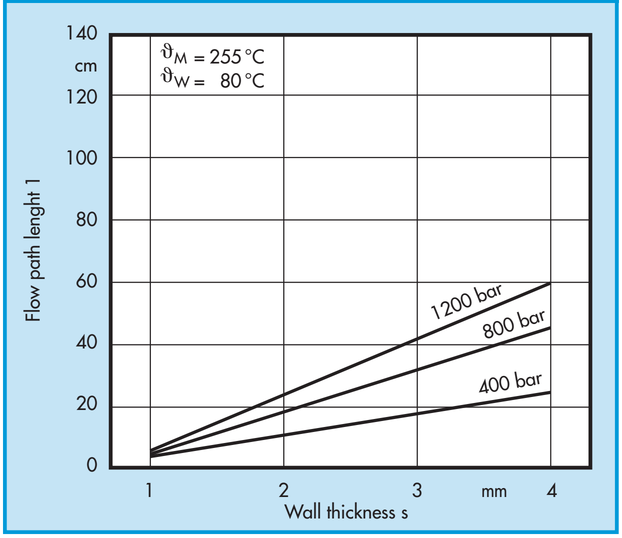


Fig. 53: Flow path length of Vandar 4632 Z and 4662 Z as a function of the wall thickness of the test spiral at different injection pressures



5.5 Weld line strength

Weld line strength can be determined by comparing the mechanical properties of test specimens produced in single- and double-gated moulds. From the tensile stress at break determined in a tensile test, it can be seen that with unreinforced Celanex no failure occurs in the weld line, i. e. the tensile test bar produced in the double-gated mould has the same tensile strength as that from the single-gated mould.

With unreinforced Vandar, on the other hand, a decline in tensile stress at break of 10 – 20 % may expected in tensile test bars produced in double-gated moulds.

With the glass-fibre-reinforced grades, tensile strength drops to 40 – 60 % of its initial value in the double-gated specimen. The position of the weld line must therefore be taken into account in designing articles made from glass-fibre-reinforced grades.

5.6 Shrinkage

In defining shrinkage, a distinction is made between shrinkage MS and after-shrinkage AS. The sum of shrinkage MS and after-shrinkage AS is referred to as total shrinkage TS.

The shrinkage of the polyester grades is dependent on the wall thickness of the molding, the tool wall temperature, melt temperature, gate design and injection conditions (injection rate, injection pressure, holding pressure):

> Celanex: figs. 54 – 58,
> Vandar: fig. 59.

Shrinkage was measured after 24 hours' storage at room temperature. After-shrinkage (and hence total shrinkage) was determined after 2 hours' storage at 140 °C.

The shrinkage of the unreinforced polyester grades is virtually independent of flow direction (longitudinal, transverse) and increases with rise in wall thickness. In the case of glass-fibre-reinforced polyester, shrinkage is dependent on flow direction. It is considerably lower in the flow (longitudinal) direction, i. e. in the direction of glass fibre orientation, than in the transverse direction. This anisotropy can lead to warpage of the moulding, which can often be minimized by relocating the gate and observing the principles of correct moulding design for plastics. Warpage is also influenced by the type of gate and tool temperature. It is important to aim for wall thickness to be as uniform as possible throughout the moulding.

With rising tool temperature, shrinkage increases but after-shrinkage decreases (figs. 60 – 62).

For parts requiring especially high dimensional stability, a tool temperature of 80 – 120 °C is recommended, depending on the Celanex grade.

Fig. 54: Shrinkage MS as a function of wall thickness for the following Celanex grades:
unreinforced: Celanex 2500
10% GF: Celanex 2300 GV1/10
20% GF: Celanex 2300 GV1/20
30% GF: Celanex 2300 GV1/30

