Celanese
The chemistry inside innovation™

CELSTRAN® LFRT
LONG FIBER REINFORCED THERMOPLASTICS

Product Manual

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1 Introduction

1.1 General Information

Celstran® LFRT are long fiber-reinforced thermoplastics (LFRT) made by Celanese. Various processing methods are used to produce high-strength components from these materials. Almost all partially crystalline and amorphous thermoplastics are suitable as thermoplastic matrix materials.

These grades are produced in a special patented pultrusion process.

The fibers incorporated in this process can be glass, carbon, aramid or stainless steel. In pultrusion the continuous filaments are pulled through the thermoplastic melt. Process control and die are optimized so that a high impregnation quality without damage to the fibers is achieved **(Fig. 1.1)**.

- markedly higher mechanical properties
- reduced creep tendency
- very good stability at elevated temperatures in humid conditions
- very low warpage

The special effect of the long-fiber reinforcement is manifested by the fiber skeleton whose outer shape remains unchanged after the resin matrix is burned off, **(Fig. 1.2)**. By absorbing impact energy and allowing it to dissipate into the molding, this fiber skeleton imparts, among other things, the good impact strength of Celstran materials. The long fiber reinforcement also has a beneficial effect on the properties at elevated service temperatures and on the creep properties.

The range of Celstran® LFRT products comprises a number of possible matrix-fiber combinations. They are intended mainly for injection molding, but they can be used also for extrusion or blow molding.

Fig. 1.1

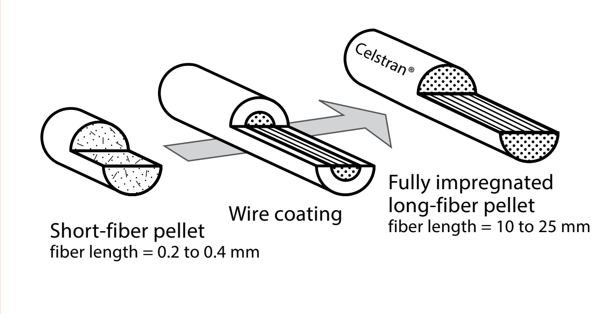

Diagram of a fully impregnated long fiber pellet (right) compared with wire coating (center) and short fiber pellets (left)

Fig. 1.2

After burning off, a molding (example: pump head made from Celstran® PA66-GF50, top) retains its geometry almost intact as a fiber skeleton (bottom)

1.2 Quality Management

Meeting the quality requirements of our customers is a critical activity for Celanese. We constantly pursue and update the certifications needed for this purpose. 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 Celanese Integrated Management System (TIMS) for quality, environmental and risk management.

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 Celanese 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. Celanese received the certification for this standard in 2003.

Our Celstran® LFRT production facility in Kaiserslautern, Germany, is currently certified according to the following important ISO standards:

- ISO 9001
- ISO 14001
- ISO 50001
- ISO/TS 16949

The relevant Celanese laboratories are accredited to meet general requirements according to ISO/IEC 17025:2000 for testing and calibration laboratories.

Our celanese.com website provides further information, including the details of business lines and facilities covered and PDF files of all certificates of registration.

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2 Grades & Applications

2.1 Overview of applications

Industry	Description	Main Applications	Celstran® Long Fiber Solutions
Automotive	Celstran® LFRT is present in nearly every automobile on the road.	Interior (IP, Airbag, Center Console), Exterior (Mirror Housing, Mirror Lever Arm)	Celstran® PP, Long Glass Fiber [1,2,3,4,5] Celstran® PA, Long Glass Fiber [1,3,4] Celstran® POM, Long Aramid Fiber Celstran® POM, Long Stainless Steel Fiber [4]
Consumer Electronics	Celstran® LFRT is a unique and high-tech choice in consumer electronics applications.	Electrically conductive and dissipative applications (laptops, sensor housings, shielded connectors)	Celstran® PA, Long Carbon Fiber Celstran® PPS, Long Carbon Fiber Celstran® PPS, Long Stainless Steel Fiber [4,5] Celstran® PCABS, Long Stainless Steel Fiber [3,4]
Building & Construction	Delivering exceptional toughness, structural durability and aesthetics, Celstran® LFRT is used to replace wood and metal.	Building profiles, scaffolding, furniture, solar panels, industrial power tools, flooring	Celstran® PA, Long Glass Fiber [1,3,4] Celstran® TPU, Long Glass Fiber [1,3,4] Celstran® PP, Long Glass Fiber [1,2,3,4,5] Celstran® PBT, Long Glass Fiber [1,2,3,4]
Oil & Gas	Celstran® LFRT offers solutions that stand up exceptionally well to oil and salt water and retain their properties under extreme performance requirements.	Fuel tank connectors, seismic cable connectors, sensor housings on oil rigs	Celstran® TPU, Long Glass Fiber [1,3,4] Celstran® PPS, Long Glass Fiber
Agriculture	Celstran® LFRT delivers weight reduction and resistance to corrosion as a metal replacement solution.	Heavy agricultural equipment, ventilation fans, gardening equipment, spray nozzles	Celstran® PP, Long Glass Fiber [1,2,3,4,5] Celstran® PA, Long Glass Fiber [1,3,4] Celstran® PP, Stainless Steel Fiber [4,5] Celstran® PA, Stainless Steel Fiber [4,5]

Possible specialty formulations:
1) UV stabilization,
2) Low emission,
3) Heat stabilization,
4) Speciality appearance options,
5) High % fiber loaded concentrate

Fig. 2.1

Example: Celstran® LFRT PP-GF40-0414 P10/10

- Matrix material
- Type of fiber
- Fiber content in % (w/w)
- Product family
- Additional suffix
- Pellet length in mm
- Color

Matrix material:	PP
Type of fiber:	GF (glass), SF (stainless steel)
Product family:	04 = homopolymer
	05 = copolymer
Additional suffix:	01 = Standard formulation Copolymer
	03 = Standard formulation Homopolymer
	05 = UV stabilized
	14 = Standard formulation GF40
	53 = low-C-emission
	55 = low-C-emission and UV stabilized
Color:	without = natural
	10 – 19 = black

Celstran® LFRT PP

Fig. 2.2

Example: Celstran® LFRT PA66-GF40-0101 P10/10

- Matrix material
- Type of fiber
- Fiber content in % (w/w)
- Product family
- Additional suffix
- Pellet length in mm
- Color

Matrix material:	PA66
Type of fiber:	GF (glass), CF (carbon), SF (stainless steel)
Product family:	01 = high gloss
	02 = heat stabilized
Additional suffix:	01 = standard formulation
	11 = standard formulation
	12 = UV stabilized
Color:	without = natural
	10 – 19 = black

Celstran®

2.2 Survey and nomenclature of Celstran®

(Figs. 2.1 and 2.2) show examples of the nomenclature of the standard product ranges Celstran® LFRT PP and Celstran® LFRT PA.

In principle, grade names follow the logic demonstrated by these three examples; however, exceptions do exist. A representative from Celanese or one of Celanese's authorized distributors will gladly guide you to the ideal material based on your specific technical requirements.

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2.3 Form supplied

To a large extent, Celstran® LFRT and Compel® are supplied to individual requirements both in terms of the thermoplastic matrix and of the fibers used for reinforcement.

Possible matrix systems are:

- polypropylene, PP
- high-density polyethylene, PEHD
- polyacetal, Hostaform® POM
- polybutylene terephthalate, Celanex® LFRT PBT
- polyethylene terephthalate, Impet® PPS
- polyphenylene sulphide, Fortron® PPS
- thermoplastic polyurethane, TPU
- polyamide 66, PA66
- polyamide 6, PA6
- polyamide 12, PA12
- acrylonitrile-butadiene-styrene copolymer, ABS
- polycarbonate, PC, and PC blends with ABS
- polyetheretherketone, PEEK
- polyphenol oxide, PPO.

Other matrix systems are being prepared.

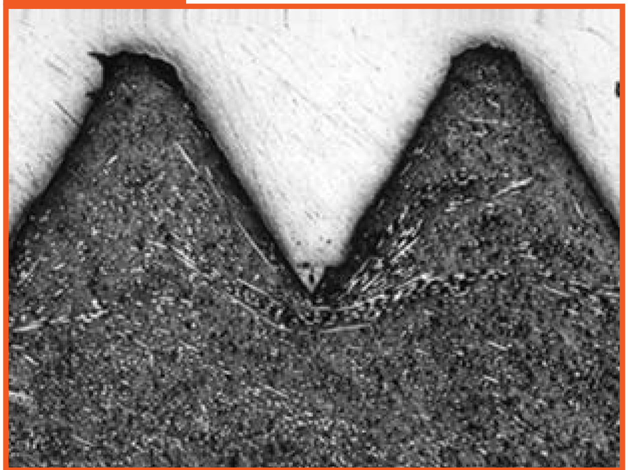
The following reinforcing fibers are available:

- glass
- carbon
- aramid
- stainless steel filaments

Celstran® LFRT is supplied in 25-kg bags and 500 kg or 1000 kg containers.

Silo truck delivery is also possible (20 tons) with Celstran® LFRT. Because of the high impregnation of the fibers, pneumatic conveyance is possible.

Fig. 3.1



Long-fiber reinforcement in a threaded part reduces notch sensitivity in the thread root

3 Physical Properties

3.1 General information

Sections 3 "Physical Properties" and 4 "Environmental Effects" cover the important properties that are descriptive of Celstran and Compel, specifically – where available – as a function of temperature and time.

All properties are determined by standardized test methods wherever possible. A survey of the physical properties is given in section 3 "Material Data". The values are also available as a data sheet.

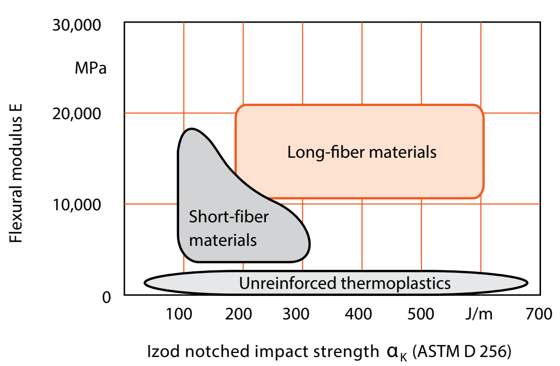
With gentle processing a skeleton-like fibrous structure is formed in Celstran® LFRT and Compel® LFRT materials moldings. As a result, they have properties characteristic of fiber composites. Compared with short-fiber-reinforced plastics there is a substantial improvement particularly with regard to:

- impact strength, notched impact strength and low-temperature impact strength
- energy absorption capacity under impact stress
- rigidity and strength at elevated temperatures
- mechanical and thermal properties in continuous service (creep, fatigue)
- warpage reduction

Of particular importance to designers is the sharply reduced creep tendency brought about by the long-fiber reinforcement. The orientation of the reinforcing fibers frequently contributes to a reduction in notch sensitivity. A typical example is a screw injection-molded from Celstran® LFRTs: the fiber orientation gives it increased strength in the thread root between the thread flights, **(Fig. 3.1)**.

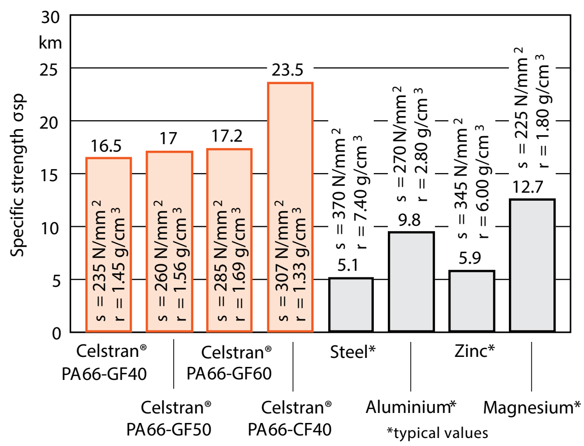
Generally speaking, long-fiber-reinforced plastics have a high modulus of elasticity – typical values are between 10,000 and 20,000 MPa – with no change in their good impact and notched impact strength, **(Fig. 3.2)**. Owing to their high rigidity and strength, long-fiber-reinforced plastics are frequently chosen to replace metals. In many cases, the specific strength of these materials far surpasses that of metals, **(Fig. 3.3)**.

