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Replacing Metals with Ixef® PARA

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Ixef® polyarylamide (PARA) compounds reinforced with glass deliver high-performance properties. They have very high rigidity and high flowability coupled with excellent surface quality, extremely low creep and high dimensional stability. This combination of properties make these compounds particularly suited to replace metals in the production of high-tech components.

Ixef® PARA is a partially crystalline, partially aromatic polyamide. It is obtained by polycondensation of m-xylylenediamine and adipic acid by a standard production process for polyamides. The aromatic groups, because of their structure, are less mobile than aliphatic monomers and give rise to the high rigidity and strength, high creep resistance and dimensional stability of this material(1). Adding glass fibers further enhances these properties. Other characteristic properties of the material are its excellent surface quality and very high flow.

Ixef® PARA can be glass-fiber-reinforced (up to 60 %) and/or mineral-filled, carbon-fiber-reinforced and also flame-retardant or impact-modified. Mineral fillers can give, for example, even higher rigidity or better surface quality.

Because of the partially aromatic structure of Ixef® PARA, its glass transition temperature of 85 °C (185 °F) is higher than that of PA 6,6 or PA 6. Its melting point is 235 °C (455°F). Because of its approximately 50°C (90°F) higher processing temperature and low melt viscosity, the material has very good flow properties in injection molding. High filler contents can therefore be added without losing the excellent flow properties and good surface finish.

A glass-fiber-reinforced PARA guarantees an exact fit between the individual parts of a cutter block system for the Flex Integral electric shaver (manufacturer and picture courtesy of Braun AG, Kronberg)

Table 1: Mechanical properties of glass-fiber-reinforced Ixef® PARA

Properties	Glass, 50 %	Glass, 60 %
Tensile modulus [GPa]	20	24
Tensile strength [MPa]	255	280

Specific Properties

Ixef® PARA compounds have high rigidity (Figure 1). This property derives from the chemical structure of PARA and the excellent compatibility of the polymer with glass fibers[2].

With the addition of 60 % glass fibers, Ixef® PARA 60 GF has even higher strength properties (Table 1), while retaining good melt flowability and good surface quality in the finished component. In many applications, components made from this glass-fiber-reinforced product are replacing metal components, since the material far exceeds the specific strength of metal alloys (Figure 2).

PARA compounds have excellent creep resistance, even under high stresses. Figure 3 compares the creep behavior of Ixef® PARA GF 50 and PA 6 GF 30. The higher creep resistance of PARA is due to the aromatic group in the polymer structure and the good adhesion between the glass fibers and the PARA.

Even at elevated temperatures, the reinforced PARA is very creep resistant. Figure 4 compares the creep behavior of Ixef® PARA GF 50, a zinc alloy (ZAMAK 3) and an aluminium alloy AG3. The initial elongation of Ixef® PARA GF 50 is higher than that of the aluminium alloy but the slope of the curve is approximately the same. The zinc alloy displays severe creep and breaks after one day.

Because of this high creep resistance, reinforced PARA is an ideal material for high-precision components where even slight deformation under constant load is not permissible. Generally speaking, only materials with extremely high creep resistance can meet these high requirements.

Figure 1: Comparison of the strength of PARA with that of engineering plastics

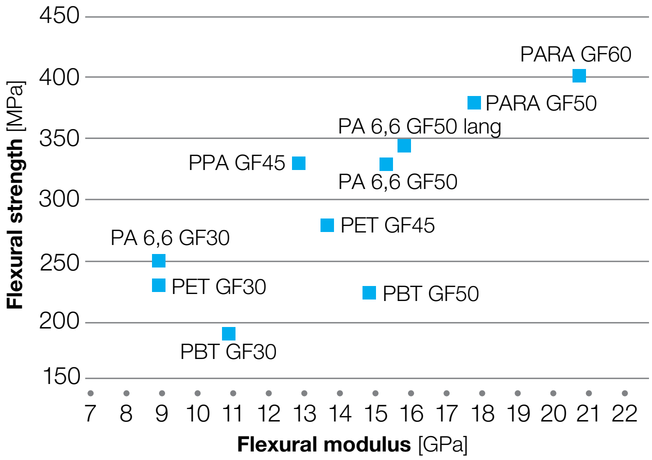
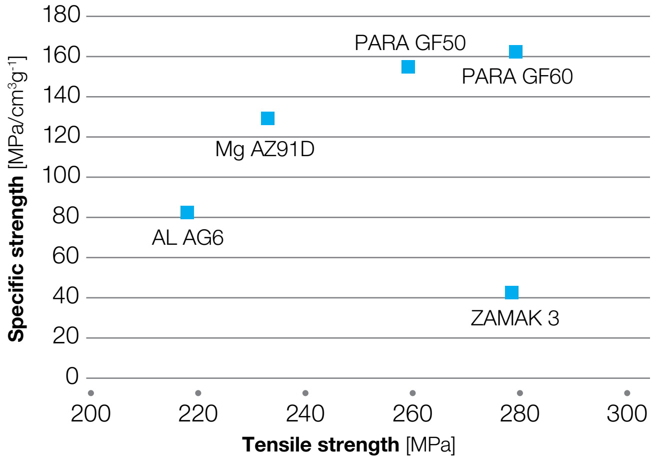


