IXEF® polyarylamide

design & molding guide

version 2.1

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At a glance

IXEF®: reinforced polyarylamide-based compounds

Although the properties can vary from grade to grade, the most striking characteristics of parts manufactured from IXEF compounds can be summarized as follows:

- **Very high rigidity**
  Tensile modulus up to 23 GPa at 20 °C.
- **Excellent resistance to mechanical stresses**
  Flexural strength can attain 400 MPa at 20 °C.
- **Easy processing, also for thin-walled sections**
  Good injectability and high productivity even with high fibre content.
- **Low mould shrinkage, highly reproducible**
  Precision moulding, absence of sink marks and close dimensional tolerances can be achieved.
- **Conception of miniaturised parts**
  Rigidity, injectability of complex, thin shapes.
- **Excellent surface finish**
  Superb surface appearance for reinforced products, even with a high glass fibre content.
- **Very low coefficient of linear thermal expansion**
  Value comparable to that of metals.
- **High thermo-mechanical properties**
  Flexural modulus at 140 °C up to 7 GPa.
- **Very low creep**
  Deformation less than 1 % after 1000 hours under 50 MPa at 50 °C, for example, for certain compounds.

Contents

Nomenclature of the IXEF product range

The range of IXEF compounds comprises of different products families, essentially for injection moulding:

Grades	Characteristics
IXEF 1000 series	Compounds reinforced with glass fibres
IXEF 1002	30% glass fibres
IXEF 1022	50% glass fibres
IXEF 1023	50% glass fibres; UV stabilised for internal applications
IXEF 1025	50% glass fibres; UV stabilised for external applications
IXEF 1027	50% glass fibres; heat stabilised grade
IXEF 1028	50% glass fibres; laser printable
IXEF 1032	60% glass fibres
IXEF 1500 series	Flame-retardant compounds reinforced with glass fibres (UL 94 V-O)
IXEF 1501	30% glass fibres
IXEF 1521	50% glass fibres
IXEF 1600 series	Impact modified reinforced compounds
IXEF 1622	50% glass fibres and an elastomer
IXEF 2000 series	Compounds containing mineral reinforcements either alone or in combination with glass fibres
IXEF 2004	65% mineral reinforcements and glass fibres
IXEF 2011	Mineral reinforced
IXEF 2030	55% mineral reinforcements and glass fibres
IXEF 2057	Mineral reinforced
IXEF 2500 series	Flame-retardant compounds with mineral reinforcements and/or glass fibres (UL 94 V-O)
IXEF 2530	Flame-retardant version of the IXEF 2030 grade
IXEF 3000 series	**Compounds reinforced with carbon fibres**
IXEF 3006	30% carbon fibres
IXEF 5000 series	**Compounds reinforced with glass fibres, self lubricating**
IXEF 5002	20% glass fibres with PTFE

* Non-exhaustive list: other grades tailor made for special applications or markets are also available on demand.

1 - IXEF, a composite material

The IXEF compounds are a family of thermoplastic products reinforced with glass fibres and/or mineral fillers, whose properties can vary considerably from grade to grade.

The IXEF polyarylamides are composite materials. Parts manufactured by injection moulding are thus not isotropic, but instead exhibit a «stratified» structure.

A part seen in cross-section perpendicular to the flow direction presents a series of layers (figure 1):

a. first, a skin zone of around one micron composed of pure polymer, which gives the part its surface appearance.

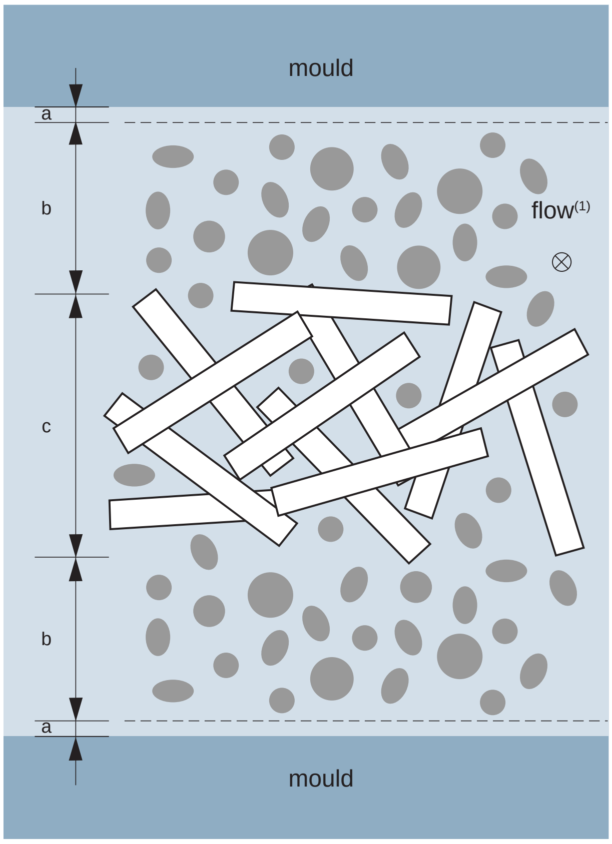
b. then, an intermediate layer where the fibres are clearly oriented in the direction of the flow, caused by the shear stresses which are at their maximum close to the wall of the mould during injection.

c. finally, a core region where the fibres tend to orient themselves in a plane perpendicular to the flow direction (since the fibres are less subject to shear in the middle of the part).

The qualitative and quantitative distribution of the orientation layers is influenced primarily by the following parameters:

- the thickness of the cavity. The finer the thickness, the more glass fibres are oriented in the flow direction.
- the rheological and thermal characteristics of the material. An increase of material temperature or of the mould increases the thickness of the skin zone, which improves the surface appearance.
- the processing conditions. The higher the injection speed, the more the fibres are oriented in the direction of the flow.

Figure 1: Cross-section of an injected part



(1) **Note:** The material flow is perpendicular to the cross-section

2 - IXEF, a semi-crystalline material

The resin used in all IXEF compounds is a **semi-crystalline** polymer: polyarylamide. The term «semi-crystalline» indicates that there is a **crystalline phase**, corresponding to the matrix zones in which the macromolecules are spatially arranged in a regular manner, and to an **amorphous phase** characterized by disorder of the macromolecules (figure 2).