Fig. 3.2



Long-fiber reinforcement in a threaded part reduces notch sensitivity in the thread root

Fig. 3.3



Long-fiber reinforcement in a threaded part reduces notch sensitivity in the thread root

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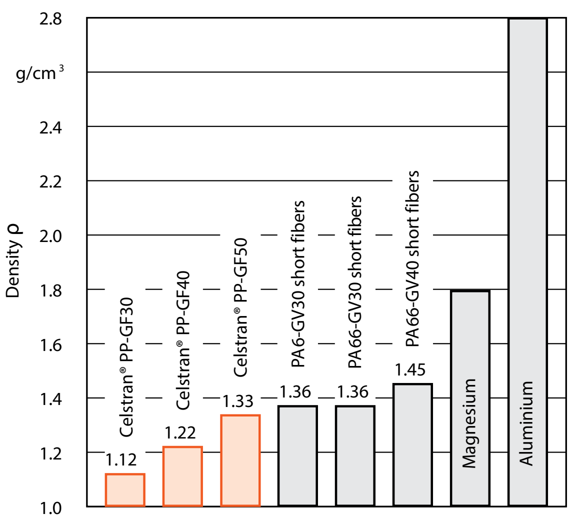
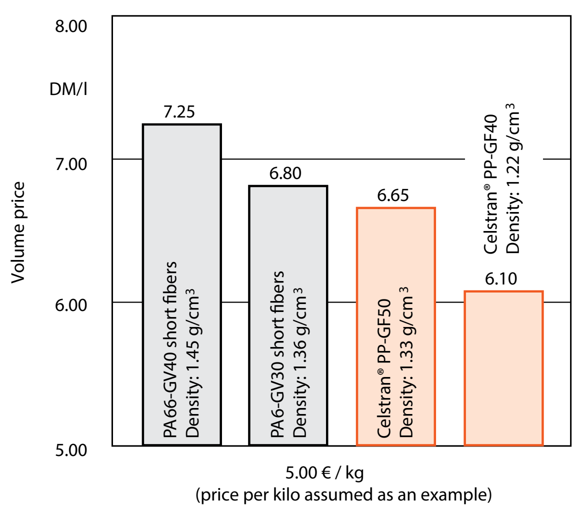
Fig. 3.4



Density of some long- and short-fiber reinforced plastics compared with light metals

Fig. 3.5



Comparison of the volume price of Celstran® LFRT PP and short-fiber-reinforced PA66 that result from differences in density, assuming identical prices per kilo

A special advantage of Celstran® LFRT PP is its low density compared, e.g., to short-glass-fiber-reinforced PA **(Fig. 3.4)**.

Despite frequently having a higher glass-fiber loading, long-fiber PP materials typically offer a density advantage when compared to competing short-fiber PA6 and PA66 grades. This advantage can translate into significant cost savings for customers **(Fig. 3.5)**.

3.2 Mechanical properties

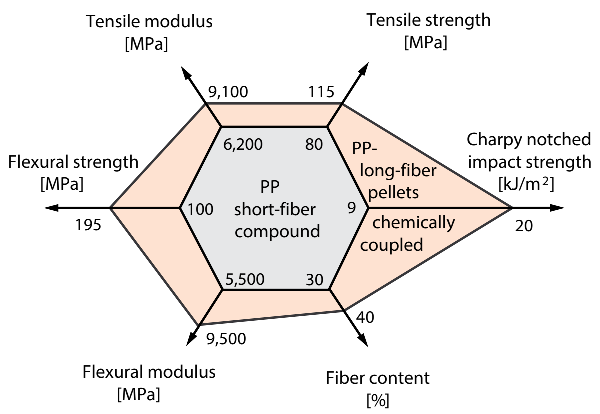
3.2.1 Preliminary remarks

The properties of Celstran® LFRT are determined by the standard test methods used for the CAMPUS® materials database. These properties make it easier for designers to make a preliminary selection of materials.

The physical property values given in section 3 "Material Data" may vary due to different production conditions and processing parameters. In the case of Compel® LFRT, the values – also given in section 3 "Material Data" – were determined using specimens taken from compression-molded parts. These values are, therefore, not comparable with those for Celstran® LFRT. They reflect, with reasonable accuracy, the actual property values attained in moldings.

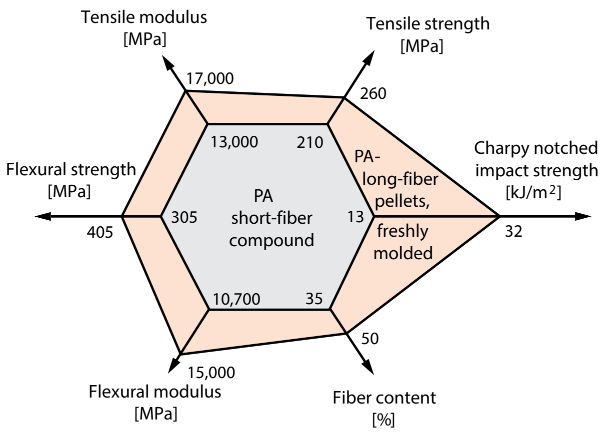
In dimensioning components, the long-term properties and possibly the temperature-dependency of the properties, as well as the values obtained under short-term stress, must be taken into account. These long-term properties are the ones actually improved by long-fiber reinforcement, compared with the unreinforced or short-fiber-reinforced matrix materials.

Fig. 3.6



Improvement in some typical mechanical properties of glass fiber reinforced PP upon switching from commercial short-fiber products to commercial long-fiber products

Fig. 3.7



Improvement in some typical mechanical properties of glass fiber reinforced PA66 on switching from commercial short-fiber products to commercial long-fiber products

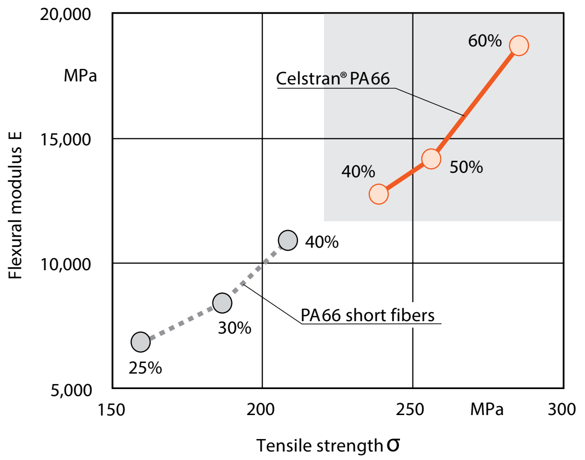
3.2.2 Short-term stress

Reinforcement with long fibers particularly improves strength and modulus of elasticity at elevated temperatures and/or under long-term stress, compared with short-fiber reinforcement. Long-fiber reinforcement also gives better impact strength.

As shown in **(Fig. 3.6)**, the flexural strength and flexural modulus values of a Celstran® LFRT PP-GF40 are almost twice that of a PP with 30% short-glass-fiber reinforcement. The value for Charpy notched impact strength is nearly three times higher.

A corresponding picture emerges when comparing PA with short- and long-glass-fiber reinforcement **(Fig. 3.7)**.

Fig. 3.8

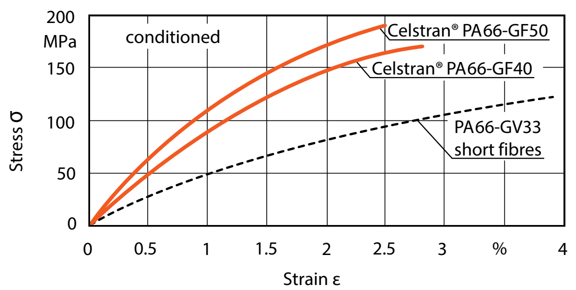


Tensile strength and flexural modulus of some Celstran® PA66 grades compared with short-glass fiber reinforced PA66

With its combination of high flexural modulus and high tensile strength, PA-based Celstran® LFRT grades can be selected as a replacement material where light metal castings have been used in the past **(Fig. 3.8)**. The high rigidity of Celstran® LFRT PA grades – especially when compared to short-fiber-reinforced PA – offers a clear benefit **(Fig. 3.9)**.

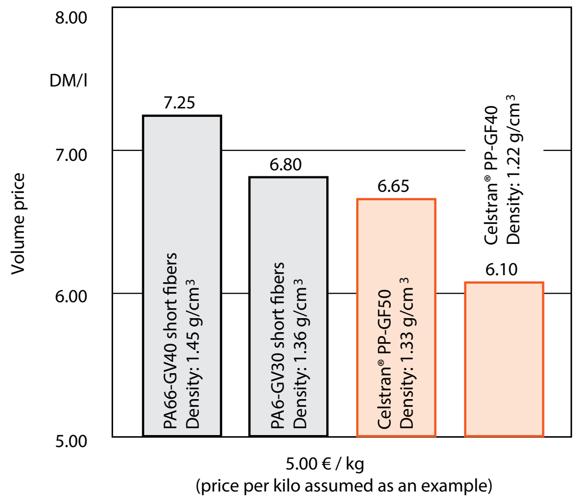
Reinforcement with long glass fibers also increases the tensile modulus and tensile strength when POM is used as the matrix material, as shown by the stress-strain diagram for Celstran® LFRT POM-GF40 **(Fig. 3.10)**.

Fig. 3.9



Stress-strain curves for Celstran® PA grades and short-glass fiber reinforced PA66

Fig. 3.10



Comparison of the volume price of Celstran® PP and short-fiber-reinforced PA66 that result from differences in density, assuming identical prices per kilo

3.2.3 Creep properties

Designers must know the creep properties of components subject to constant mechanical stress. Depending on the test conditions, these properties indicate how:

- strain at constant stress increases with time (creep test according to ISO 899 part 1)
- stress at constant strain decreases with time (stress relaxation test according to DIN 53441).

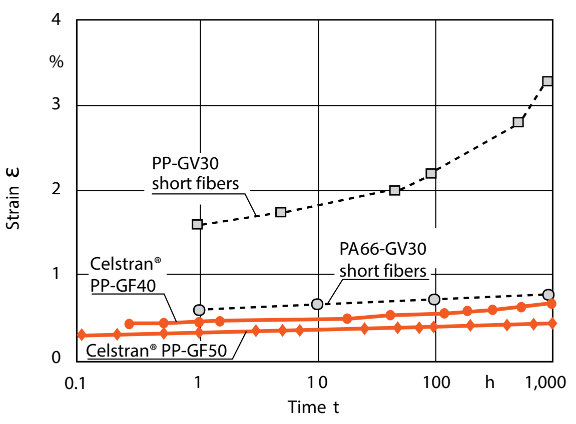
The increase in strain under constant load, known as flow, and shown in stress-strain curves, is considerably less in the case of Celstran® LFRT PP than in the case of a comparable short fiber-reinforced PP **(Fig. 3.11)**.

As the diagram shows, the creep tendency is even less than that of short fiber-reinforced PA66.

Similar to PP-based materials, the long glass fibers in PA66 reduce the creep tendency substantially. This is evident particularly at high load with a tensile stress of 90 MPa **(Fig. 3.12)**.

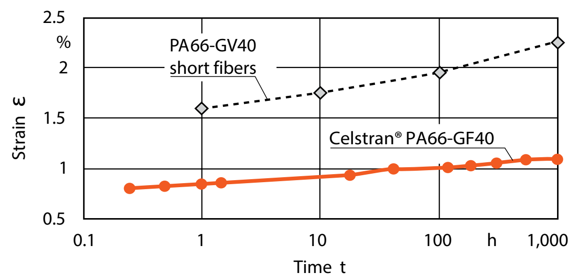
Details of the creep properties of Celstran® PA66-GF 40 – measured in accordance with ISO 899 part 1 – are given in **(Figs. 3.13)** and **(3.14)**. The corresponding details for Celstran® PA66-GF60 are given in **(Figs. 3.15 and 3.16)**.