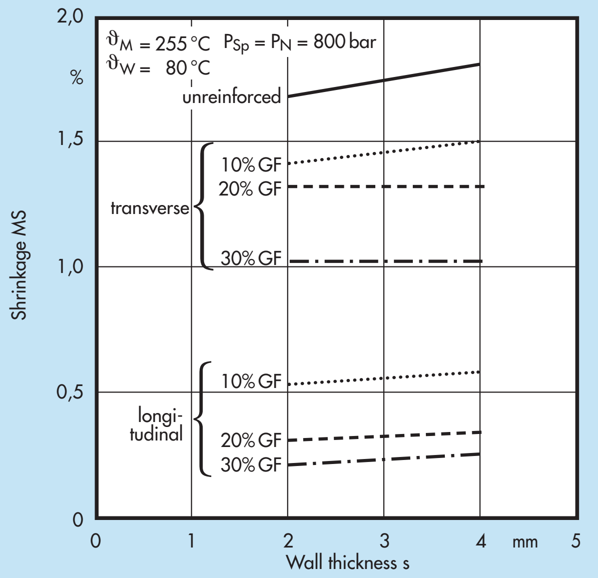


Fig. 55: Shrinkage MS as a function of wall thickness for easyflowing glass fiber reinforced Celanex grades
15 % GF: Celanex 3200
30 % GF: Celanex 3300

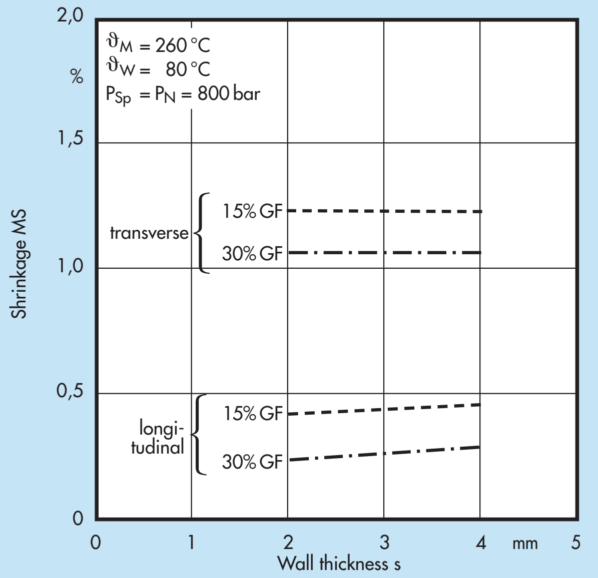


Fig. 56: Shrinkage MS as a function of wall thickness
for flame-retardant Celanex grades:
unreinforced: Celanex 2360 FL
10% GF: Celanex 2360 GV1/10 FL
20% GF: Celanex 2360 GV1/20 FL
30% GF: Celanex 2360 GV1/30 FL

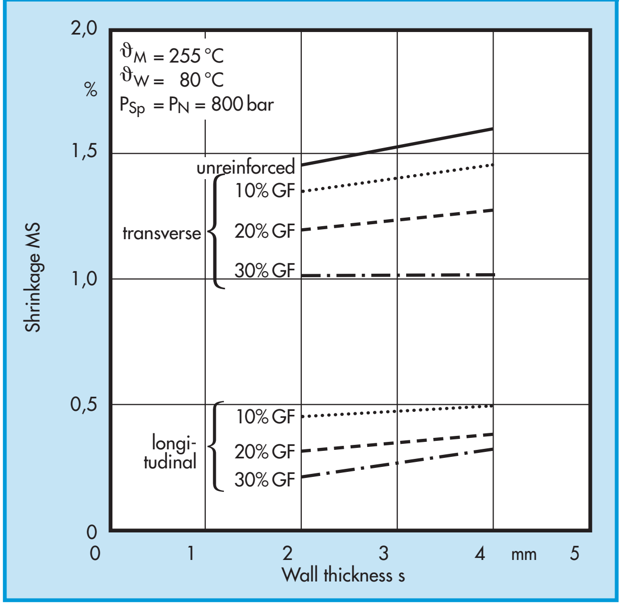


Fig. 57: Shrinkage MS as a function
of wall thickness for Celanex grades
with increased surface gloss:
15 % GF: Celanex 2302 GV1/15
30 % GF: Celanex 2302 GV1/30