A solid semi-crystalline polymer can present different states depending on the temperature and/or the speed of stress:

- The vitreous state (zone below the glass transition temperature (Tg)), where the macromolecules are theoretically frozen, irregardless of whether or not they belong to the amorphous or crystalline phases.
- The rubbery state (zone between the Tg and the melting temperature (Tf)): one can consider that the amorphous phase is in the liquid state (possible movement of the macromolecules) while the macromolecules in the crystallites remain frozen.

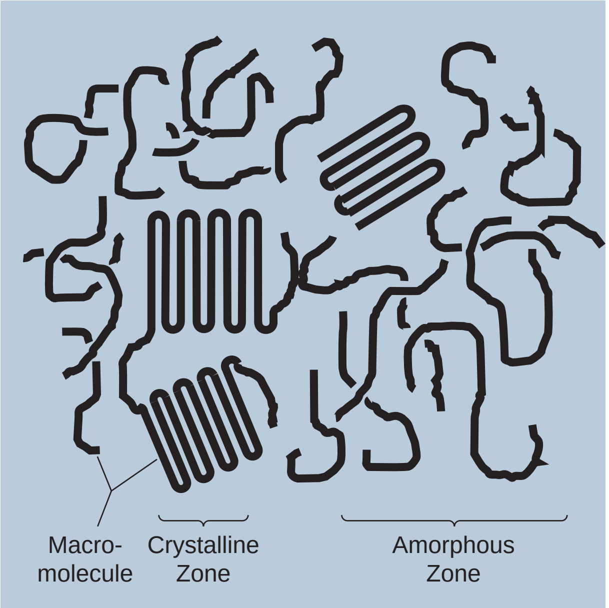
The glass transition temperature thus characterizes the change of state: from vitreous to rubbery. The melting temperature corresponds to the melting of the crystallites.

The level of crystallinity obtained depends heavily on the thermal history of the material, and particularly on the moulding parameters: processing temperature, mould temperature, moulding cycle time, post-treatment after moulding (annealing).

To develop a high crystallinity of IXEF compounds under normal injection moulding conditions, it is essential to bring the temperature of the mould to between 120 and 140 °C.

Under these conditions, the injected parts exhibit excellent dimensional stability, an exceptional surface appearance, and very good mechanical properties, even at high temperatures (see section VI.A.2.).

Figure 2: Diagram of the crystalline and amorphous zones in a semi-crystalline polymer



By contrast, if the temperature of the mould is less than 120 °C, the injected parts will not obtain the maximum level of crystallinity throughout its thickness. If these are subsequently exposed to temperatures above the glass transition temperature, they will crystallize and thus undergo an annealing process which will affect their dimensional stability. Water pickup can aggravate this phenomenon by lowering the glass transition temperature.

The amorphous state is thus more unstable than the crystalline state: dimensional variations over time, greater sensitivity to solvents and water.

Crystallization phenomena can be studied by Differential Scanning Calorimetry (DSC). This analytical method involves comparing the energy liberated or absorbed by a test material with that of a reference material subjected to the same heating and cooling rates.

The following figures compare a DSC analysis of a part made of IXEF® polyarylamide injected in a mould at 120 °C (above the Tg) (figure 3) with that of the same part but using a mould at 60 °C (below the Tg) (figure 4).

The peak near 90 °C in the case of the part manufactured in a 60 °C mould corresponds to the energy released during crystallization of resin which was not fully crystallized during injection. This peak does not appear in the case of the IXEF part made in a 120 °C mould.

Figure 3: DSC analysis of a part injected in a mould at 120 °C

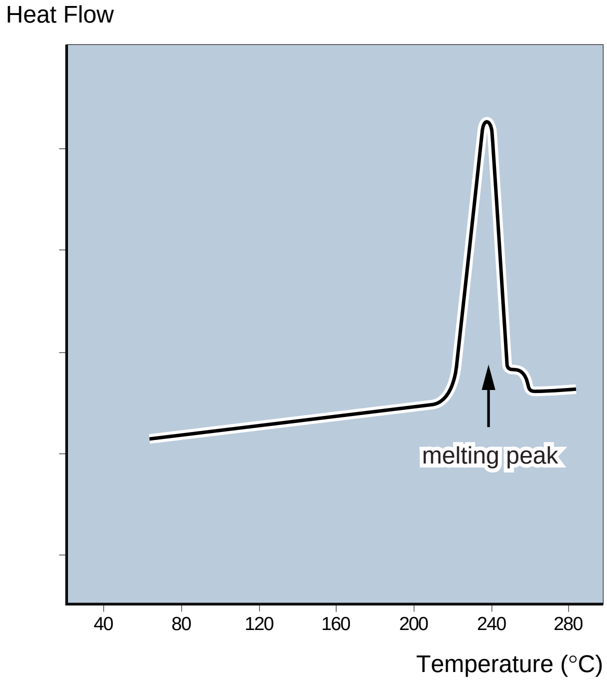
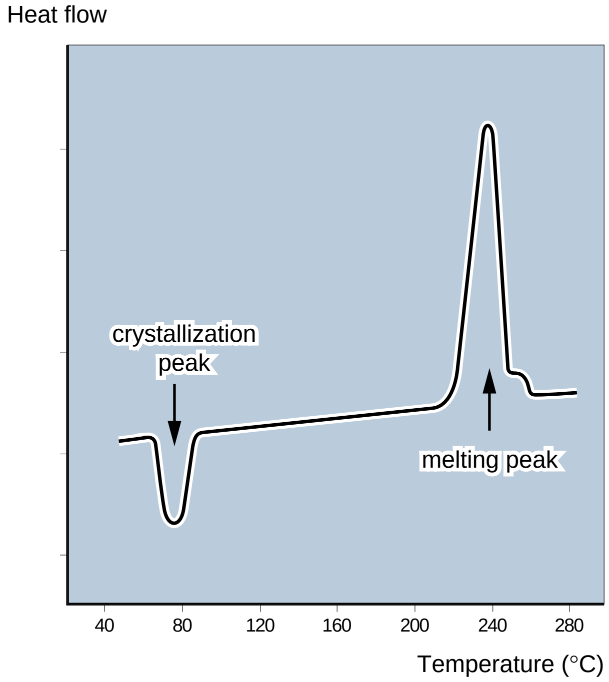


Figure 4: DSC analysis of a part injected in a mould at 60 °C



B - Short-term mechanical properties

1 - Tensile properties

Among the mechanical tests, the tensile test is one of the most frequently performed because it corresponds to a uniform, mono-axial stress (ISO 527).