Fig. 3.11



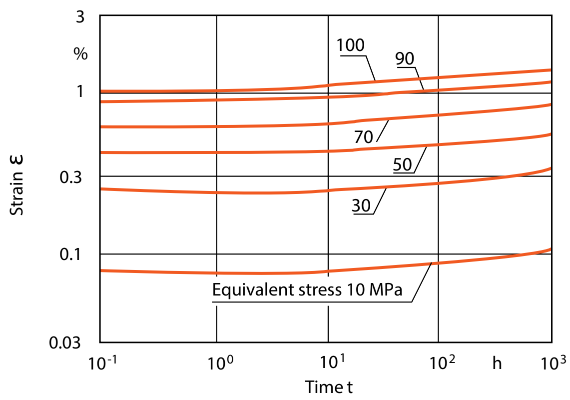
Creep curves for two Celstran® PP grades (PP-GF 40 and PP-GF50) compared with short glass-fiber-reinforced PP (PP-GF30) and short glass fiber-reinforced PA66 (tensile stress 35MPa)

Fig. 3.12



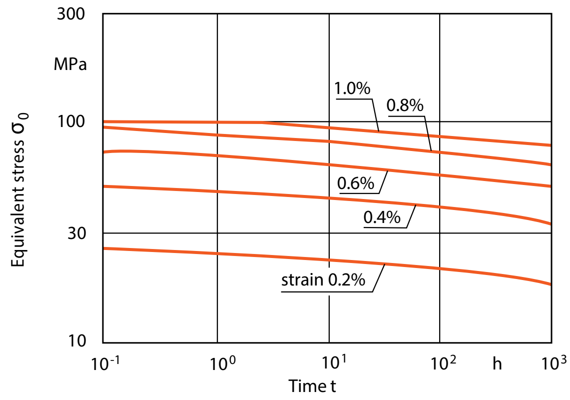
Decrease in creep tendency of PA66 when reinforced with long fibers: comparison of a short glass fiber-reinforced material and Celstran® PA66-GF40 (tensile stress: 90 MPa)

Fig. 3.13a



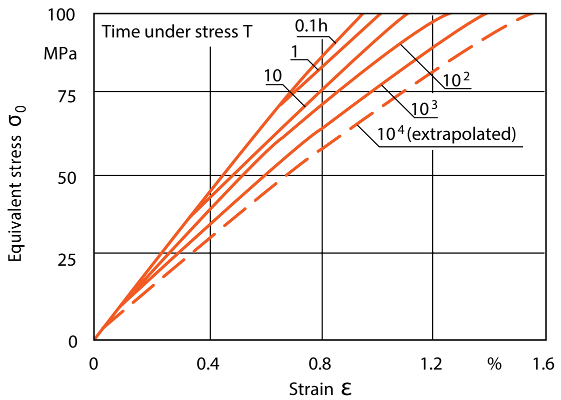
Characteristic values for the creep behavior of Celstran® PA66-GF40: creep curves for various stress values

Fig. 3.13b



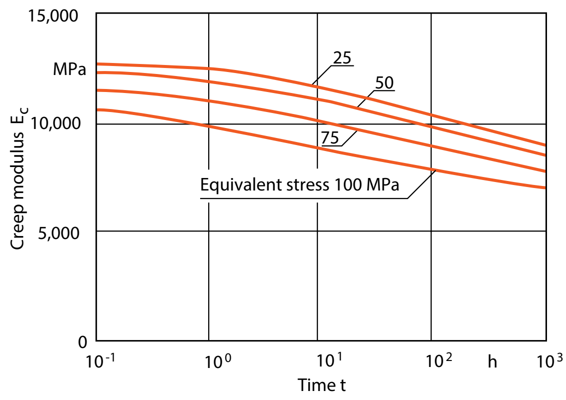
Characteristic values for the creep behavior of Celstran® PA66-GF40: creep curves for various strain values

Fig. 3.14a



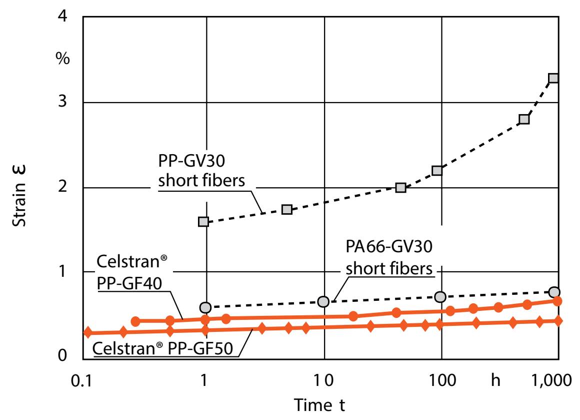
Characteristic values for the creep behavior of Celstran® PA66-GF40: stress-strain curves for various times under stress

Fig. 3.14b



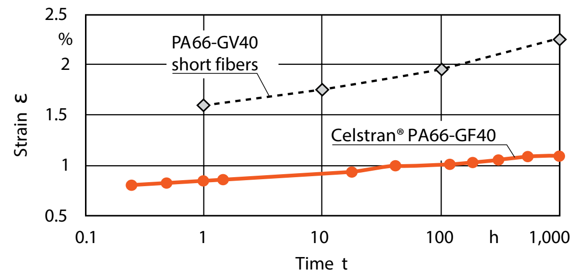
Characteristic values for the creep behavior of Celstran® PAA66-GF40: creep modulus as a function of time for various stress values

Fig. 3.15a



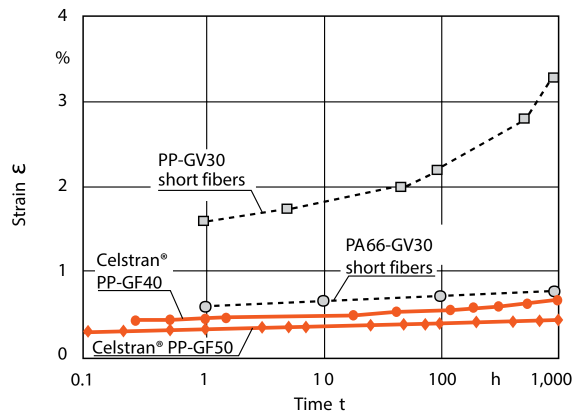
Characteristic values for the creep behavior of Celstran® PA66-GF60: creep curves for various stress values

Fig. 3.15b



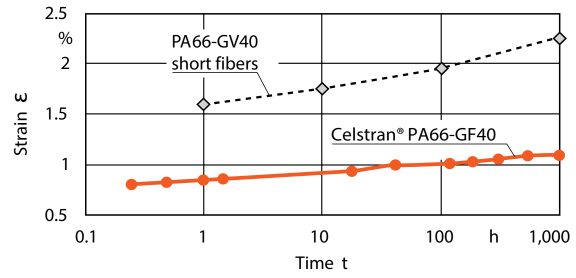
Characteristic values for the creep behavior of Celstran® PA66-GF60: creep curves for various strain values

Fig. 3.16a



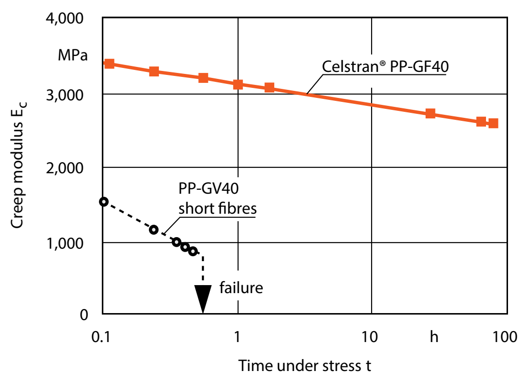
Characteristic values for the creep behavior of Celstran® PA66-GF60: stress-strain curves for various times under stress

Fig. 3.16b



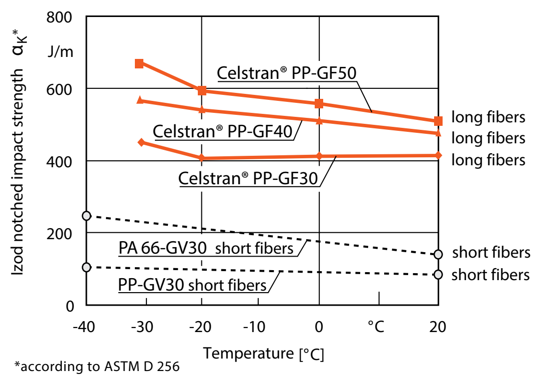
Characteristic values for the creep behavior of Celstran® PA66-GF60: creep modulus as a function of time for various stress values

Fig. 3.17



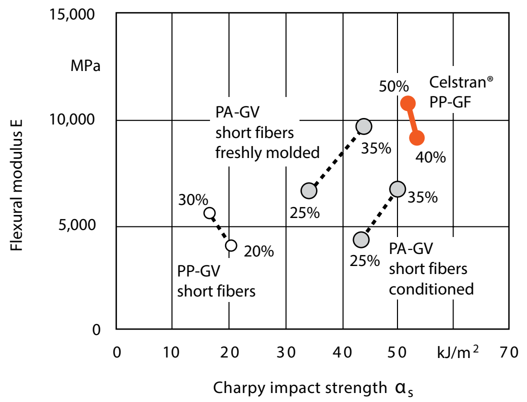
Flexural creep modulus of Celstran® LFRT PP-GF40 as a function of time compared with a PP with 40% by weight short glass fibers [6] (flexural stress: 120 MPa, temperature: 120°C)

Fig. 3.18



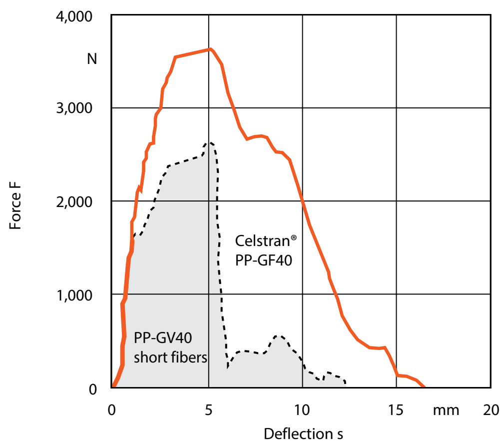
Improvement in low-temperature impact strength by long fiber reinforcement: comparison of various Celstran® LFRT PP grades with short glass fiber-reinforced PP and with short glass fiber-reinforced PA66

Fig. 3.19



Flexural modulus as a function of Charpy impact strength of Celstran® LFRT PP compared with short fiber-reinforced plastics

Fig. 3.20



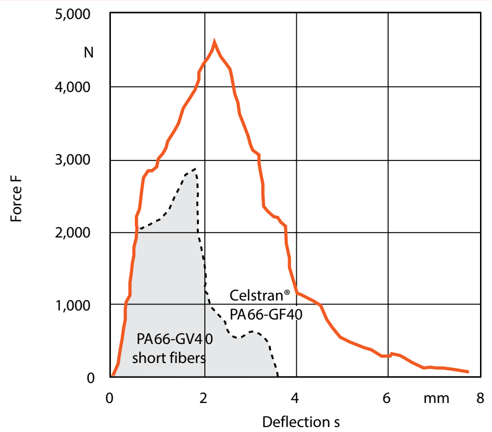
Force-deflection curve in the instrumented puncture test on Celstran® LFRT PP-GF40 and a polypropylene with 40% short glass fibers

For stress at high temperature and very high load (120° and 120 MPa), **(Fig. 3.17)** shows the creep properties of Celstran® PP-GF40, characterized by the flexural creep modulus compared with a short fiber-reinforced PP. In this accelerated test, the long fiber-reinforced material does not fail even after 100 hours under load.

3.2.4 Toughness

Toughness is crucial to the behavior of a component under impact stress. As already shown in **(Fig. 3.6)** for Celstran® LFRT PP and **(Fig. 4.7)** for Celstran® LFRT PA, long fiber reinforcement brings an above-average increase in impact strength.

Fig. 3.21



Force-deflection curve in the instrumented puncture test on Celstran® LFRT PA66-GF40 and a polyamide with 40% by weight short glass fibers

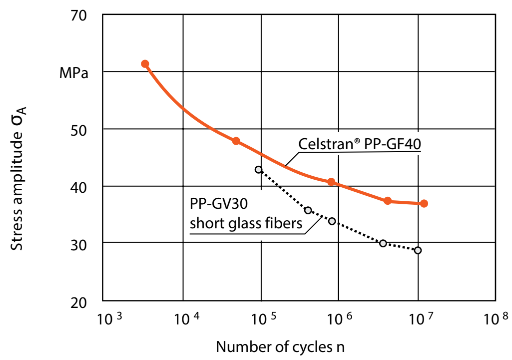
Fig. 3.22

Stress amplitude	Number of cycles until failure of	
MPa	Celstran® PP-GF40 long fibers	PP-GV40 short fibers
80	14	1
60	300	66
50	871	182

Results of the tensile fatigue test on glass fiber-reinforced polypropylene at elevated temperature (70°C)

* Fatigue strength: Stress amplitude determined in a fatigue test that a specimen withstands for a specific number of load cycles without fracture.

Fig. 3.23



Flexural fatigue strength of Celstran® LFRT PP-GF40 compared with PP reinforced with 30% by weight short glass fibers

This applies to impact strength not only at room temperature but also at low temperature **(Fig. 3.18)**. With the combination of high flexural modulus and very good impact strength **(Fig. 3.19)**, the long fiber-reinforced Celstran® LFRT can be used in cases when a short fiber-reinforced plastic cannot sufficiently offer this combination of properties.

Direct information on the behavior under impact stress is provided by the multi-axial stress in the penetration test. The results are shown in **(Fig. 3.20)** for Celstran® LFRT PP and **(Fig. 3.21)** for Celstran® LFRT PA. In both cases, the long-fiber reinforcement substantially increases the maximum force and the fracture energy (this corresponds to the area beneath the curve as well).

3.2.5 Fatigue

Components that are subject to fluctuating stress must be dimensioned by means of the fatigue strength.

Compared with short fiber reinforcement, long fiber-reinforced materials offer substantially improved fatigue strength at room temperature, and especially at elevated temperature and under high load **(Fig. 3.22)**.

The flexural fatigue strength* of Celstran® LFRT PP-GF40 compared with a short fiber-reinforced PP is shown in **(Fig. 3.23)**.