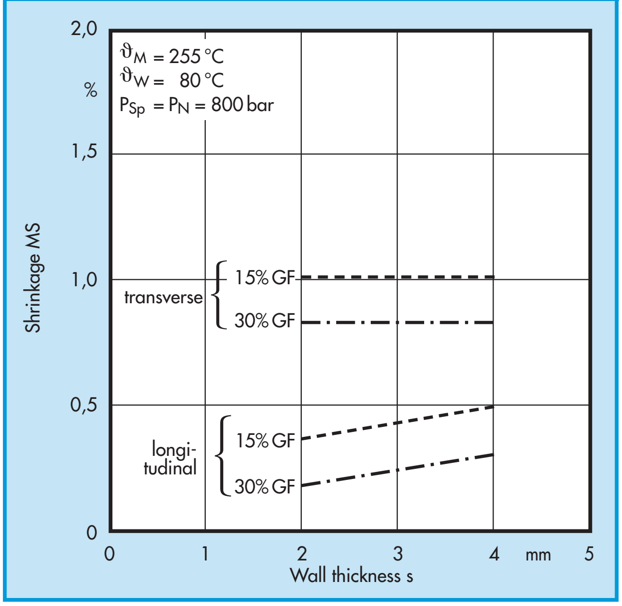


Fig. 58: Shrinkage MS as a function
of wall thickness
for low warp Celanex grades:
30% GF: Celanex 733 LD
30% GS: Celanex 2300 GV3/30
40% GF/MF: Celanex J600

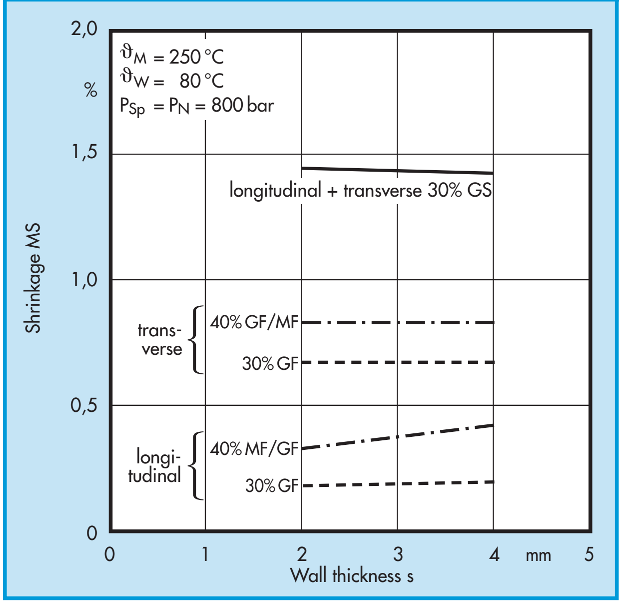
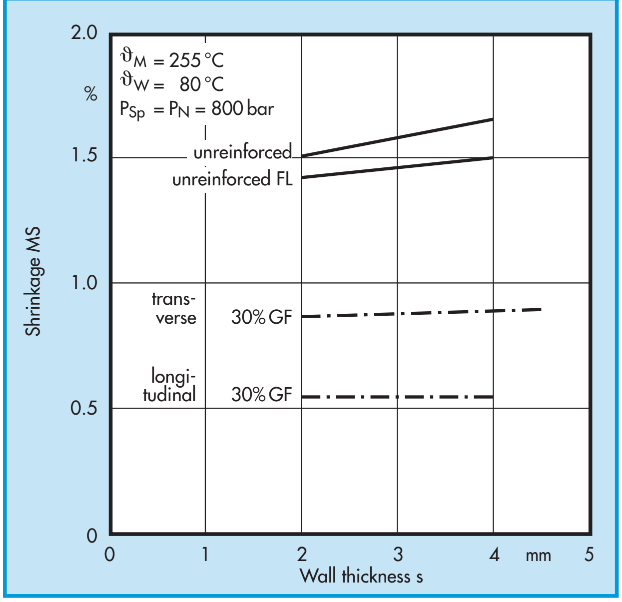


Fig. 59: Shrinkage MS as a function of
wall thickness for the following Vandar grades:
unreinforced: Vandar 4602 Z
unreinforced, flame-retardant: Vandar 8000
30% GF: Vandar 4662 Z



The mold shrinkage values shown in Figs 54–59 were measured 24 h after the parts had been ejected from the mold. Post-shrinkage is completed after 36 h at room temperature or after 2 h at 140°C. For unreinforced PBTs, post-shrinkage may be up to 0.5%, for glass-fiber-reinforced grades up to 0.2%. Post-shrinkage at higher storage or test temperatures must be determined empirically on the component. Figures 60 to 62 show examples of total shrinkage as a function of mold wall temperature.