The tensile test, performed by deforming a specimen at constant speed, allows determination of several important characteristics:

- the tensile modulus E
- the breaking stress σ_R
- elongation at break ε_R

Figure 5 presents the stress[σ_R]-strain[ε_R] diagram, which illustrates that IXEF® compounds do not behave like perfectly elastic materials. Instead, they possess a visco-elastic behaviour whose viscous component remains low.

IXEF compounds possess good tensile mechanical characteristics, as shown by Table 1.

The tensile test also makes it possible to determine the Poisson ratio (the ratio of the fractional contraction in breadth to the fractional increase in length when the material is stretched) in a direction perpendicular to the direction of stress.

$$\nu = \frac{\varepsilon_y}{\varepsilon_x}$$

Under the reference conditions (20 °C, dry product), the average value to be considered for the IXEF 1022 grade is 0.35.

The effect of the temperature on the tensile mechanical properties is presented in figure 7 for the IXEF 1022 compound.

For the two characteristics, one observes a decrease as the temperature increases. This decrease grows sharper and displays an inflection point at the polyarylamide glass transition temperature (85 °C).

The presence of fibres in IXEF compounds is responsible for the anisotropic mechanical behaviour of injection-moulded parts.

Generally, the glass fibres tend to orient themselves in the flow direction (see section I.A.1. and figure 6). The mechanical properties are thus greatest in this direction.

Figure 8 presents the variation of the tensile mechanical properties (σ_R, E) in relation to the flow direction of the compound in a plate injected using a film gate.

Table 1: Tensile properties of the IXEF grades (DAM) (ISO 527)

Type	σ_R (MPa)	ε_R (%)	E (GPa)
1002	190	2.0	11.5
1022	255	1.9	20
1032	280	1.8	24
1501	185	2.3	13
1521	230	1.9	20
1622	235	2.6	17
2011	140	1.3	18
2030	140	1.2	21.5
2057	100	1.6	12
2530	150	1.2	20

Figure 5: Tensile strength (σ) as a function of the elongation (ε) of IXEF-type compounds

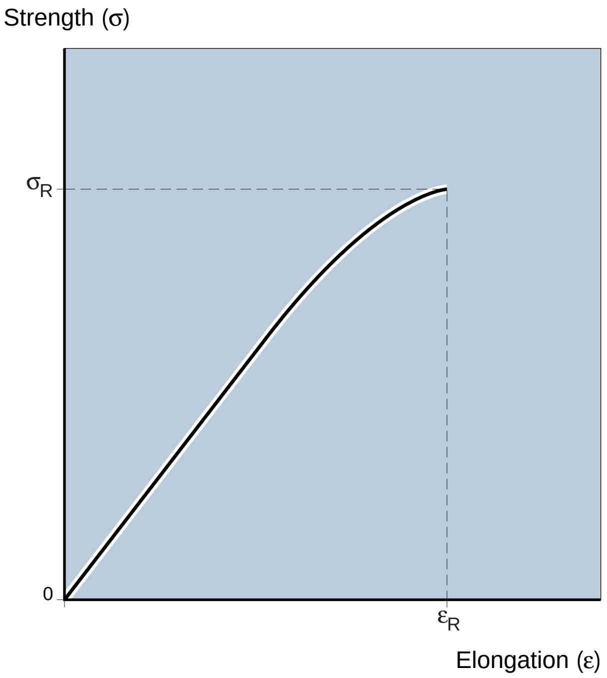


Figure 6: Plate used to measure strength as a function of the angle of application

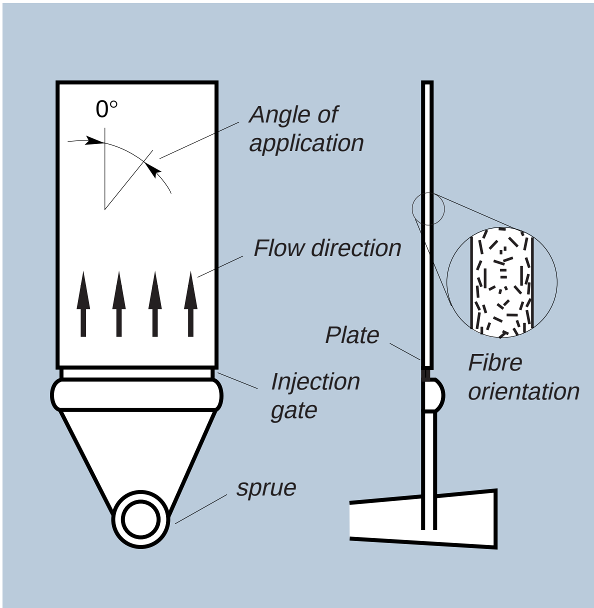


Figure 7: Tensile properties of IXEF 1022 (DAM) as a function of temperature

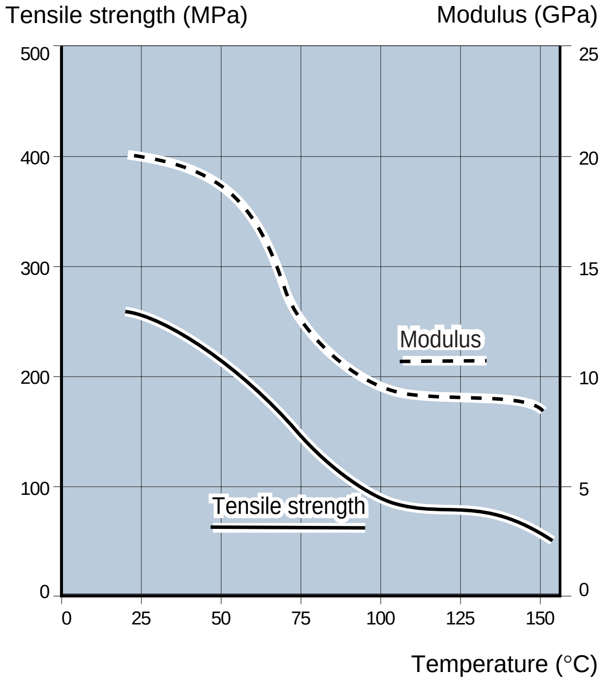
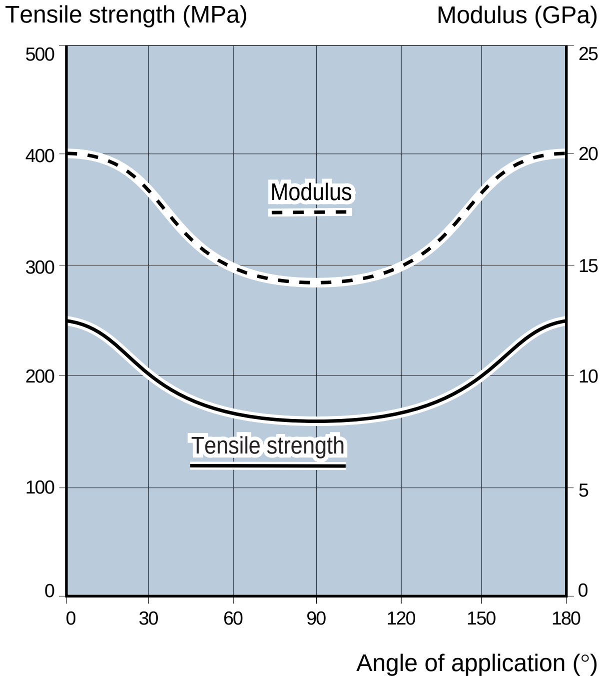