3.2.6 Surface properties

Celstran® LFRT moldings generally have a good surface because of the good flowability of the melt. For parts with visible surfaces, the following grades are highly suitable:

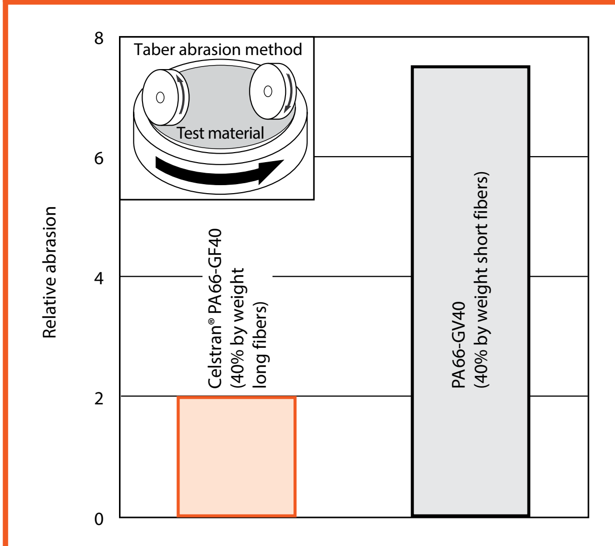
- Celstran® PP grades with modification 04 (high gloss)
- Celstran® PA grades with modification 01 (high gloss)

In each case, graining of visible surfaces is recommended.

Sliding properties: As with unreinforced plastics, the addition of PTFE improves the sliding properties of Celstran® LFRT. Specialty versions of Celstran® LFRT modified with PTFE can be provided upon request. Please contact your regional representative for further information.

Wear: Like sliding properties, wear is a characteristic feature of the system. Abrasion is dependent on variables such as the sliding partner, surface pressure, sliding speed and lubrication. Under comparable conditions, Celstran® LFRT PP and Celstran® LFRT PA generally display less abrasion than corresponding short fiber-reinforced materials **(Fig. 3.24)**.

Fig. 3.24



Abrasion against steel of long and short fiber-reinforced PA66 (40% by weight glass fibers)

3.3 Thermal properties

3.3.1 Coefficient of expansion

Fiber reinforcement substantially reduces the coefficient of linear thermal expansion of plastics. Because of the skeleton structure, flow direction is more homogeneous compared to short-fiber-reinforced materials.

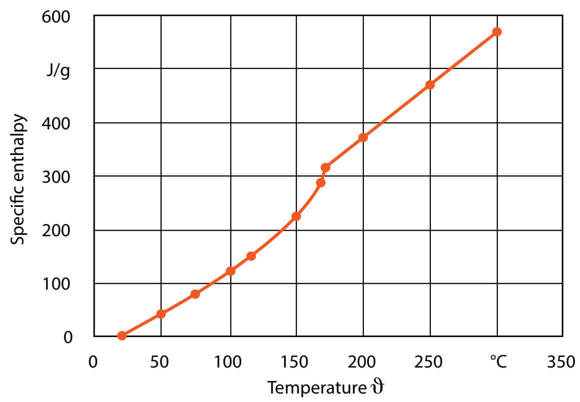
The expansion coefficient of Celstran® LFRT reaches values of 10 to 20 $\cdot 10^{-6} \cdot °C^{-1}$ in the temperature range of –30 to +30°C for the different test specimen geometries **(Fig. 3.25)**. It is thus in the same range as steel ($12.1 \cdot 10^{-6} \cdot °C^{-1}$) and aluminum ($22.5 \cdot 10^{-6} \cdot °C^{-1}$).

Fig. 3.25

Material	Coefficient of expansion (-30 to +30°C)	
Celstran®	in flow direction [10−6 · °C−1]	perpendicular to flow direction [10−6 · °C−1]
PA66-unreinforced	90	not measurable
PA66-GF40	19	not measurable
PA66-GF50	17	not measurable
PA66-GF60	15	not measurable
PA66-CF40	13	not measurable
PP unreinforced	83	not measurable
PP-GF30	16	36
PP-GF40	15	34
PP-GF50	13	17
PET-GF40	16	72
PBT-GF40	19	75
PC/ABS-GF40	18	70
PPS-GF50	12	39
TPU-GF40	13	52
TPU-GF50	10	50
TPU-CF40	18	64
Blends		
PA66-SF6	66	74
ABS-SF6	64	96
PC-SF10	43	

Coefficients of thermal expansion (range: –30 to +30°C) of some frequently used Celstran® grades

Fig. 3.26



Specific enthalpy (based on 20°C) as a function of temperature for Celstran® PP-GF40

3.3.2 Specific heat, enthalpy

For designing the processing machines and molds and for dimensioning moldings, it is necessary to determine the amount of heat required to melt the long fiber-reinforced thermoplastics, and then finally remove it from the mold by cooling.

(Fig. 3.26) shows the specific enthalpy curve of Celstran® PP with 40% by weight long glass fibers as a function of temperature.

Fig. 3.27

Temperature [°C]	Specific enthalpy in J/g, based on 20°C, of PP	Glass	Celstran® PP-GF30	Celstran® PP-GF40	Celstran® PP-GF50
20	0	0	0	0	0
50	55	24	46	43	40
72	100	42	82	77	71
100	160	64	131	122	112
115	200	76	163	150	138
150	310	104	248	228	207
170	400	120	316	288	260

Values for specific enthalpy of polypropylene, glass and Celstran® LFRT PP grades, based on 20°C

Fig. 3.28

Celstran® PP-GF40:
Cooling from 250°C to 72°C

	Enthalpy at	250°C	470 J/g
–	Enthalpy at	72°C	77 J/g
=	heat to be removed		393 J/g

Procedure for calculating the amount of heat to be removed on solidification

The amount of heat to be removed from the mold can be calculated from the melt temperature and the demolding temperature for Celstran® LFRT PP with the values given in **(Fig. 3.27)** in accordance with the procedure in **(Fig. 3.28)**.

3.3.3. Thermal conductivity

Generally speaking, reinforcing fibers have higher thermal conductivity than the matrix material. Therefore, the thermal conductivity of fiber-reinforced plastics can be influenced in part by the fiber content. The thermal conductivity of Celstran® LFRT PP-GF50 black (at 30°C) is $\lambda = 0.28 \pm 0.01$ W/(m·K).

3.4 Electrical properties

Reinforcement with electrically nonconductive glass fibers or aramid fibers has no appreciable influence on the electrical properties of the individual matrix material. In particular, the very good electrical insulating properties and good dielectric strength of the plastics remain virtually unchanged.

Of the Celstran® LFRT grades with carbon-fiber reinforcement, PA66-CF40 has good conductivity and even some shielding effect against electromagnetic radiation.

Because of these electrical properties, this material is used, for example, in the housings of laptops. By adding a small amount of stainless steel filaments, the shielding effect and surface conductivity of plastics can be increased specifically. The Celstran® LFRT SF masterbatches were specially developed to meet these requirements.

3.5 Optical properties

Fiber-reinforced thermoplastics are not transparent and are translucent only if the wall thickness is low.

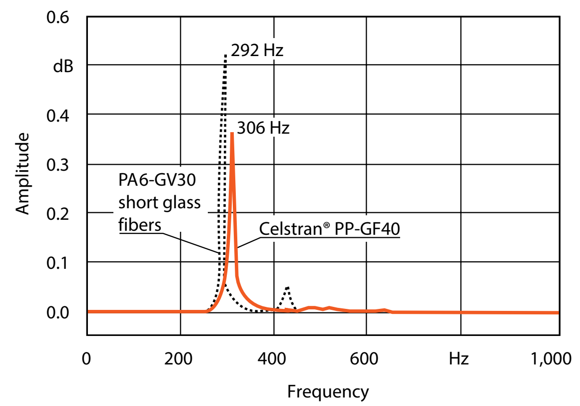
3.6 Acoustic properties

Components made from long glass-fiber-reinforced Celstran® LFRT PP offer the following acoustic advantages:

- They have considerably better sound-deadening properties than components made from short fiber-reinforced PA or metal.
- Noise emission is lower because of the higher sound-deadening effect.
- Due to their high rigidity, the natural frequency is higher, given otherwise unchanged conditions. As a result, additional ribs to increase the natural frequency are not necessary.
- They have lower oscillation amplitudes – with the same design rigidity.
- Large-volume hollow components also attain high acoustic damping.
- They permit a reduction in weight because of their acoustic passivity.

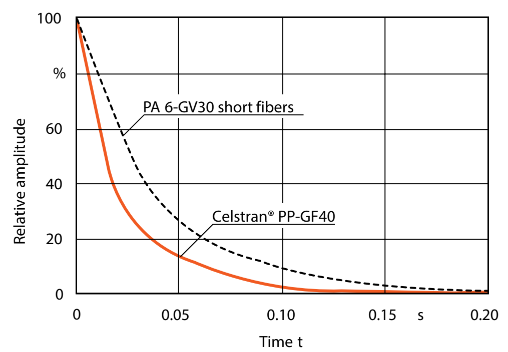
The good acoustic damping is shown by oscillation measurements on cable trays for the electronic engine control system of cars. Because of the lower weight and higher rigidity, the cable tray made from Celstran® LFRT PP-GF40 has a higher natural frequency at a much lower amplitude than a cable tray made from PA6, with 30% short glass fibers **(Fig. 3.29)**.

Fig. 3.29



Frequency spectra on excitation with a rectangular impulse, measured on cable trays made from Celstran® PP-GF40

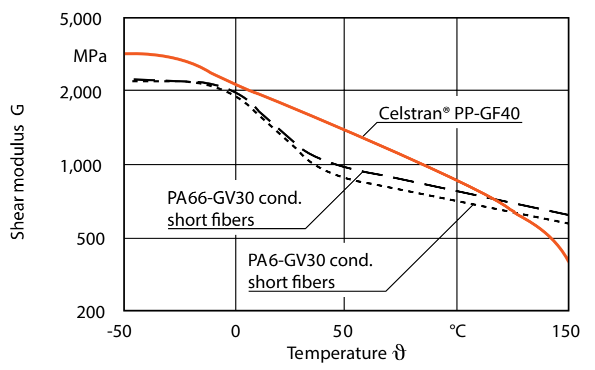
Fig. 3.30



Decay curve on excitation with a rectangular impulse, measured on cable trays made from Celstran® PP-GF40 and from a PA6 with 30% short glass fibers

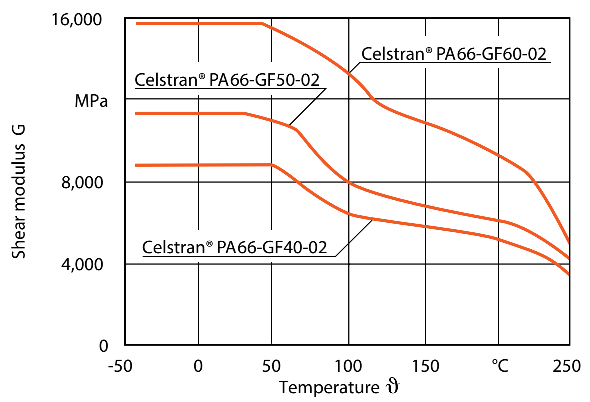
Because of their good acoustic damping properties, components made from Celstran® LFRT have good sound-deadening properties **(Fig. 3.30)**.

Fig. 4.1



Shear modulus of Celstran® LFRT PP-GF40 as a function of temperature compared with conditioned PA6 and PA66, each with 30% short glass fibers

Fig. 4.2



Shear modulus of various Celstran® LFRT PA grades as a function of temperature

4.1 Thermal properties

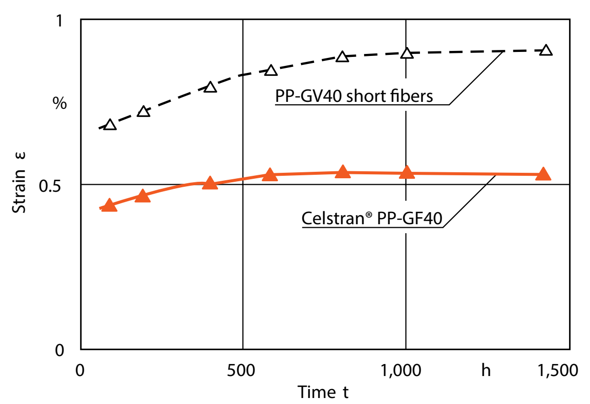
4.1.1 Heat deflection temperature

Because of the long fiber reinforcement, the heat deflection temperature of all Celstran® LFRT grades is significantly higher than that of the corresponding short fiber-reinforced matrix materials.

The long fiber reinforcement of Celstran® LFRT PP-GF40 accounts for the shear modulus up to a temperature of 130°C and is thus higher than that of short glass-fiber-reinforced PA6 and PA66 **(Fig. 4.1)**. Shear modulus of Celstran® LFRT PA is plotted against temperature in **(Fig. 4.2)**.