Fig. 61: Shrinkage MS and total shrinkage TS of Celanex 3200-2 as functions of tool temperature, AS = after-shrinkage

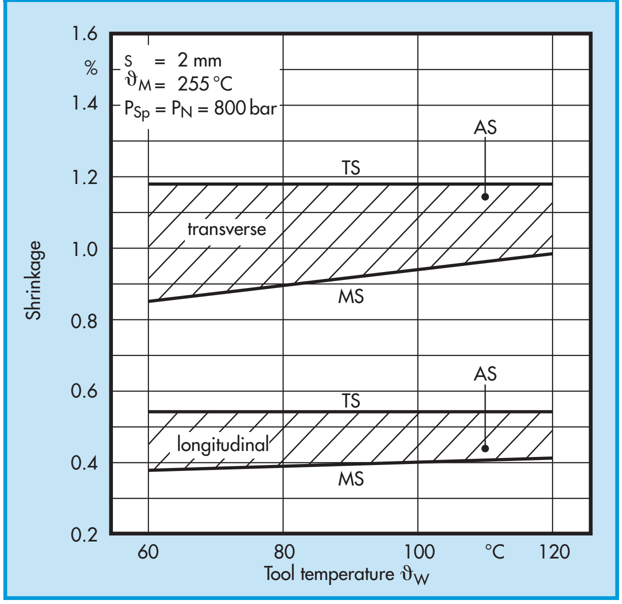


Fig. 60: Shrinkage MS and total shrinkage TS of Celanex 2500 as function of mold wall temperature, AS = after-shrinkage

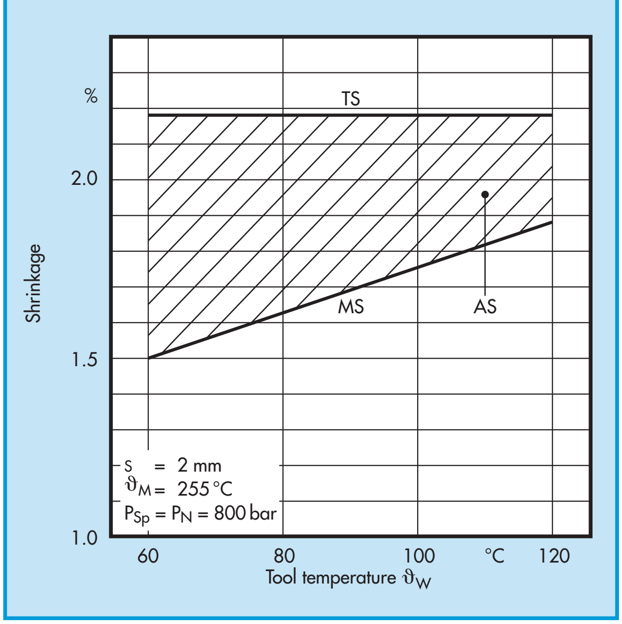
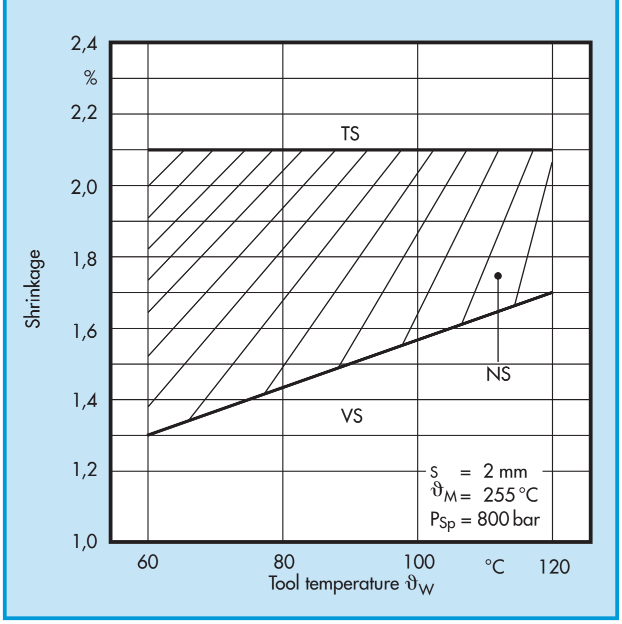


Fig. 62: Shrinkage MS and total shrinkage TS of Celanex 2360 FL as functions of tool temperature, AS = after-shrinkage