Figure 8: Tensile properties of IXEF 1022 (DAM) as a function of the angle of application



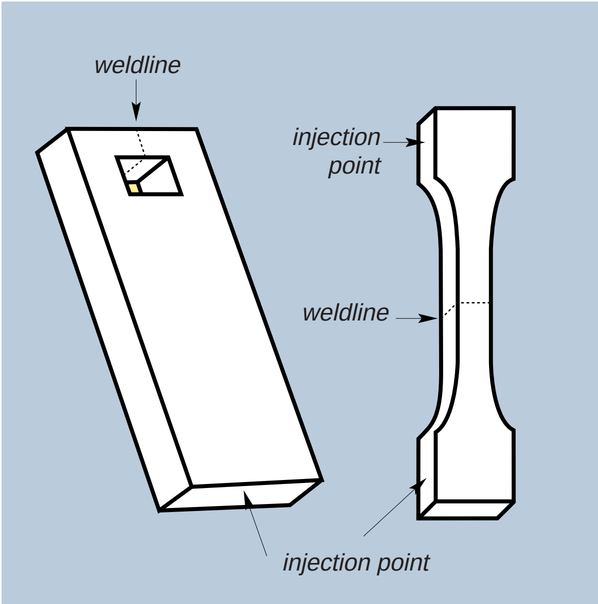
Weldlines are caused by two molten material flows meeting head on. During injection moulding, weldlines are formed by multiple gates or by the presence of inserts in the mould (figure 9). Such weldlines constitute a weak point for all glass fibre-reinforced thermoplastics, including IXEF.

The mechanical strength along a weldline can be maximised by adapting the processing conditions (see section VI.A.), allowing adequate venting (see section VI.B.2.) or using overflow tabs which make it possible to modify the flow pattern across the weldline.

The design of the part can also be modified so that the weldlines are located in areas which are subject to less stress.

In the case of the most severe weldline, the tensile strength at break is considered to be around 90 MPa for most IXEF grades. Obviously, the quality of the weldline is a decisive parameter.

Figure 9: Example of weldlines



2 - Flexural properties

The flexural tests are generally performed in accordance with the ISO 178 or ASTM D 790 standards. Two essential characteristics are measured with the flexural test: the flexural modulus and the flexural strength. In fact, this test combines compressive, tensile and shear stresses.

With regard to flexural strength, the flexural test provides values that are higher than those obtained by a tensile test. This phenomenon can be explained by a combination of several effects:

- a «stratified» structure (see section I.A.1.).
- the existence of residual internal compressive stresses in the skin and tensile stresses at the centre of the specimen resulting from the injection moulding process.
- as the result of the distribution of the stresses, a greater plasticizing effect than in a tensile test.

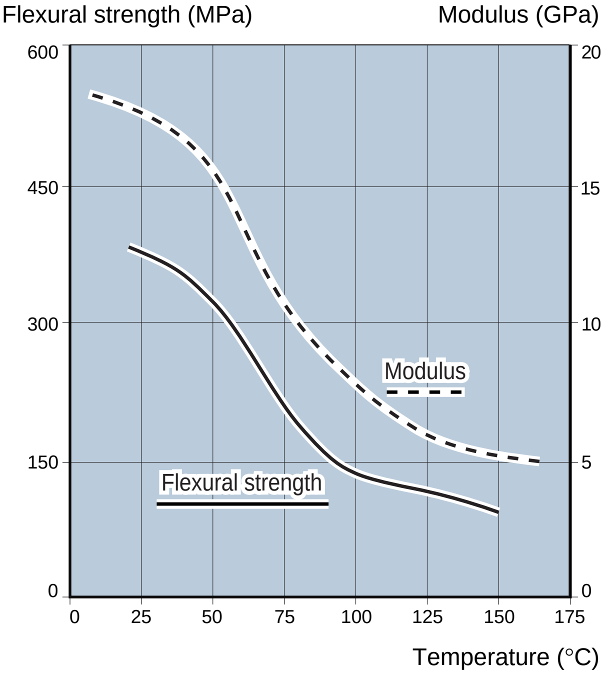
Table 2 provides the values measured on various IXEF® compounds.

Figure 10 shows the flexural strength and flexural modulus values of the IXEF 1022 grade as a function of the temperature.

Table 2: Flexural properties of
the IXEF grades (DAM) (ISO 178)

Type	σ_R (MPa)	E (GPa)
1002	280	11
1022	380	18
1032	400	21
1501	275	11.5
1521	340	18.5
1622	370	17
2011	240	16
2030	220	19
2057	170	11.5
2530	220	20

Figure 10: Flexural properties of
IXEF 1022 (DAM) as a function of temperature



3 - Impact properties

The impact tests define the deformation and breaking energies of a material or a structure when they are subject to high-speed stresses.

In the case of an IZOD impact, the mass undergoes a pendular movement at a defined speed. The specimen (notched or unnotched) is fixed at one end at the base of the pendulum stroke.

The IZOD strength, which reflects the impact resistance, is the relationship between the energy absorbed by the specimen and the projected surface area of the rupture plane. The IZOD impact resistance (notched or unnotched specimen) at 20 °C of the IXEF® compounds is presented in table 3.