Furthermore, the long fiber reinforcement significantly reduces the creep tendency compared with that of corresponding short fiber-reinforced plastics. This is shown by the stress-strain curves of PP measured at 120°C **(Fig. 4.3)**.

Fig. 4.3



Creep curves for Celstran® LFRT PP-GF40 compared with a PP with 40% by weight short glass fibers

4.1.2 Heat aging

The heat aging of plastics is not a pure material property but is dependent on environmental circumstances, the loading condition and the natural color of the material.

The base material used for Celstran® LFRT PP is stabilized effectively against thermo-oxidative degradation and, therefore, displays good aging properties.

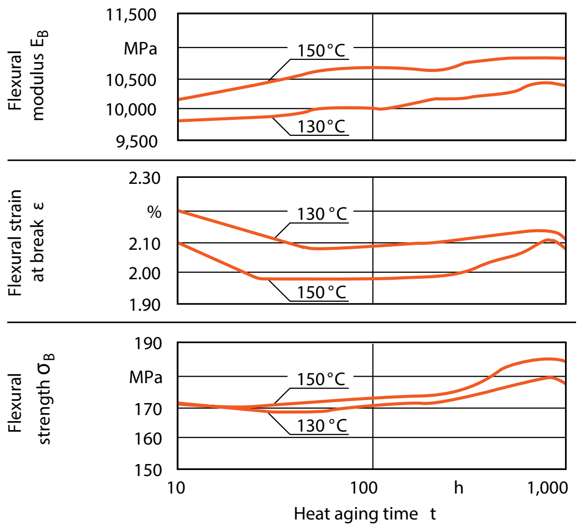
Because of their good heat aging properties, lightly stressed Celstran® LFRT PP components are suitable for continuous service temperatures up to 130°C. Under short-term stress – up to about 1,000 hours – temperatures up to 150°C can be tolerated (medium: air).

In the flexural test based on ISO 178, the flexural modulus and flexural strength even rise slightly after heat aging, whereas the strain, normally highly sensitive to aging, falls only slightly **(Fig. 4.4)**.

The base material of the heat-stabilized Celstran® LFRT PA (modification -02) is stabilized against thermo-oxidative and hydrolytic degradation.

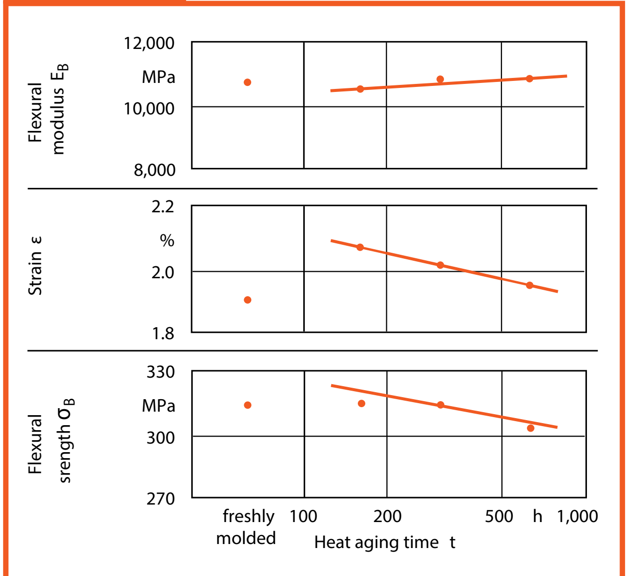
Components made from heat-stabilized Celstran® LFRT PA are suitable under low loading for continuous service temperatures up to 150°C and for short periods – up to about 1,000 hours – for temperatures of 170 to 200°C (medium: air).

Fig. 4.4



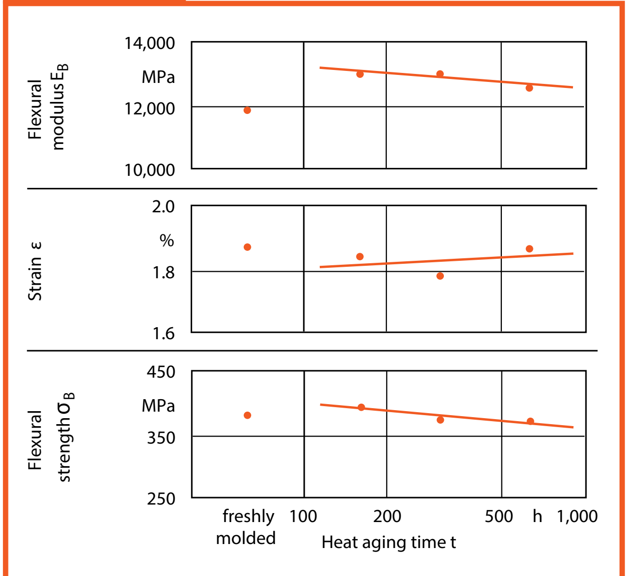
Heat aging of Celstran® PP-GF40-04-P10 black

Fig. 4.5



Heat aging of Celstran® PA-GF40-02-P10 black

Fig. 4.6



Heat aging of Celstran® PA-GF50-02-P10 black

After more than 500 hours at a temperature of 150°C, Celstran® LFRT PA66-GF40-02 has a flexural modulus of over 10,000 MPa **(Fig. 4.5)**, while Celstran® LFRT PA66-GF50-02 has a flexural modulus of over 12,000 MPa **(Fig. 4.6)**.

Celstran® LFRT is frequently chosen to replace light metals in the manufacture of complex casings. Its superior heat aging properties, combined with the natural advantage of plastics, allows for the functional integration of components.

Fig. 4.7

Material	Color	Thickness (mm)	Flamm. class UL 94	Temperature index	Elec. with impact	Mechan. without impact
Polypropylene						
PP-GF30	natural	1.57	HB	65	65	65
PP-GF40	natural	1.57	HB	65	65	65
PP-GF50	natural	1.57	HB	65	65	65
Polyamide						
PA66-GF40	natural	1.57	HB	65	65	65
	black	3.17	HB	65	65	65
PA66-GF50	natural	1.57	HB	65	65	65
	black	3.17	HB	65	65	65
PA66-GF50-01	all	1.5	HB	65	65	65
		3.0	HB	65	65	65
PA66-GF60	natural	1.57	HB	65	65	65
	black	3.17	HB	65	65	65
PA6-CF35-10	black	1.2	V-0			

UL rating of flammability and relative temperature index (RTI) of some Celstran® LFRT PP and PA grades

4.2 Flammability

The behavior of numerous Celstran® LFRT grades in the event of fire has been tested and classified to UL 94. **(Fig. 4.7)** shows an extract from these ratings, which are constantly being updated.

Celstran® LFRT PP-GF30 test specimens have withstood exposure to edge and surface flame application in accordance with DIN 4102 B2.

Test results according to FMVSS 302 – frequently used in the automotive industry – were recorded as follows on test specimens with 1 mm thickness:

- Celstran® LFRT PP-GF40
  burning rate: 1.61 inch/min
- Celstran® LFRT PP-GF50
  burning rate: 1.63 inch/min

Both materials qualify for a standard burning rate of less than 4 in/min. Their burning rate is below the value of 2.37 in/min measured on short fiber-reinforced PP-GV30.

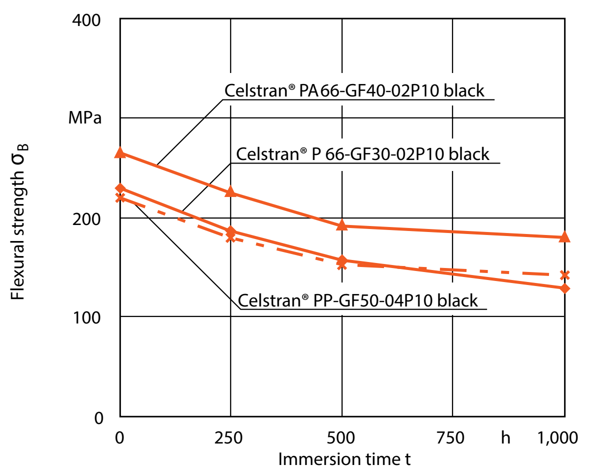
4.3 Chemical resistance

The chemical resistance is by the base material. Celstran® LFRT PP and Celstran® LFRT PA are resistant to glycol-water mixtures (engine-cooling in cars) up to 135°C.
The changes over time of the mechanical properties at 132°C are shown in **(Figs. 4.8, 4.9, 4.10 and 4.11)**.

4.4 Weathering and UV resistance

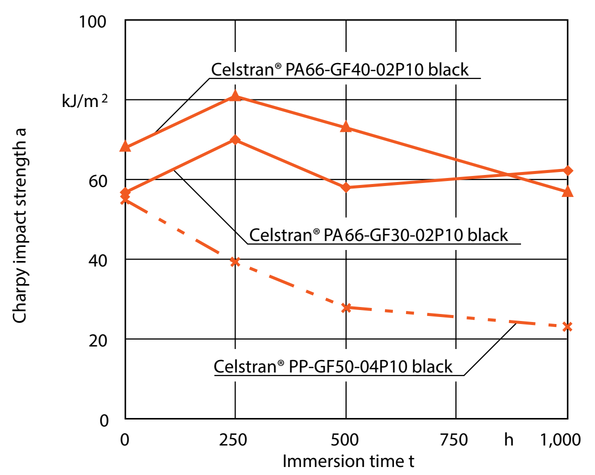
Celstran® LFRT PP and Celstran® LFRT PA, which have the property of highly effective light-stabilization can be supplied upon request.

Fig. 4.8



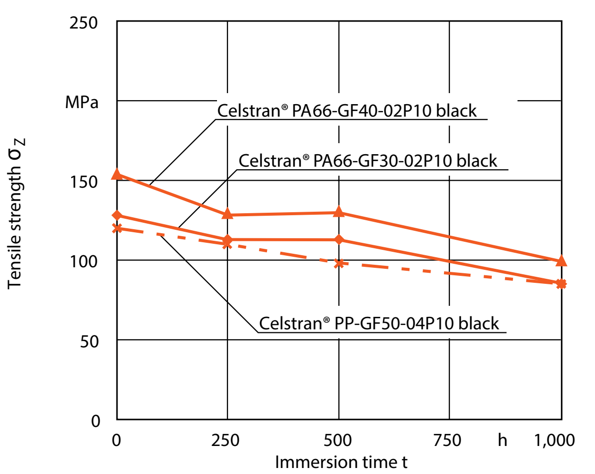
Effect of heat aging at 132°C in a glycol-water mixture on the flexural strength of various Celstran® LFRT grades

Fig. 4.9



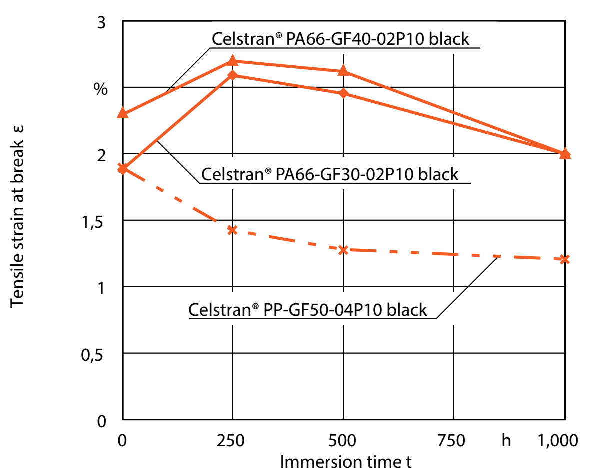
Effect of heat aging at 132°C in a glycol-water mixture on the Charpy impact strength of various Celstran® LFRT grades

Fig. 4.10



Effect of heat aging at 132°C in a glycol-water mixture on the tensile strength of various Celstran® LFRT grades

Fig. 4.11



Effect of heat aging at 132°C in a glycol-water mixture on the elongation at break of various Celstran® LFRT grades

5 Processing

Celstran® LFRT is intended for injection molding, blow molding and extrusion. While processing all Celstran® LFRT grades, care should be taken to ensure that fiber breakage is kept to a minimum. The longer the glass fibers in the component, the better are its mechanical properties.

5.1 Preparation

The pellets should be stored in a dry place in closed containers until they are processed in order to prevent contamination and moisture absorption (including condensation).

Celstran® LFRT PP and Compel® LFRT PP
Drying is not normally required before processing. Should the material become damp due to incorrect storage, it must be dried for 2 hours at 80°C.

Celstran® LFRT PA Drying in a dehumidifying dryer for 4 hours at 80°C is, recommended before processing.

Other Celstran® LFRT grades Drying in a dehumidifying dryer is recommended before processing. The drying conditions are given in the product data sheet – see **(Fig. 5.5)**.