Figure 2: Comparison of the tensile strength and specific strength values of glass-fiber-reinforced Ixef® PARA with those of metal alloys*



According to DIN/ISO 527

Figure 3: Comparison of the creep behavior PARA GF 50 and PA 6 GF 30 At 23 °C (73 °F) after 500 hours

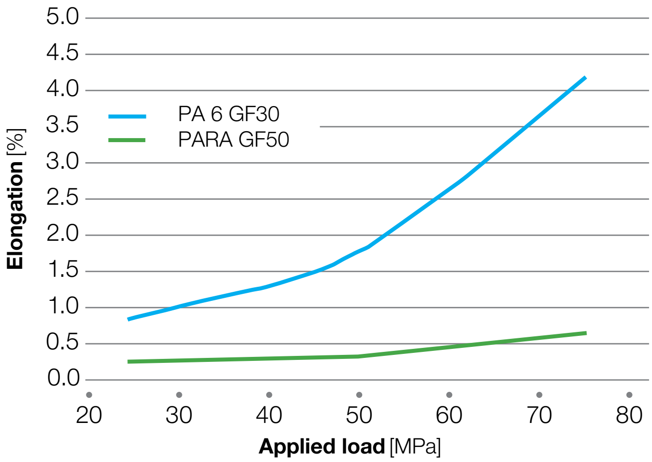


Figure 4: Comparison of the creep behavior PARA

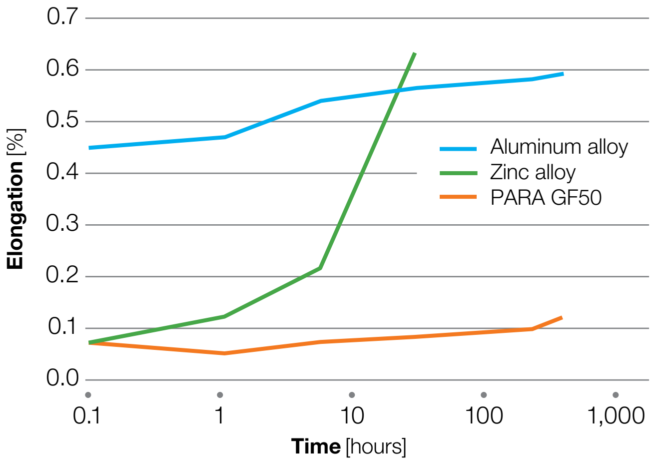


Figure 5: Comparison of flexural fatigue strength of PARA GF 50 and metal alloys at 23 °C (73 °F)

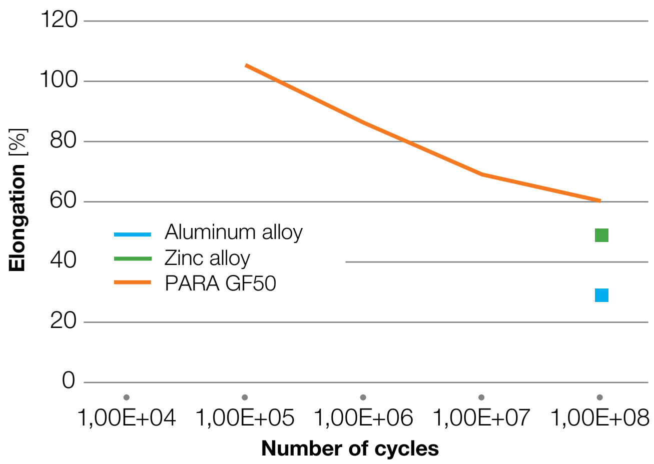
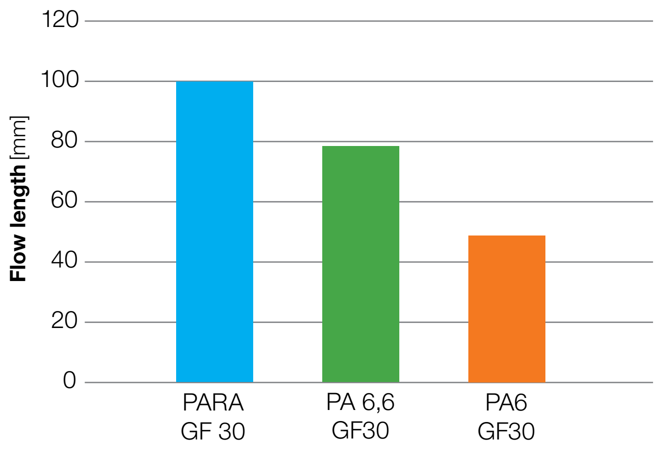