Figure 11 shows the influence of temperature on the impact resistance of the IXEF 1022 compound. We find that this property remains virtually constant below the glass transition point. Above this temperature, the impact resistance increases because of the viscous state of the amorphous regions.

The IZOD test apparatus is easy to construct and quite inexpensive; it allows one to evaluate approximately the deformation and break energies.

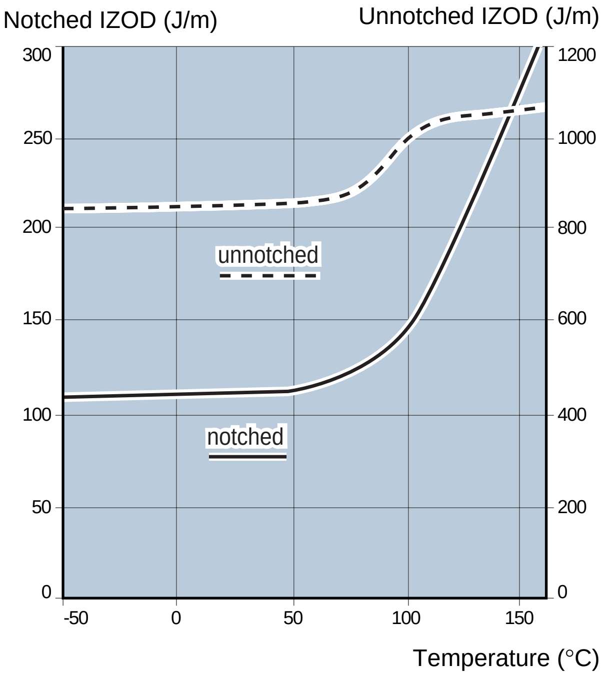
Its main drawbacks are:

- the exact trajectory is not known (variation of the speed of impact during the loading period).
- complex stresses combining simultaneous flexural and shearing actions.
- the not-insignificant importance of the geometry of the sample and boundary conditions (support conditions).

Table 3: Impact resistance of the IXEF grades (DAM) (ISO 180)

Grade	Notched specimens (J/m)	Unnotched specimens (J/m)
1002	70	460
1022	110	850
1501	60	450
1521	95	700
1622	115	1350
2011	15	560
2030	50	260
2057	35	300
2530	55	290

Figure 11: IZOD impact strength of IXEF 1022 (DAM) as a function of temperature



The technique of evaluating impact behaviour by instrumental tests of the Instrumented Falling Weight type offers the same type of advantages and disadvantages.

Nevertheless, this method can be considered as being closer to normal use conditions of the materials.

During the test, a dart of a given geometry and size falls onto the centre of a flat test plate of material fixed in a support.

The energy of the dart is adjusted by the height of the fall and the mass of the dart in order to approximately represent 10 times the rupture energy of the sample.

The maximum force during impact, the deformation at break and the resilience are given for various IXEF grades in table 4.

Table 4: Instrumented Falling Weight (thickness 2 mm)
(ASTM D 3763)

GRADE	Maximum impact force (N)		Deformation at break (mm)		Resilience (J/mm)	
	(a)	(b)	(a)	(b)	(a)	(b)
IXEF 1022	955	-	3.0	-	0.80	-
IXEF 1032	1126	1200	2.6	3.0	0.76	0.96
IXEF 1622	1020	979	4.6	6.2	1.39	1.92
PA 66 30% GF	790	-	4.4	-	0.94	-

(a) dry
(b) after water pickup (65% R.H.)

C - Long-term mechanical properties

1 - Tensile creep

The «creep» phenomenon refers to the evolution of the deformation of a material under a constant load. This evolution is the result of the visco-elastic nature of thermoplastic materials.

Reinforcement with glass fibres reduces this deformation but cannot eliminate it completely.

By their very nature, creep tests generally take a very long time. Nevertheless, it is important to be able to take into account modifications of a material's mechanical properties over time within reasonable periods. To do this, one generally relies upon modelling based on short-term tests. Such models are created on the basis of tensile tests (stress-deformation) performed at different stress speeds - in practice, between 10^{-3} and 10^{3} % per minute - as well as short-term creep tests (up to 100 hours).

This model makes it possible to evaluate the stress-strain behaviour in the range of very low deformation speeds and then to generate long-term creep curves (deformation/time) for various levels of stress.

Figures 12, 13 and 14 give the simulation results for IXEF 1022 and 1032 at 50 °C and 120 °C for several different stress levels.