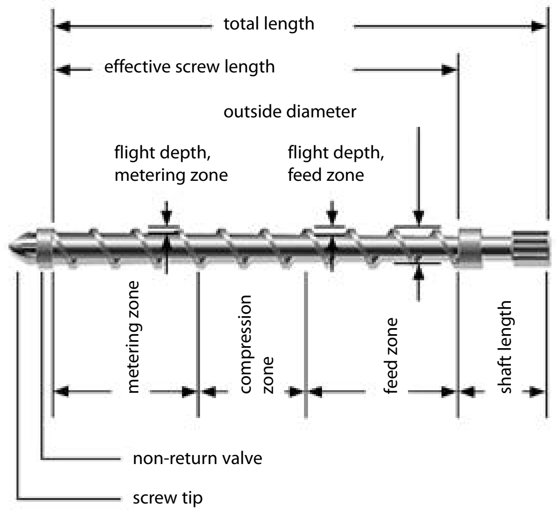
5.2 Injection molding of Celstran® LFRT plastics including mold making

Celstran® LFRT products can be processed by the various injection molding methods commonly used for thermoplastics. For the gentlest possible melting, it is generally recommended that screw speed, injection speed and back pressure should be kept as low as possible.

5.2.1 Machine requirements

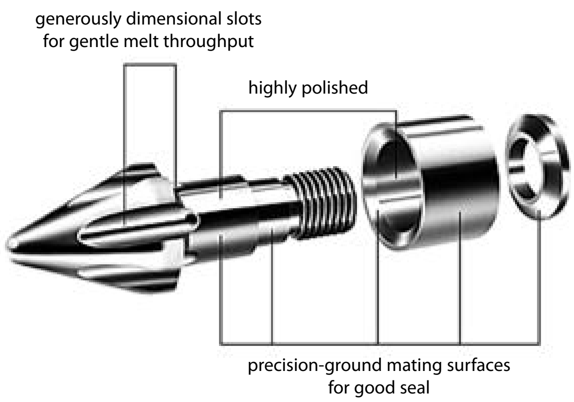
All Celstran® LFRT grades can be processed on commercial injection molding machines. For optimum care of the reinforcing fibers and to prevent feed problems resulting from the relatively long pellets, fairly large plasticizing machines should be used, preferably with a screw diameter of more than 40 mm.

Fig. 5.1



Metering Screw for Celstran® LFRT

Fig. 5.2



Three Piece Screw Tip Ring

Pellets 7 mm long are available for processing glass fiber-reinforced Celstran® LFRT PA66 grades on smaller machines. Three-zone screws are recommended **(Fig. 5.1)** if possible with a deep-flighted feed zone, low compression ratio and a three-piece annular nonreturn valve of large cross-section to ensure smooth, even flow **(Fig. 5.2)**. Plasticizing units with mixing zones are not suitable.

Since all Celstran® LFRT grades contain reinforcing fibers, it is necessary for the plasticizing unit to be wear-resistant. Depending on the matrix material, additional corrosion protection may be necessary, e.g., for PA66 or PPS.

Fig. 5.3

	Celstran® PP	Celstran® PA
Machine size	preferably fairly large machines	
Screw	standard 3-zone screw, screw diameter preferably ⩾ 40 mm	
Non-return valve	streamlined non-return valve for good flow, with large cross-section	
L/D	18 : 1 to 22 : 1	1 : 1.8 to 1 : 2.5
Compression ratio	1 : 1.8 to 1 : 2.5	1 : 1.8 to 1 : 2.5
Functional zone ratios	feed 50 to 60% compression 20 to 30% metering 20%	
Flight depth	feed zone preferably ⩾ 4.5 mm	
Steel quality	wear-resistant steels HRC ⩾ 56	wear-resistant and corrosion-resistant steels HRC ⩾ 56
Shot weight	30 to 60 % of machine capacity	
Nozzle	open, diameter ⩾ 4mm, preferably ⩾ 6mm, own temperature control for the nozzle	
Gating	if possible, central sprue gate, diameter ⩾ 4 mm, preferably ⩾ 6 mm, all flow channels streamlined for good flow, gate diameter ⩾ 3mm, if possible no pin or film gates	

Recommended equipment and parameters for injection molding machines for processing Celstran® PP and Celstran® PA

Details of recommended machine equipment are given in **(Fig. 5.3)**. Pneumatic conveying equipment has proven to be successful for automatic material supply.

The diameter of the conveying lines should be at least 40 mm. Preferably, low air speeds (up to about 16 m/s) should be used. Suction tubes that are cut at an angle have proven successful for feeding the product.

Fig. 5.4

		Celstran® LFRT PP		
		PP-GF30	PP-GF40	PP-GF50
Temperature 290 cylinder	[°C]	230 to 270	250 to 290	250 to 290
Temperature nozzle and melt	[°C]	240 to 270	260 to 290	280 to 290
Temperature mold	[°C]	30 to 70	40 to 70	40 to 70
Injection speed	[mm/sec]	40 to 60	40 to 60	40 to 60
Screw speed	[min-1]	40 to 60	40 to 60	40 to 60
Holding pressure	[bar]	400 to 800	400 to 800	400 to 800
Injection pressure	[bar]	600 to 1200	600 to 1200	600 to 1200
Back pressure			as low as possible	

Processing conditions for Celstran® LFRT PP and PA

Gravimetric metering equipment is recommended for producing blends with a fairly low fiber content.

The conveying and metering equipment used to produce conductive blends of Celstran® LFRT plastics with stainless steel filaments must not have any magnetic components. These blends can also be processed on machines with smaller screws (diameter 20 mm and above) because of the good stability of the stainless steel filaments.

5.2.2 Processing conditions

Celstran® LFRT plastics can be injection molded without any problems. Machine settings that result in optimum finished parts are dependent on the molded part geometry, the injection mold and the injection molding machine used. Settings that have proven successful are given in **(Fig. 5.4)** for Celstran® LFRT PP and Celstran® LFRT PA, and **(Fig. 5.5)** for other Celstran® LFRT grades.

Fig. 5.4 Continued

Celstran® LFRT PA					
heat stabilized = 02			high-gloss = 01		
PA66-GF40	PA66-GF50	PA66-GF60	PA66-GF40	PA66-GF50	PA66-GF60
275 to 310	280 to 315	285 to 320	270 to 305	270 to 305	275 to 310
305 to 315	310 to 320	315 to 325	290 to 305	295 to 305	295 to 310
80 to 120 pref. **90**	80 to 120 pref. **90**	80 to 120 pref. **90**	70 to 110 pref. **90**	70 to 110 pref. **90**	70 to 110 pref. **90**
40 to 75	40 to 75	40 to 75			
40 to 60	40 to 60	40 to 60			
500 to 800	500 to 800	500 to 800			
1200 to 1500	1200 to 1500	1200 to 1500			
as low as possible					

Continued

Fig. 5.5

Product	Drying		Processing temperatures [±10°C]		
	Time	Temp	Cylinder temperatures		
	[h]	[°C]	at hopper	center	nozzle
Polybutylene terephthalate					
PBT-GF40-01P10	4	120	255	260	265
PBT-GF50-01P10	4	120	260	265	270
Polycarbonate blend					
PC/ABS-GF25-02P10	4	90	265	270	275
PC/ABS-GF 0-02P10	4	90	270	275	280
Polyethylene					
PE-HD-GF60-03P10	2	90	230	240	250
Polyethylene terephthalate					
PET-GF40-01P10	4	150	265	270	275
PET-GF50-01P10	4	150	270	275	285
Polyphenylene sulphide					
PPS-GF50-01P10	4	130	305	315	320
Polyoxymethylene (Polyacetal)					
POM-GF40-01P10	3	80	195	200	205
Thermoplastic polyurethane					
TPU-GF30-01P10	4	80	240	245	250
TPU-GF40-01P10	4	80	245	250	255
TPU-GF50-01P10	4	80	250	255	260
TPU-GF50-01P10	4	80	255	260	265
With aramid fibers					
PA66-AF35-02P10	4	80	295	310	315
POM-AF30-01P06	3	80	200	205	210
PPS-AF35-01P06	4	130	315	320	320
With carbon fibers					
PA66-CF40-01P10	4	80	300	305	310
PPS-CF40-01P10	4	130	305	310	315
TPU-CF40-01P10	4	80	245	250	255

Drying and processing conditions for other Celstran® LFRT grades

Fig. 5.5 Continued

Processing temperatures [±10°C]			Injection speed	Back pressure	Screw spread	Comments
Nozzle	Melt	Mold				
				[bar]	[min-1]	
260	265	90	medium	0 to 3	30 to 50	Predry to 0.015% moisture content
265	270	90	medium	0 to 3	30 to 50	
275	275	80	medium	0 to 3	30 to 50	
280	280	80	medium	0 to 3	30 to 50	
240	250	70	medium	0 to 3	40 to 60	
270	275	150	medium	0 to 3	30 to 50	Predry to 0.015% moisture content
280	285	150	medium	0 to 3	30 to 50	
310	320	150	medium	0 to 2	30 to 50	Predry to 0.02% moisture content
205	205	80	medium	0 to 2	30 to 50	Melt < 230 °C
245	250	70	medium	0 to 3	30 to 50	Predry to 0.02% moisture content Melt < 275 °C
250	255	70	medium	0 to 3	30 to 50	
255	260	70	medium	0 to 3	30 to 50	
260	265	70	medium	0 to 3	30 to 50	
310	315	90	medium	0 to 3	30 to 50	
210	210	70	medium	0 to 3	30 to 50	
320	320	150	medium	0 to 3	30 to 50	
310	310	90	medium	0 to 3	30 to 50	
315	315	150	medium	0 to 3	30 to 50	
255	255	70	medium	0 to 3	30 to 50	

Continued

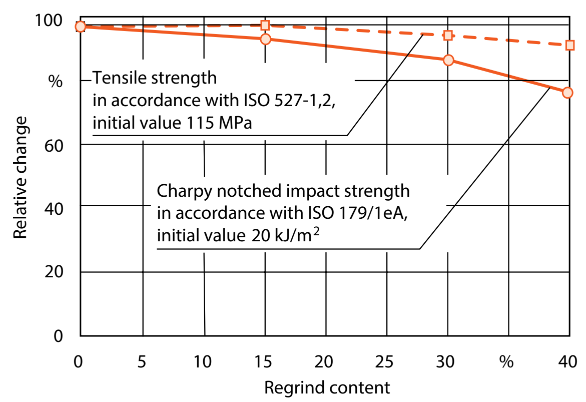
Plasticizing and cylinder temperatures
Gentle plasticizing is necessary to keep fiber length reduction during melting at a minimum. The required melt temperature is achieved first by cylinder heating (heat supply from outside by heat conduction), and second, by friction (heat supply through internal and external friction, produced by back pressure and screw speed).

The melt shear occurring on melting may shorten the long reinforcing fibers. It is, therefore, particularly important to maintain very low back pressure or even to plasticize without back pressure, but at the same time, ensure uniform metering and adequate melt homogeneity.

It is recommended that the screw speed be as low as possible so that about 90% of the cooling time can be utilized for metering. In order for a maximum amount of heat to be supplied via the cylinder heating, the pellets should melt rapidly in the feed zone. For this material, therefore, a somewhat higher temperature profile should be chosen than that used for processing corresponding short fiber compounds.
The material residence time in the plasticizing unit should be no less than 3 minutes.
A residence time of approx. 5 minutes is recommended.

Mold wall temperatures
The recommended mold wall temperatures are governed by the matrix material. Details are given in Figs. 5.4 and 5.5. For Celstran® LFRT PP, mold wall temperatures of 40 to 50°C have proven successful. Moldings with a very good surface are obtained if the mold wall temperature is raised to 70°C. The mold wall temperatures for Celstran® LFRT PA are normally 90°C.

Fig. 5.6

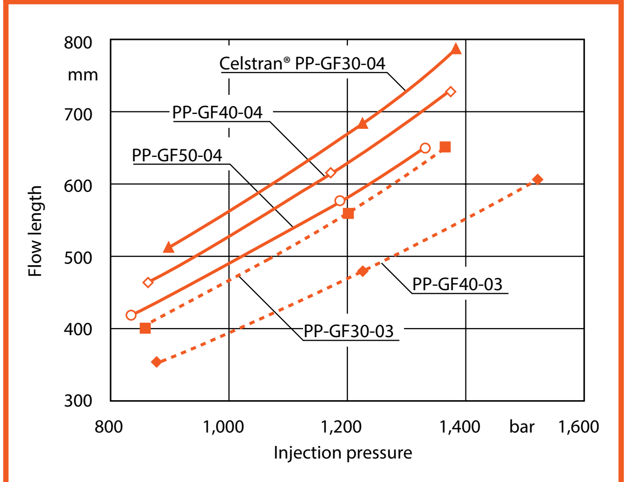


Change in tensile strength and Charpy notched impact strength as a result of regrind addition

Injection and holding pressure
High shear can also occur in the melt in the injection operation and shorten the fibers. Therefore, low injection speeds are recommended. Injection and holding pressure should be adapted to the molded part geometry. A holding pressure of 60 to 100% of the injection pressure is recommended. To ensure a constant molded-part quality, holding pressure time must be adequate. This is achieved when the molded part weight remains constant despite a lengthy holding pressure time, with a constant total cycle time.