5.7 Possible problems and their solutions in injection moulding of Celanex, Impet and Vandar

Corrective measures / **Problems**	Cylinder-temperature	Nozzle-temperature	Tool-temperature	Injection-rate	Injection-pressure	Holding-pressure	Back-pressure	Screw-speed	Cooling-time	Sprue, gate	Gate, location	Material predrying	Nozzle-diameter	Venting
Brittleness	–		+				–	–		+		x	+	
Discolouration	–	–		–			–	–		+			+	x
Matt areas	+	+	+	+	+			+			x			x
Sink marks or voids	x	x	+	+	+	+	+	–	+	+		x	+	
Weld lines	+		+	+	+	+	+	+		+	x			x
Incomplete mould filling	+	+	+	+	+	+	+			+			+	x
Flash formation	–		–	–	–	–	–	–						
Sprues sticking			+/–		–	–			+/–	+				
Moulded parts sticking	–		+/–	–	–	–			+/–					
Warpage			x		x	x			+	+	x			

+ means: increase or enlarge
– means: reduce
x means: check

5.8 Injection moulding – Special processes

Celanex and Impet grades can be processed without any problem by gas-assist and MuCell injection molding. For the MuCell process, the material characteristics of the most important polyester grades were determined in the Ticona Technical Center. These can be made available to customers on request.

6. Further processing

6.1 Machining

Semi-finished products and mouldings made from Celanex, Vandar and Impet have good machining properties. The machines and tools normally used for metalworking and woodworking are suitable. Because of their high softening temperature, these polyester grades have no tendency to smear. Additional cooling during the machining operation is therefore unnecessary.

Drilling speeds of 50 – 60 m/min with a feed of 0.5 mm/rev, and turning and milling speeds of 250 – 400 m/min with a feed of 0.2 mm/rev should not be exceeded.

Further instructions are available from our local office.

6.2 Assembly of mouldings and semi-finished products

With the present drive towards efficient, low-cost manufacture of plastics assemblies, the actual technique of assembly has become increasingly important. For manufacturing and fabrication reasons, it is often necessary to produce component parts separately and then assemble them as required. Celanex, Vandar and Impet mouldings can be joined efficiently to produce assemblies with good resistance to mechanical stress. Various assembly methods are suitable and these are described in detail in our series of publications entitled “Calculations · Design · Applications”. In series B “Design of technical mouldings”, the following brochures have so far appeared on this subject:

B.3.1	Design calculations for snap-fit joints in plastics parts
B.3.2	Fastening with metal screws
B.3.3	Plastics components with integrally molded threads
B.3.4	Design calculations for press-fit joints
B.3.5	Integral hinges in engineering plastics
B.3.7	Ultrasonic welding and assembly of engineering plastics

– Welding

Celanex, Vandar and Impet mouldings can be joined by ultrasonic, vibration, spin or hot plate welding, depending on the joint geometry and type of application. In hot plate welding, because of the strong tendency of the melt to stick to the hot plate, contactless radiant heating is preferable. For prototype construction, hot gas welding with a welding rod may also be employed.

In laser transmission welding, high joint strengths are obtained with natural-colored PBT (transmitting part) on black PBT. If a close color match is required between the top and bottom components, the transmitting part is colored with special laser-transmitting colorants.

With an increasing content of reinforcing materials, flame retardants or other modifiers, welding properties can be adversely affected. Potential reductions in quality may in some cases be countered by design measures such as widening the joint area.

– Adhesive bonding

For bonding Celanex, Vandar and Impet, two-pack adhesives based on epoxy resins, polyurethanes or silicone resins are recommended. Depending on the application, cyanoacrylate or hot melt adhesives may also be used. Because of the material’s good solvent resistance, solvent bonding is not recommended.

– Other methods

Celanex, Vandar and Impet mouldings can be joined to each other or to articles made from different materials by conventional methods such as riveting, flanging or staking or by using metal threaded inserts designed for ultrasonic or heat installation in the plastic.

Mechanical assembly with screwed, snap-fit or press-fit joints is also an option and offers the advantage of detachable joints in some cases. Assembly with spring clamps is also possible.

6.3 Surface decoration

Consumer taste and publicity needs are not always fully satisfied by the pigmentation of plastics or by the possibility of obtaining two-colour mouldings in the injection moulding process. There is in addition a demand for plastic products which, for decorative and/or information purposes, are given a printed, painted or hot stamped finish. Flock coating and metallizing of the surface are further special types of finish supplied.

6.3.1 General surface requirements

To attain an aesthetically pleasing decorative effect, it is essential for the mouldings to have a smooth, flawless surface. Irregularities or scratches, weld lines or other surface defects are not as a rule obliterated by surface decoration but remain visible on the decorated surface and detract from its appearance. This should be taken into account by exercising care in polishing the mould and by maintaining optimum processing conditions (mould and melt temperature, injection pressure, injection rate).With nearly all mouldings, the surfaces are likely to be soiled and so generally speaking a cleaning process should precede surface decoration.