Figure 12: Tensile creep of IXEF 1022 with 2 mm thickness at 50 °C

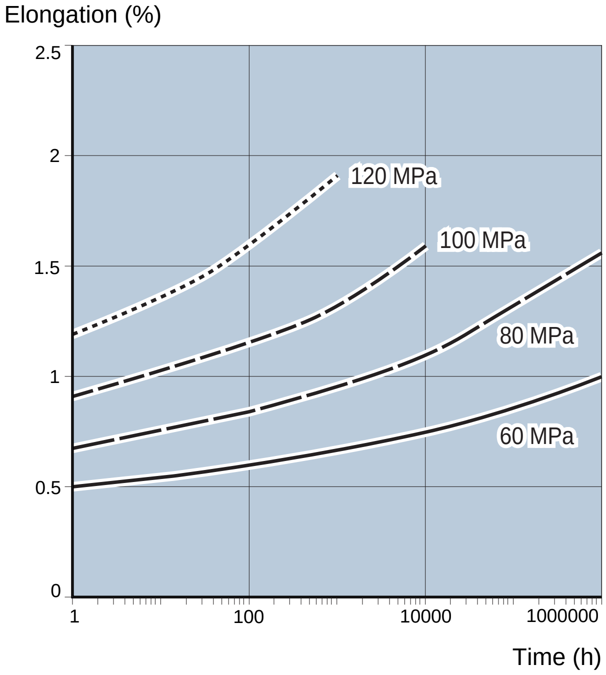


Figure 13: Tensile creep of IXEF 1022 with 2 mm thickness at 120 °C

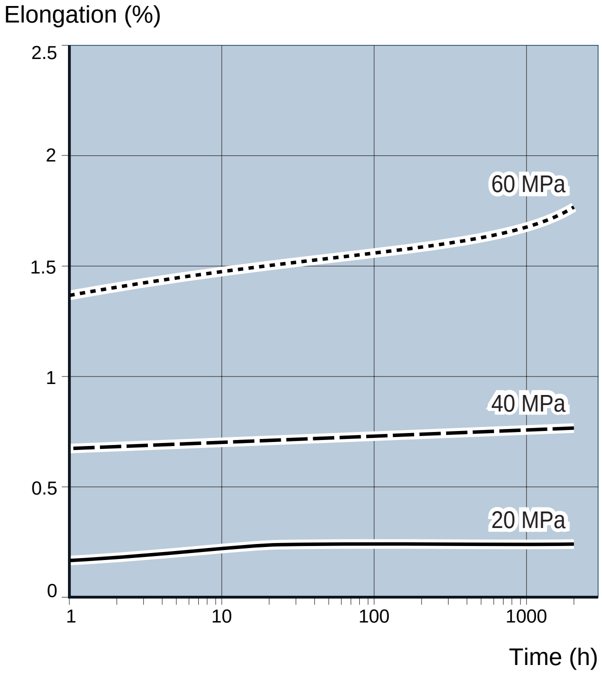
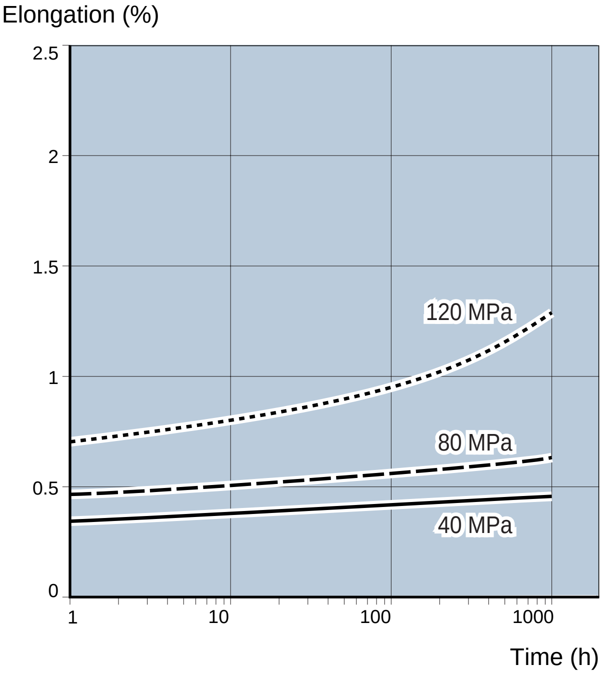


Figure 14: Tensile creep of IXEF 1032 with 2 mm thickness at 50 °C



2 - Fatigue

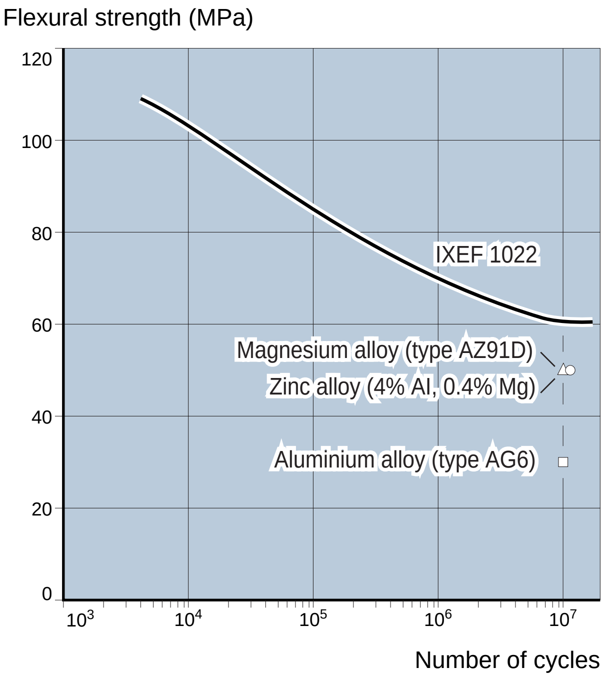
Just like metals under long-term dynamic stresses, thermoplastic materials (whether reinforced or not) will undergo the phenomenon of fatigue when the amplitude of the stress is sufficient.

Any calculation of a structural part subject to dynamic stresses must take the fatigue limit of the material into account.

The fatigue tests under alternating or undulating stress make it possible to determine the Wöhler curve of the material. The Wöhler curve represents the variation of the maximum stress amplitude as a function of the number of cycles at a given frequency.

Figure 15 presents the Wöhler diagram (undulating flexural fatigue test) for the IXEF 1022 compound compared to metals (test conditions: frequency 25 Hz - 3 point flexural test at 23 °C).

Figure 15: Flexural strength at 23 °C for undulating loading (thickness 2 mm)



A - Density

The density ρ (kg/dm^3) of IXEF compounds vary by grade, depending primarily on the amount of glass fibres and mineral filler.

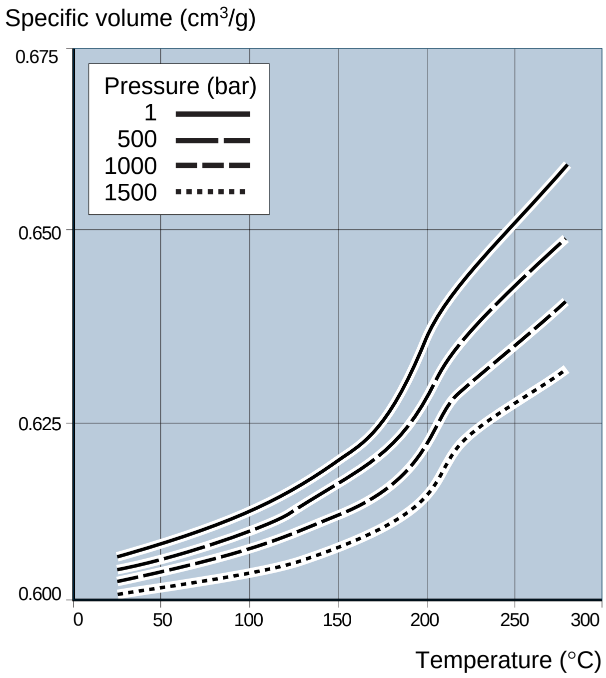
The density values of the main IXEF grades, measured at ambient temperature and atmospheric pressure, are given in table 5.

The density and thus the specific volume (1/ρ) vary as a function of the temperature. The specific volume of the IXEF 1022 grade as a function of the temperature and the pressure is given in figure 16.