Figure 6: Comparison of the injection molding behavior in the spiral flow test



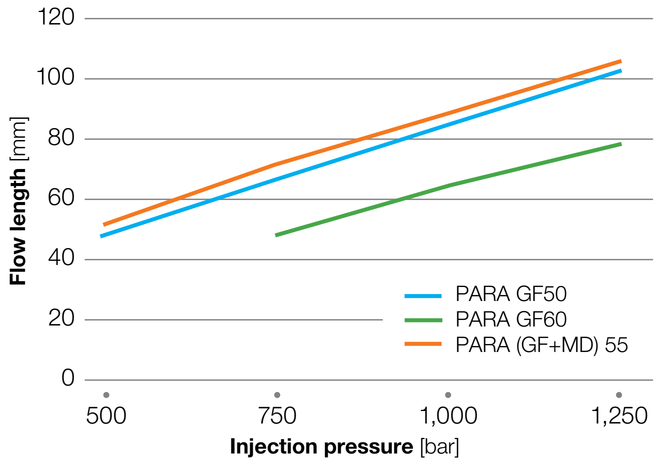
Very many engineering parts have to withstand long-term dynamic stresses, e.g. vibrations. The fatigue resistance of a material can be read off the Wöhler curve. The Wöhler curve shows the residual strength of a material as a function of the number of cycles at a certain frequency. Figure 5 compares the Wöhler curves for PARA GF 50, a standard zinc alloy (4 % Al, 0.4 % Mg) and an aluminium alloy (type: AG6). After 10 million cycles, PARA GF 50 exhibits a higher residual strength than the aluminium and zinc alloys.

As with any other anisotropic compound, PARA exhibits different thermal expansion values according to the orientation of the reinforcing fibers. The coefficients of linear thermal expansion in the flow and transverse directions for PARA GF 50 are 1.5 x $10^{-5}K^{-1}$ and 3.7 x $10^{-5}K^{-1}$. The thermal expansion coefficient of PARA GF 50 in the flow direction is approximately the same as that for steel.

In comparison with standard polyamides such as PA 6 and PA 6,6, PARA has significantly lower and slower water absorption. This is attributable to its aromatic structure(3). The amide group has an affinity for water. PARA contains a relatively small number of amide groups per unit of weight. PARA GF 50, for example, absorbs only about 1 % water at 50 % relative humidity (23 °C), while PA 6,6 GF 30 absorbs 2.2 %.

Generally speaking, PARA GF 50 has good resistance to the various media used in the automotive industry. These include petrol/ethanol mixtures (80/20) and engine oils according to laboratory tests performed at 60 °C (140 °F) (or at boiling temperature below that)). This high-performance compound is not affected by aliphatic hydrocarbons (white spirit, kerosine), aromatic hydrocarbons (benzene, toluene), ketones, esters, ethers, weak bases, aldehydes (except formaldehyde) or alcohols (except light alcohols that plasticize polyamides). It is always necessary to verify the chemical resistance under the anticipated use conditions of the components(4). Polyarylamides stand up well in comparison with PA 6, PA 11, PBT, PC and PPE(5).