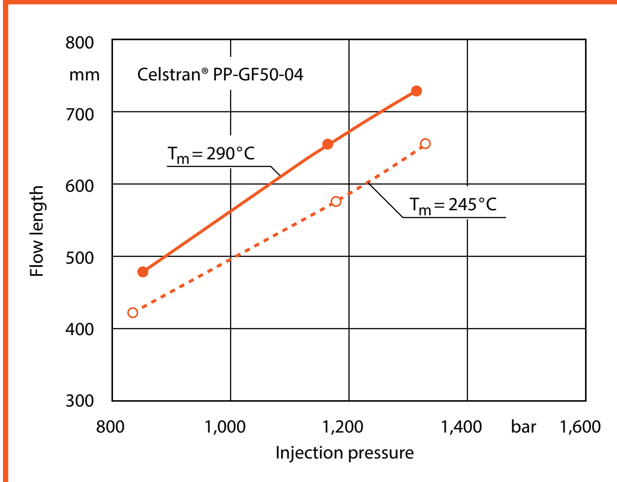
Regrind addition
When Celstran® LFRT plastics are processed, it is possible to add coarsely ground production waste to virgin material of the same grade. Additions of up to 10% have virtually no adverse effect on molded part properties [3] **(Fig. 5.6)**.

Fig. 5.7



Flow lengths of the commercial Celstran® LFRT PP grades

Fig. 5.8



Influence of melt temperature T_m on the flow length of Celstran® PP-GF50-04

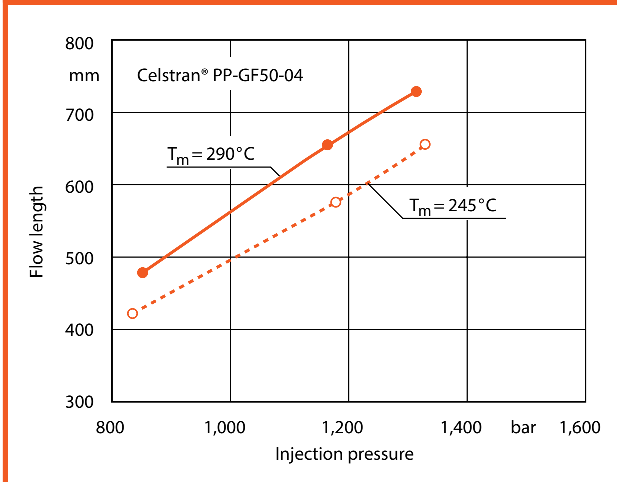
5.2.3 Flow properties and flow path lengths

In the spiral flow test under simulated service conditions, the Celstran® LFRT PP grades reach flow path lengths up to 550 mm for 2 mm wall thickness at an injection pressure of 1,000 bar and a melt temperature of 245°C **(Fig. 5.7)**.

Raising the melt temperature by 45 K to 290°C increases the flow path length by about 15% **(Fig. 5.8)**.

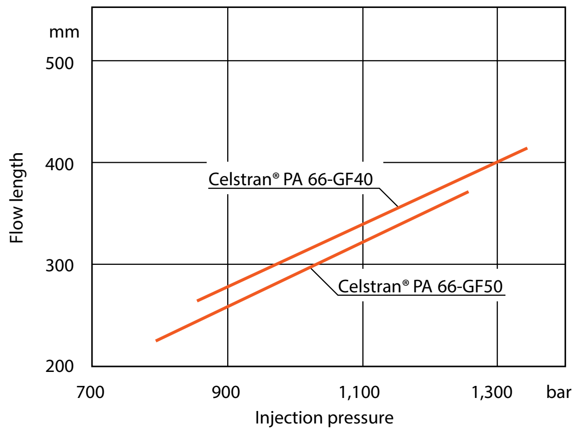
Thus, despite reinforcement with long glass fibers, the flowability of Celstran® LFRT PP is better than that of standard PP compounds with comparable short glass fiber content **(Fig. 5.9)**.

Fig. 5.9



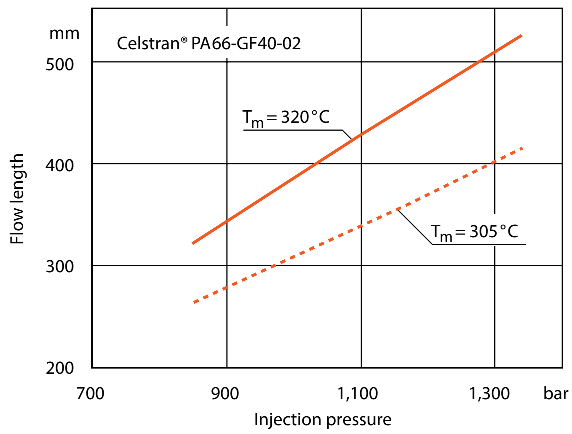
Flow lengths of Celstran® PP-GF30 compared with PP with 30% short glass fibers

Fig. 5.10



Flow lengths of Celstran® PA66-GF40 and PA66-GF50

Fig. 5.11



Influence of the melt temperature T_m on the flow length of Celstran® PA66-GF40-02

Similarly, Celstran® LFRT PA grades also have better flowability than corresponding short fiber compounds. Even the heat-stabilized grades reach flow path lengths up to 300 mm in the spiral flow test at an injection pressure of 1,000 bar and a melt temperature of 305°C **(Fig. 5.10)**.

Raising the melt temperature by only 15 K to 320°C increases the flow path length by over 20% **(Fig. 5.11)**.

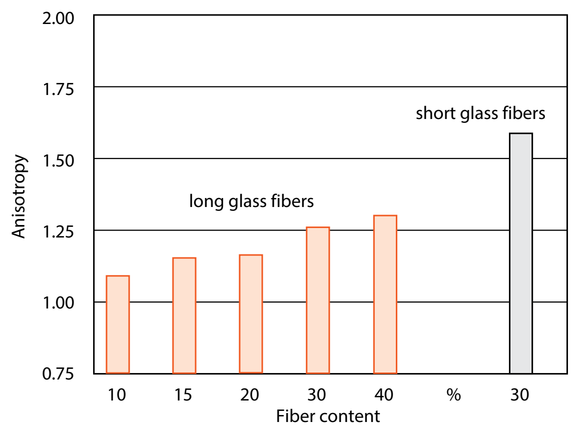
5.2.4 Shrinkage

Shrinkage has a major influence on the dimensional stability and warpage of a molding. It is governed not only by the fiber content, but also, to a considerable extent, by the fiber orientation and the processing conditions. Shrinkage data can, therefore, be no more than guide values.

Despite reinforcement with long glass fibers, the anisotropy of shrinkage, i.e., the ratio of longitudinal to transverse shrinkage, is fairly low and generally more favorable than that of short fiber-reinforced plastics. The average shrinkage measured on test bars is 0.25% in flow direction and 0.3% in transverse direction.

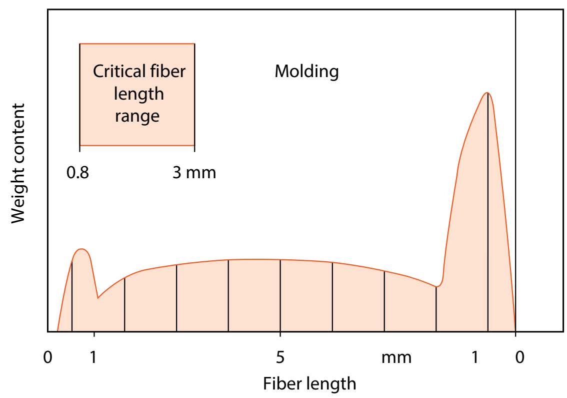
Due to the low anisotropy of shrinkage, the warpage tendency of Celstran® LFRT components is similarly low.

Fig. 5.12



Component anisotropy, determined from the ratio of the flexural modulus measured in flow direction and transversely to it

Fig. 5.13



Indication of fiber length distribution of Celstran® components: correctly produced molding, critical fiber length range drawn diagrammatically [7]

Additional information on the dimensional accuracy of Celstran® LFRT components can be derived from the ratio of the flexural modulus in flow direction to transverse direction. This anisotropy is much lower in Celstran® LFRT PP components compared with identical components made from a corresponding short fiber compound, as shown by tests on an injection molded air intake pipe for a car engine **(Fig. 5.12)**.

5.2.5 Gate and mold design

As with the injection unit, shortening of the reinforcing fibers must be kept at a minimum when designing molds. For this reason, the diameters and radii of curvature of runners in flow direction and the cross-sections of gates must be dimensioned as large as possible.

For Celstran® LFRT PP and Celstran® LFRT PA, a central sprue gate with a diameter of at least 4 mm (preferably 6 mm), with all runners designed to promote smooth even flow has proven successful. The diameter of the gate should, if possible, be greater than 3 mm. Smaller cross-sections (down to 1 mm diameter) can be chosen for blends with Celstran® LFRT SF (stainless steel fibers). Pinpoint and film gates can be used with good results, provided they have adequately large cross-sections.

Hot runner technology for sprueless processing of Celstran® LFRT thermoplastics can readily be applied, provided open hot runner nozzles are used. If the recommendations for plasticizing and mold design are observed, a molding with a fiber length distribution in which a high proportion of fibers are above the critical length [7] is obtained (see section 1.3), i.e., optimum reinforcing effect is achieved **(Fig. 5.13)**.

5.2.6 Special methods

The usual special methods can be used for injection molding Celstran® LFRT plastics. For example, the gas injection method has proven successful for a gear lever.

Decorative effects can be achieved with two-color injection molding. When multicomponent injection molding is used, i.e., for producing combinations of hard and soft materials, the compatibility and bond strength between the matrix material and the soft component must be considered. Practical experience has shown that Celstran® LFRT PP can also be processed without any problems by foam injection molding.

Virgin and recycled polyolefins are often processed into complex large components by special methods, such as transfer molding, low-pressure injection molding or intrusion. In such applications, the effect of Celstran® LFRT or Compel® LFRT products is to improve properties; adding as little as 10 to 40% by weight provides the required rigidity and strength for these components. In addition, the stable parts are easier to demold, and thus, shorter cycle times are possible.

5.3 Blow molding of Celstran® LFRT

Fundamental tests carried out by a machine manufacturer have shown that long glass fiber-reinforced plastics can be blow molded if a conventional blow molding machine is equipped with a special screw that has a gentle action for melting the pellets [8].

The long glass fiber-reinforced materials used for blow molding normally have fiber contents between 5 and 30% [8]. To achieve these low contents, a corresponding amount of Celstran® LFRT with a higher fiber content is added to the unreinforced matrix material by means of a metering unit.

5.3.1 Materials

The most important matrix material in blow molding is PE-HD. For low-fiber contents, the blow molding grade normally employed for the unreinforced blow-molded part is used. Celstran® LFRT PE-HD-GF60-01P10 is added to this material.

For higher fiber contents, a PE-HD with a lower viscosity, i.e., with higher MFI, must be employed for uniform, gentle incorporation of the long fiber material. In this case, it is particularly important to ensure homogeneous fiber distribution in the melt of the added Celstran® LFRT component. This can be achieved by adapting the extruder temperatures. The long glass fibers give the melt the elasticity necessary for blow molding. With PP as the matrix material, blow-molded parts are obtained that withstand higher service temperatures.

As with PE-HD, Celstran® LFRT PP-GF50 is added to a PP with low melt viscosity via a metering and mixing unit to achieve the desired content of long glass fibers in the molding.

Blow-molded PP parts with long glass fibers are suitable for applications in the engine compartment of vehicles. Since they do not exhibit environmental stress cracking, they can also be used for moldings in contact with fuel, lubricants or cooling water. Because of their exceptional strength even at elevated temperatures, these parts are suitable for service temperatures up to 130°C under low load. In the case of both PE-HD and PP, the achievable blow-up ratio with reinforced plastics is lower than with standard blow molding materials [8].

Coextrusion enables the production of moldings with an unreinforced inner and outer layer by blow molding. As a result, the surface quality can be influenced within a wide range. Materials with a high glass fiber content can also be processed by this method [8].

5.3.2 Machine requirements

Celstran® LFRT can be processed on commercial blow molding machines with single-screw extruders.

In selecting the machine and screw, ensure the following factors:

- The material is melted as gently as possible to minimize fiber damage
- The fibers remain uniformly distributed in the melt

The screw must not have any shear elements. Maddock shear elements in particular must be avoided. Barrier-type screws are also unsuitable because they cause considerable fiber breakage. Other mixing elements should also be avoided if possible. If it is necessary to use them, they should have an adequately large free cross-section for the melt flow.