Table 5: Density of the IXEF compounds (ISO 1183)

IXEF Grade	Density (kg/dm^3)
1002	1.43
1022	1.64
1032	1.77
1501	1.54
1521	1.75
1622	1.60
2011	1.58
2030	1.74
2057	1.61
2530	1.85

Figure 16: Specific volume of IXEF 1022 as a function of temperature and pressure



B - Coefficient of linear thermal expansion

Like all non-isotropic composite materials, the thermal expansion coefficient of IXEF compounds depends on the orientation of the reinforcing fibres.

The coefficients of linear thermal expansion measured at 23 °C in the longitudinal direction (α_L) and the transversal direction (α_T) of the material flow for the IXEF 1022 grade are 1.5 x 10^{-5} K^{-1} and 4.6 x 10^{-5} K^{-1}, respectively.

The thermal expansion coefficients in the flow direction α_L of IXEF compounds are similar to those for steels.

In addition, α_L varies extremely little with the temperature in the range of -30 °C to 100 °C. This offers an important advantage when using metal inserts as it prevents the development of exaggerated thermal stresses.

Table 6: Coefficients of linear thermal expansion in the flow direction for the IXEF grades (ISO 11359)

Grade	Coefficient of thermal expansion (α_L) (10^{-5} K^{-1})
1002	1.8
1022	1.5
1032	1.4
1501	1.8
1521	1.7
1622	1.5
2011	1.9
2030	1.8
2057	3
2530	2.2

Figure 17: Coefficients of linear thermal expansion for IXEF 1022

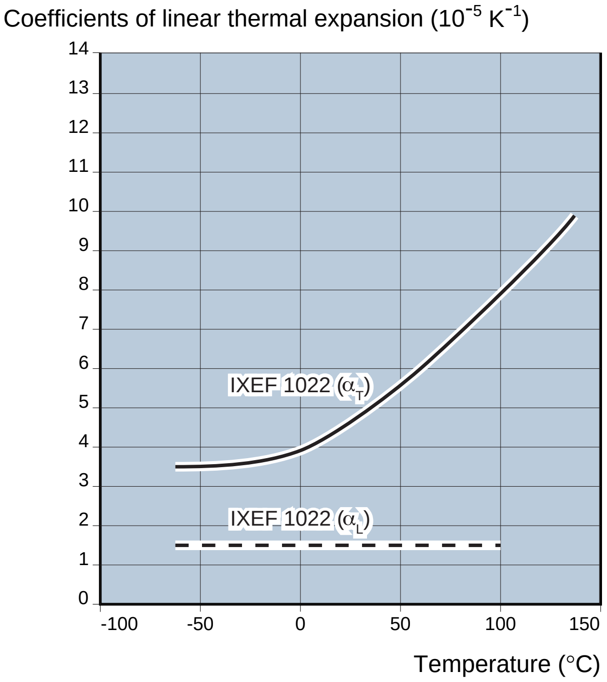
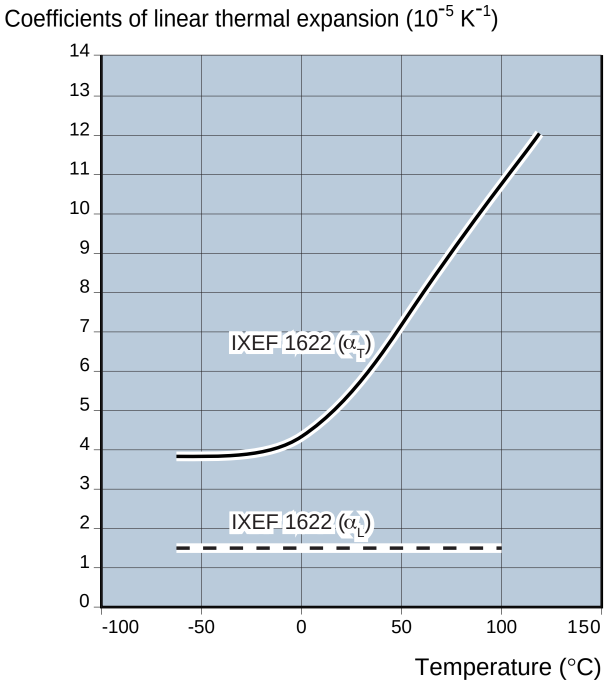
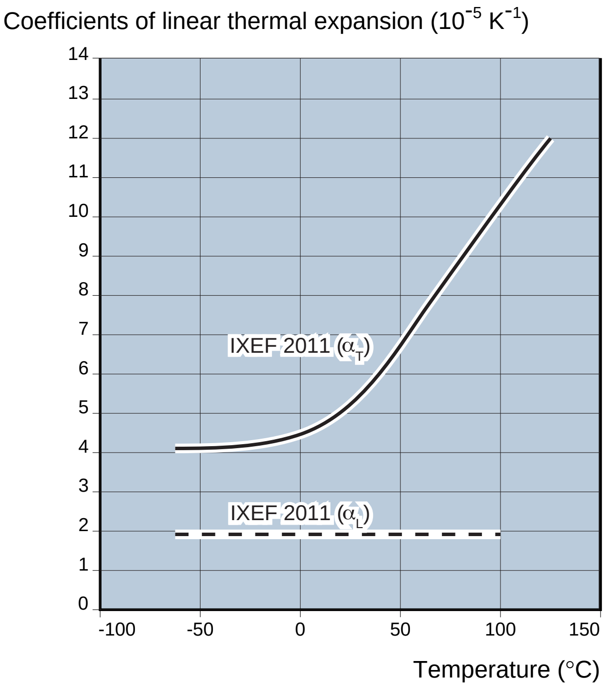