Figure 7: Comparison of the flow behavior of different polyarylamides at 0.5 mm (0.02 in.) wall thickness



Processing Properties and Surface Quality

Because of their very good flowability, PARA compounds can be used to produce thin-walled moldings with high rigidity and strength. In the case of other plastics, this is often only achieved by design measures such as ribs and increased wall thickness. With glass-fiber-reinforced polyarylamide grades PARA GF 50 and 60 GF, wall thicknesses of 0.5 mm (0.02 in.) can be obtained. A comparison of the injection molding behavior of different plastics, as determined in the spiral flow test, is shown in Figure 6. The flow behavior of different polyarylamides (PARA GF 50 and 60 GF) and PARA (GF+MD) is shown in Figure 7.

The high flowability of PARA compounds has other advantages: sink marks can largely be avoided. In addition, faster injection rates can be employed and thus a more effective holding pressure achieved, which again helps prevent sink marks.

Table 2: Comparison of the shrinkage behavior injection molding conditions

Direct gate/holding pressure 750 bar
Ixef® PARA GF 30: mold temperature 120 °C (248 °F), material temperature 280 °C (310 °F)
PA 6,6 GF 30: mold temperature 80 °C (176 °F), material temperature 285 °C (545 °F)

PARA	Plate Thickness [mm]	Shrinkage in the Flow Direction [%]	Shrinkage in the Transverse Direction [%]
PARA GF 30	2	0.13	0.43
	4	0.25	0.65
PA 6,6 GF 30	2	0.34	0.83
	4	0.45	0.98

Figure 8: Components made from PARA compounds can be successfully painted or electroplated because of their good surface quality

Ixef® PARA exhibits very low mold shrinkage, e.g. PARA GF 50 has an average shrinkage of 0.3 %. The actual shrinkage values depend on the characteristics and content of the reinforcing material, the geometry of the molding (particularly wall thickness values), the location and design of the gates and the degree of packing during cooling (i.e. the effective holding pressure in the mold). Table 2 shows the shrinkage values of Ixef® PARA and PA 6,6. Both products are filled with 30 % glass fibers.

The shrinkage values for PARA GF 50 and 60 GF are even lower[6]. Table 2 also indicates that a glass-fiber-reinforced thermoplastic is an anisotropic material, i.e. shrinkage will vary according to the direction of flow. This anisotropy must be taken into account in molding design.

Tolerances can be estimated on the basis of standard deviations for shrinkage. Assuming a correctly set injection molding machine, longitudinal and transverse tolerances of 0.05 % can be expected for PARA compounds.

Because of their dimensional stability and replication accuracy, PARA compounds are used for the production of complex precision parts. For example, the cutter block system for an electric shaver (type: Flex Integral, manufactured by Braun AG, Kronberg; title picture) is made from PARA 60 GF. A number of thin-walled components (head carrier, pivot frame, change frame) are accurately fitted together in a complex assembly here. Tolerances on those molded parts are extremely narrow. Glass-fiber-reinforced Ixef® PARA is characterized by high surface quality. The 1 µm to 2 µm skin layer consists of pure PARA and determines the good appearance of the molding surface. The excellent surface quality of this product coupled with its extreme strength gives it access to numerous applications that were previously the preserve of metals. The example of the cutter block system for an electric shaver illustrates the very good surface quality of these high-performance compounds. The moldings can be painted or electroplated (Figure 8), depending on the type of shaver. To meet the visual requirements of the manufacturer, a flawless surface is absolutely essential.

Injection Molding Parameters[7]

PARA compounds are processed only by injection molding. No special injection molding machines are needed. The only requirement is that they are suitable for processing reinforced or filled thermoplastics. The use of hot runner systems is possible[8]. A pressure of 800 to 1,000 bar per cm^2 surface area is a sufficient mold clamping force.

The mold temperature must be between 120 °C and 140 °C (248 °F to 284 °F), since otherwise the optimum degree of crystallization will not be achieved. If this happens, post-crystallization can occur and the above-mentioned technical data will be significantly lower. The material temperature is about 280 °C (310 °F). A very high filling rate, injection pressure between 500 and 1,000 bar and holding pressure between 300 and 1,500 bar are recommended. Typical values for holding pressure time are 3 x e and for cooling time 2.5 x e^2 (e = wall thickness in mm).

Coloration is possible with PA-based masterbatches. The moldings can also be painted and electroplated without any problem because of the excellent surface and good paint adhesion.

Regrind can be blended with virgin material. In trials in which 30% regrind was added in each case, no significant changes in tensile strength, elastic modulus and elongation at break were determined after 5 processing cycles – in each cycle 30 % regrind from the previous cycle was used. It is however necessary to determine experimentally the permissible regrind content.

For more information please contact your Solvay Specialty Polymers representative.

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