The screw diameter must be matched to the required throughput, and should be at least 40 mm. In principle, large screw diameters, low compression and low speeds should be employed to minimize shear energy. The feed zone of the screw should be deep-flighted.

The compression ratio must not exceed 2:1.
The energy required for melting the pellets should, if possible, be provided solely via the barrel heating. Shear must be avoided. The extruder must not have any screens or strainer plates because these can be blocked by the fibers.

5.3.3 Parison die

Celstran® LFRT can be processed with continuous parison dies and with accumulator heads.
The glass fibers give the parison increased rigidity in longitudinal and transverse direction. As a result, the parison stretches less severely than in the case of unreinforced PE-HD or PP.

The long glass fibers provide the melt with high rigidity. The diameter of the extruded parison should be as large as possible so as to minimize the blow-up ratio. The long glass fibers reduce parison-swell markedly.

Fiber orientation in the component is influenced by the design of the flow channels in the parison die. The fibers are aligned in flow direction by means of spider legs. This results in weld lines, which should be located in component areas subject to low stress.

Narrow flow channels also cause strong fiber orientation in longitudinal direction. Layers with differently oriented fibers often form in the parison. In melt layers flowing near the wall, the fibers are oriented in longitudinal direction, whereas in the middle layer, they are oriented in circumferential direction.

5.3.4 Temperatures

The processing temperatures are governed by the plasticizing and homogenizing characteristics of the machine. Normally, the material can be readily processed with a temperature profile similar to that for unreinforced PE-HD. Should poorly dispersed fiber bundles still be visible in the melt, the temperatures must be raised.

In doing so, temperatures up to 50° C above those for unreinforced PE-HD are possible for the rear extruder zones.

In case of Celstran® LFRT PP combinations, it is advisable to use the temperature profile commonly employed for unreinforced PP. The temperatures should be 240°C at the heating zone, 230-220°C at the following zones and 210°C at the extruder tip.

5.4 Extrusion of Celstran® LFRT

Extruded sheets and profiles can be obtained from Ensinger GmbH, Nufringen, Germany. Coextruded profiles with a Celstran® LFRT core and unreinforced inner and outer layers are supplied under the trade name VHME (Very High Modulus Extrudate) by Intek Weatherseal Product Inc., Hastings, Minnesota, USA.

5.5 Safety notes

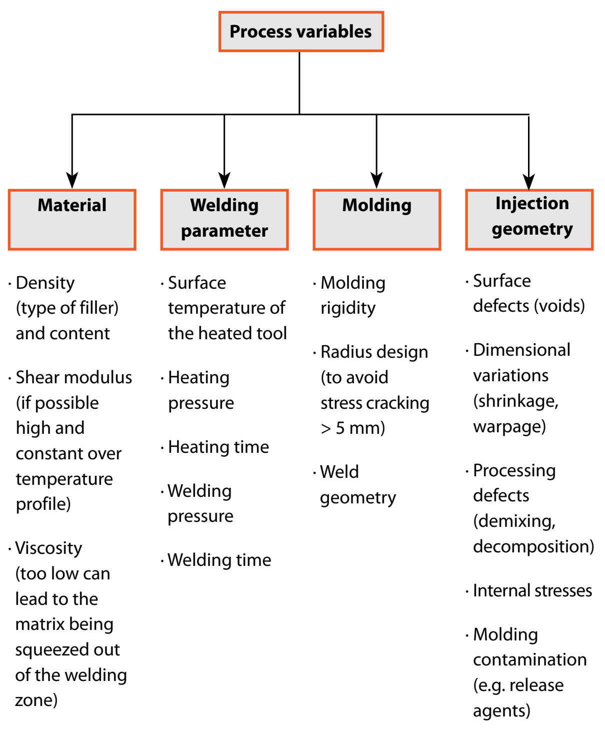
Long fiber-reinforced plastics, like many organic substances, are flammable (exceptions: Celstran® LFRT PPS is not flammable, the Celstran® LFRT PA6-CF30 and Celstran® LFRT PC/ ABS-GF40 grades are flame-retardant and reach UL 94 rating V-0).

It is in the interest of the processor when storing, processing or fabricating the material to take the necessary fire prevention measures. Certain end products and applications may be subject to special fire-prevention requirements.

The statutory safety regulations vary by country. In each case, the local regulations are mandatory. It is the responsibility of the processor to ascertain and observe such requirements.

Important information is given in safety data sheets, which are available from Celanese on request. Due to the danger of thermo-oxidative degradation, unprocessed plastificates must always be cooled down completely in a water basin.

Fig. 6.1



Major variables on heated tool welding

6.1 Machining

The two most important methods of processing plastics, injection molding and blow molding, produce molded parts that normally do not require any finishing if the molds are correctly designed. Compression-molded parts may require deflashing because some material is unavoidably squeezed out of the mold. In many cases, the flash is removed with cutting tools.

Generally speaking, the high reinforcing fiber content must be taken into account in milling, drilling or turning Celstran® LFRT, Compel® LFRT, or Fiberod parts. In principle, tools with hard metal or diamond cutters are recommended in order to achieve high-quality surfaces and long service life.

6.2 Assembly

6.2.1 Welding

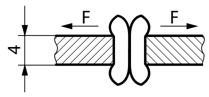
From the assembly techniques for plastic moldings, the various welding methods have achieved outstanding importance.

Moldings made from long fiber-reinforced plastics can be welded to each other or to parts made from unreinforced or short fiber-reinforced plastics. The type and quantity of reinforcing fibers must be taken into account in designing the weld area and in selecting the welding parameters.

In the case of glass-fiber-reinforced Celstran® LFRT PP, heated tool welding yields the highest values for weld strength, regardless of the fiber content. The major variables are given in **(Fig. 6.1)**.

Fig. 6.2

Weld strength: 25 to 40 MPa
(depending on the glass fiber content, welding parameters, molding geometry, injection molding)



Recommended welding parameters

for PTFE-coated heated tool	or	**for uncoated heated tool**
Temperature of the heated tool: 260°C		Temperature of the heated tool: 360°C
Heating time: 10 to 20 s		Heating time: 5 to 10 s
Heating pressure: 0.5 to 0.6 MPa		Heating pressure: 0.4 to 0.5 MPa
Welding pressure: 0.5 to 0.6 MPa		Welding pressure: 0.4 to 0.5 MPa

Heated tool butt welding of Celstran® LFRT PP

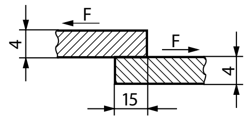
The weld strength achieved with Celstran® LFRT PP is:

- between 25 and 40 MPa in heated tool butt welding with the parameters given in **(Fig. 6.2)**.
- a tensile shear strength of about 15 MPa in heated tool lap welding under the conditions given in **(Fig. 6.3)**.

These values show that the weld strength is basically determined by the matrix material. Vibration welding also gives good values for weld strength. Values up to 25 MPa are achieved with Celstran® LFRT PP under the conditions given in **(Fig. 6.4)**.

Fig. 6.3

Tensile shear strength: 15 MPa
(depending on the glass fiber content, welding parameters, molding geometry, injection molding)



Recommended welding parameters

for PTFE-coated heated tool

Temperature of the heated tool: 360°C

Heating time: about 20 s

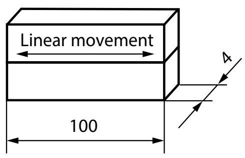
Welding pressure: about 0.3 MPa

Heated tool lap welding of Celstran® LFRT PP

Fig. 6.4

Weld strength achieved with

Celstran® PP-GF40-04: about 21 MPa
Celstran® PP-GF50-04: about 17 MPa



Recommended welding parameters

for Celstran® PP, modification 04

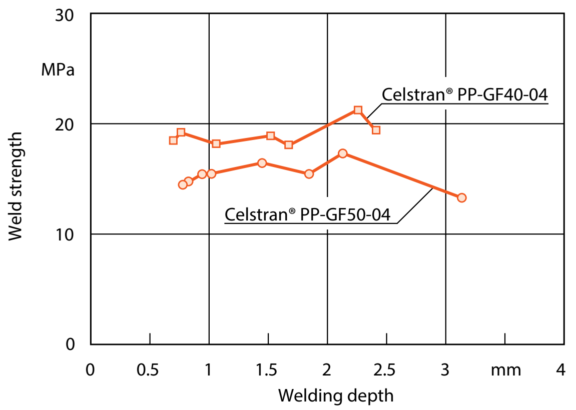
Welding pressure: 1 MPa

Welding time: 5 s

Welding depth: about 2.0 mm

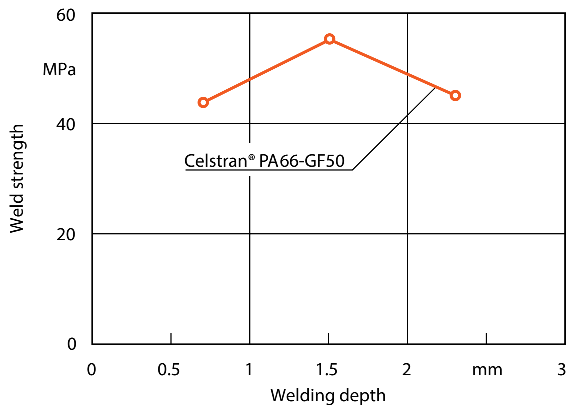
Vibration welding of Celstran® LFRT PP

Fig. 6.5



Weld strength as a function of welding depth of Celstran® LFRT PP

Fig. 6.6



Weld strength as a function of welding depth of Celstran® LFRT PA

The weld strength is largely independent of the welding depth **(Fig. 6.5)**.

In line with the higher strength of the matrix material, the weld strength of Celstran® LFRT PA66 rises to 45 – 55 MPa **(Fig. 6.6)**.

Ultrasonic spot-welding can be used instead of riveting. The characteristic welding parameters and the achievable tensile shear forces are shown in **(Fig. 6.7)**.

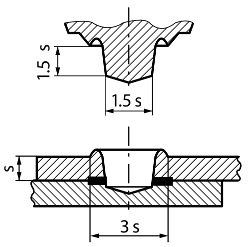
6.2.2 Adhesive bonding

In adhesive bonding of components made from Celstran® LFRT, the matrix material is of critical importance. For instance, pretreatment of Celstran® LFRT PP is necessary to lower the surface tension (corona discharge, flame application) to obtain bonded joints with adequate strength.

Bonded joints are simpler to produce with Celstran® LFRT PA. Two-pack adhesives based on polyurethane and one-pack adhesives based on cyanoacrylate give good results.

Fig. 6.7

Number of welding points	Tensile shear force in N where s = 3 mm	s = 4 mm
1	2800	3400
2	4500	5200
3	6200	8200



Recommended welding parameters

Sonotrode diameter: 4 mm

Amplitude: 0.05 mm

Ultrasonic exposure time: 1.2 s

Welding pressure: 0.25 MPa

Holding time: 3 s

Ultrasonic spot welding of Celstran® LFRT PP

7 Recycling

Recycling possibilities of Celstran® LFRT production waste (sprues, rejects) is described in section 5.2.2 "Processing conditions."

After use, Celstran® LFRT moldings can be recycled. The most important requirement is to segregate Celstran® LFRT parts from other polymers. Celstran® LFRT PP recyclate can be blended with other PP recyclates.

An addition of Celstran® LFRT PP recyclate to unreinforced PP generally improves the latter's properties because of the glass-fiber reinforcement. The same applies to Celstran® PA66 and PA66 recyclates.

Further shortening of the fibers is likely in recycling, and so moldings made from pure Celstran® LFRT recyclates have poorer values than virgin Celstran® material, especially in impact strength.

8 Photo supplement showing typical applications

Celstran® + LFRT for dashbords

Celstran® LFRT used to make the electronic accelerator pedal from Hella, Germany

Quietly efficient: Celstran® LFRT plus aluminum in fan blades

Desks with structural parts made of Celstran® LFRT PP are stable and lightweight

Power tools with comfortable Celstran® LFRT

Tilt Tray Mechanism, Celstran® PP-GF40 (company: WPK, Radevormwald)

9 Subject Index

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celanese.com/engineered-materials

Contact Information

Americas
8040 Dixie Highway, Florence, KY 41042 USA
Product Information Service
t: +1-800-833-4882 t: +1-859-372-3244
Customer Service
t: +1-800-526-4960 t: +1-859-372-3214
e: info-engineeredmaterials-am@celanese.com

Europe
Am Unisys-Park 1, 65843 Sulzbach, Germany
Product Information Service
t: +(00)-800-86427-531 t: +49-(0)-69-45009-1011
e: info-engineeredmaterials-eu@celanese.com

Asia
4560 Jinke Road, Zhang Jiang Hi Tech Park
Shanghai 201203 PRC
Customer Service
t: +86-21-3861-9266 f: +86-21-3861-9599
e: info-engineeredmaterials-asia@celanese.com