A special surface pretreatment is frequently necessary, and may be either chemical or mechanical. Decorative materials applied onto an untreated surface should in any case be given a heat treatment either as they are applied (hot stamping foil) or after application (primers, printing inks).

Roughening the moulding surface by sandblasting, grinding etc. induces a surface activation and aids adhesion of subsequently applied decorative materials. This method is very costly and therefore is hardly ever used.

6.3.2 Painting

For painting of moulded parts made of Celnaex , Impet or Vandar different one- and two-component lacquers systems are suitable; which can be solvent or water based. The choice of system depends on the lacquer properties required, eg weathering resistance, chemical resistance, scratch resistance etc.

In order to achieve a faultless adhesion of the painting the moulded parts have to be cleaned. An additional pretreatment such as flame treatment, exposure to corona discharge or possibly a base coat improves the adhesion.

6.3.3 Vacuum metallizing

By this process, a mirror-finish, metallized surface can be imparted to Celanex mouldings. The various operations required are as follows:

– Pretreatment

The surfaces to be metallized are first cleaned and degreased, followed by mechanical delustring or preferably acid etching as described before.
The primer treatment discussed above also produces satisfactory results.

– Base coating

The quality of adhesion of the evaporated metal depends mainly on the suitability of the basecoat applied to the surface to be metallized. The two component, polyisocyanate-based lacquers developed specially for vacuum metallizing have proved very good. After application, they are cured in a drying oven.

– Vacuum metallizing

Evaporation of the desired metal onto the article is carried out under the usual conditions for this method.

– Topcoating

The evaporated metal layer is very sensitive to mechanical damage. To protect it from scratches, a colorless or transparent topcoat is applied.

6.3.4 Electroplating

Celanex mouldings can be coated with a conducting metal layer then electroplated by the usual electrochemical method.

A firm adhesion of the metal layer to the plastic can be achieved with special grades. For the standard grades the coating has to be of at least sufficient thickness to be self-supporting.

6.3.5 Hot stamping

Hot stamping of Celanex mouldings is a frequently employed method of decoration because pretreatment of the surface is unnecessary. However, the surface must be clean.

The popularity of this method is reflected in the large number of hot stamping foils at present on the market which are suitable for Celanex. The choice of foil depends on the stamping method to be used (positive stamping, negative stamping, large-area stamping, relief stamping, reciprocating press, rotary press with cylindrical or flat die, stamping with brass or silicone rubber dies), the properties required of the stamping (scratch and abrasion resistance, chemical resistance, weathering resistance) and of course the shade required, including surface finish (glossy, matt). This great variety of choice makes it impossible to give general recommendations on suitable foils and stamping conditions. For example, the required temperature of the stamping die can vary between 120 and 220°C, depending on the type of foil. Stamping equipment must have accurate control systems for pressure, temperature and die dwell. A uniform contact pressure is particularly important. Exact setting of the stamping die is not in itself sufficient. Care must also be taken to ensure that the moulding is firmly and evenly supported. Soft supports such as rubber are unsuitable. High contact pressure, short dwell times and high temperature are the preferred processing conditions. Flat surfaces are of course easier to stamp than domed surfaces, solid parts easier than hollow. In certain cases, preliminary trials may be required.

It is always advisable to consult the foil manufacturer. Lists of suppliers of the primers, printing inks and stamping foils mentioned above are available on request.

6.3.6 Laser Marking

Laser marking is a “clean” process requiring no surface pretreatment, colour pastes or solvents; the moulded parts cannot be contaminated or damaged by it. Laser marking is fast, uncomplicated, extremely flexible in terms of changing fonts and characters and can be readily integrated into production units.

There are two methods for laser marking polymers: the mask projection system and the scanning system. Which of these is the most appropriate method will depend on the job at hand, the required results and the type of material. Each process requires its own special equipment.

Laser Marking of moulded parts made of Celanex

Extensive trials have already been carried out with laser marking of Celanex mouldings. High qualities of the laser marking achieve all Celanex grades in white and light grey as well as the natural FL grades. As black coloring the special color 10/9101 is availble. Other colors are available on request.

7. Fire precautions

Plastics, like virtually all organic products, are combustible. Fire prevention measures may therefore be necessary in storing, processing and fabricating plastics. Particular care should be taken to observe specific regulations in individual countries.

Certain end products and fields of application may impose special requirements from the fire prevention standpoint. It is the responsibility of the material processor and the user of the manufactured product to ascertain and observe such requirements.

8. Literature

[1] Ticona GmbH: C.3.3 Design of mouldings made from engineering plastics.
[2] Ticona GmbH: C.3.4 Guidelines for the design of mouldings made from engineering plastics.
[3] Witan, K. et al: Non-Contact Marking by Laser Beam. Kunststoffe/German Plastics 11/93.

Figs. 1 and 2:
Driver (1) and passenger (2) airbag covers made from a special Vandar grade.

Fig. 3:
Gear housing for electric window motor made from glass-fibre-reinforced Celanex.

Fig. 4:
Housing for ABS sensors made from glass-fibre-reinforced Celanex.

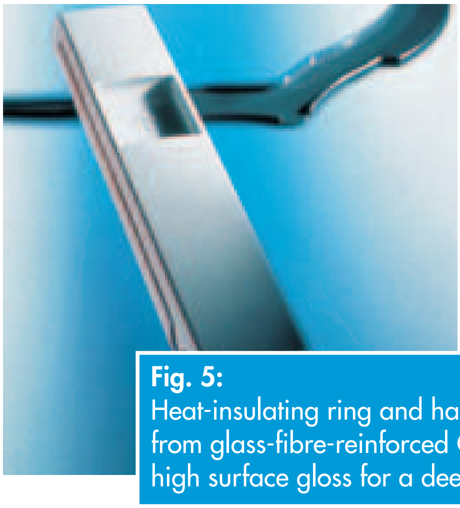


Fig. 5:
Heat-insulating ring and handle made from glass-fibre-reinforced Celanex with high surface gloss for a deep fat fryer.

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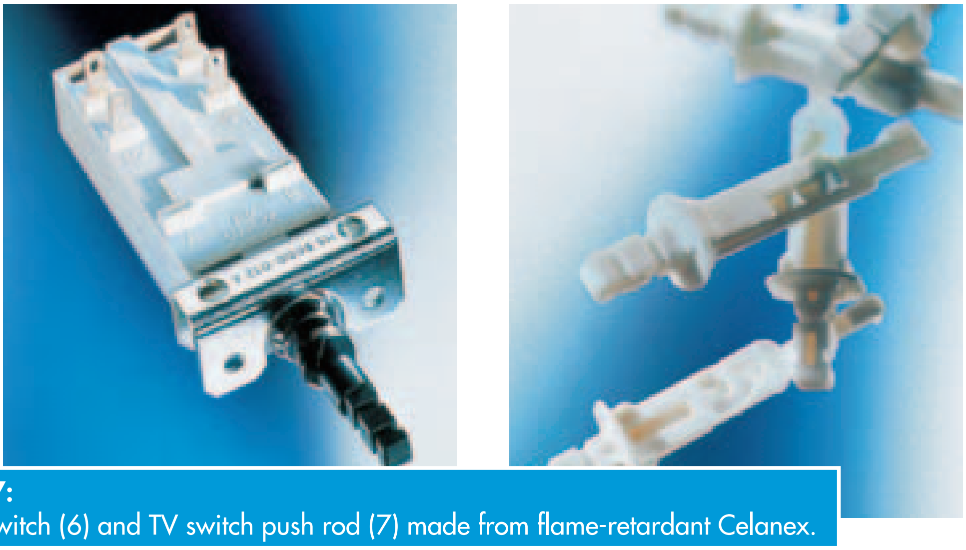


Figs. 6 and 7:
Pushbutton switch (6) and TV switch push rod (7) made from flame-retardant Celanex.

Fig. 8:
Motor component made from Celanex for washing machine drive.

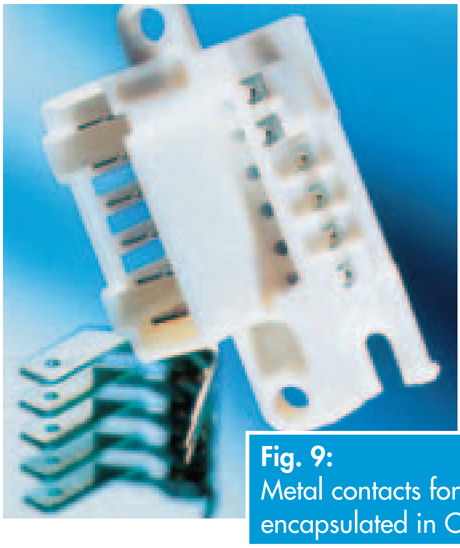
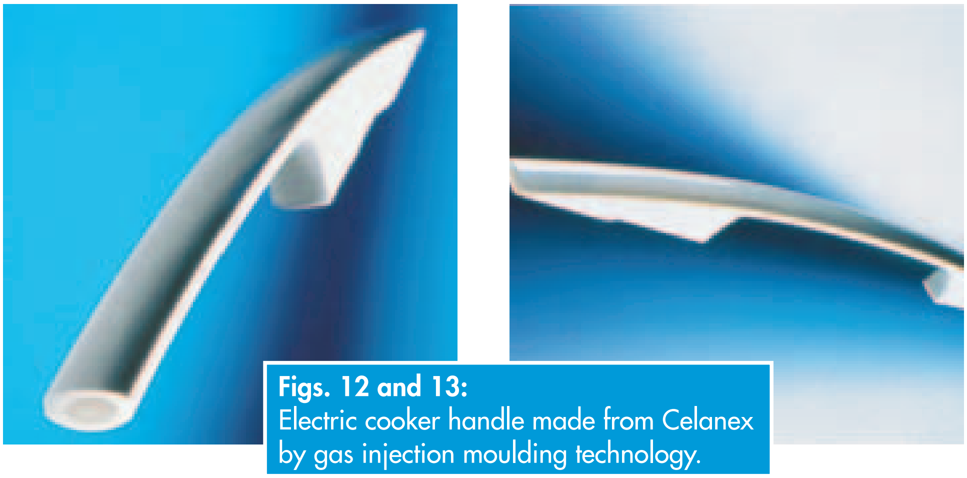


Fig. 9:
Metal contacts for a connector encapsulated in Celanex.

Fig. 10:
Connector made from Celanex for VW.

Fig. 11:
Lower base part of a parallel-travel pushbutton sequence switch made from flame-retardant Celanex.



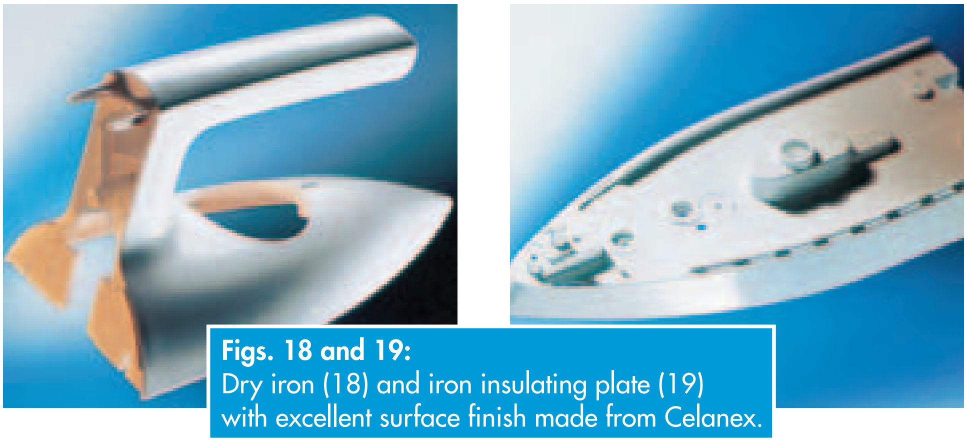
Figs. 12 and 13:
Electric cooker handle made from Celanex by gas injection moulding technology.

Fig. 14:
Electric iron handle with excellent surface finish made from Celanex.

Fig. 15:
Precision laser marking in many colour variants on Celanex surfaces.

Fig. 16:
Cooker control panels made from glass-fibre-reinforced Celanex with high surface gloss.

Fig. 17:
Sandwich toaster made from glass-fibre-reinforced Celanex with high surface gloss.



Figs. 18 and 19:
Dry iron (18) and iron insulating plate (19) with excellent surface finish made from Celanex.

Fig. 20:
Heating cost distributor housing made from Celanex with laser marking.

Fig. 21:
Base made from glass-fibre-reinforced Celanex for compact energy-saving lamps.

10. Subject index

Notice to users:

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