Figure 18: Coefficients of linear thermal expansion for IXEF 1622



C - Hardness

Figure 19: Coefficients of linear thermal expansion for IXEF 2011



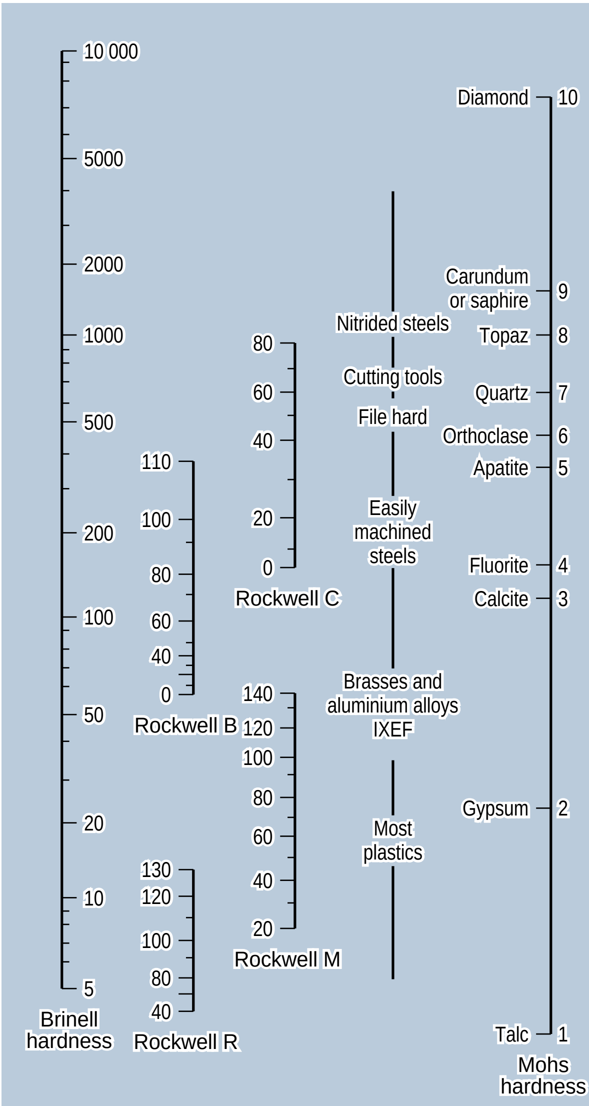
The hardness values for the IXEF 1022 grade obtained by the most commonly used test methods are given in table 7.

The relationships between the various hardness scales are given in table 8.

Table 7: Hardness of the IXEF 1022 compound

Test	Standard	Values
Ball hardness	ISO 2039/1	HRC 145
ROCKWELL hardness	ISO 2039/2	M 110
SHORE hardness	ISO 868	D 90

Table 8: Relations between hardness scales



D - Friction and abrasion

1 - Friction coefficient

A value indicative of the dynamic friction coefficient IXEF 1022/steel XC 45 was measured by test under the following conditions:

- speed: 10 m/min
- pressure: 1.15 MPa
- initial temperature: 23 °C

The dynamic friction coefficient is calculated according to the following equation

$$\mu = \frac{F}{N}$$

with:

- μ = friction coefficient
- F = measured friction load, in Newtons
- N = normal force applied to the block, in Newtons

The dynamic friction coefficients of the IXEF 1002 and IXEF 1022 grades are given in table 9.

Nevertheless, the results can vary depending on the measurement technique used. The data are only intended to allow a comparison among the various IXEF grades and other materials.

Table 9: Dynamic friction coefficients (μ) of the IXEF compounds and other materials

Grade	μ
IXEF 1002	0.36 to 0.45
IXEF 1022	0.40 to 0.53
PA 6 30% FV	0.32 to 0.42
POM 25% FV	0.49 to 0.61

2 - Abrasion resistance

The abrasion resistance values obtained with the TABER abrasion meter for the IXEF 1022 compound are:

- CALIBRASE CS17 abrasive wheel, load 1 kg, loss: 16 mg/1000 revolutions.
- CALIBRASE H22 abrasive wheel, load 1 kg, loss: 53mg/1000 revolutions.

Test done under real conditions will give more accurate information.

A - Electrical properties

IXEF compounds are increasingly used in the electrical and electronic sectors, notably for control mechanisms inside circuit breakers. This use is justified by the material's good electrical insulating properties, combined with a high dielectric strength in a wide range of temperatures and over very long periods. A description of various electrical tests is offered below. The results of these tests can be found in tables 10, 11 and 12.

1 - Volume resistivity

Volume resistivity is evaluated by measuring the electrical resistance of a sample sheet. It represents the relationship between voltage and current, the voltage between electrodes being fixed (IEC 93/167).

2 - Dielectric strength

The dielectric strength, expressed in kV/mm, is determined by the electrical voltage at which a specimen subjected to a progressively increasing alternative voltage is perforated. This yields information about the behaviour of the material when exposed to brief stresses of high electrical voltage and thus describes its insulating ability (IEC 243).

3 - Dielectric constant and dielectric loss angle

Two major characteristics are used to define the behaviour of a dielectric material in an alternating electrical field:

- the dielectric constant σ, or permittivity (IEC 250), is a measure of the capacity of the material to accumulate electrical charges when placed inside the field.
- the dielectric loss angle (tan δ) (IEC 250) is the result of a shift of the electrical polarisation in relation to the electrical field, which induces a loss of energy transformed into heat.

4 - Comparative tracking index

The comparative tracking index (CTI - IEC 112) characterizes the resistance to the creation of a conductive path of an insulating material to an electrical stress in a humid environment.

The CTI index is the maximum voltage in volts at which one can drop, between two electrodes applied to the surface of the material, 50 drops of an electrolyte (NH_4ClO, 1 % - 1 drop every 30 seconds) without forming a conducting track.

Table 10: Electrical properties of IXEF grades reinforced with glass fibres

Properties	Standards	Units	IXEF 1002	IXEF 1022	IXEF 1032	IXEF 1622
Volume resistivity	IEC 93/167	10^{15} Ω.cm	2	2	2	2
Dielectric strength	IEC 243	kV/mm	30	31	24	25
Dielectric constant (110 Hz)	IEC 250		3.9	4.6	4.5	4.4
Dielectric loss angle (110 Hz)	IEC 250		0.010	0.017	0.009	0.007
Comparative tracking index	IEC 112	V	> 400	570	600	570

Table 11: Electrical properties of fire-resistant IXEF grades

Properties	Standards	Units	IXEF 1501	IXEF 1521	IXEF 2530
Volume resistivity	IEC 93/167	10^{15} Ω.cm	2	2	2.5
Dielectric strength	IEC 243	kV/mm	31	29	23
Dielectric constant (110 Hz)	IEC 250		3.8	4.1	5.3
Dielectric loss angle (110 Hz)	IEC 250		0.010	0.012	0.023
Comparative tracking index	IEC 112	V	> 250	> 400	475

Table 12: Electrical properties of mineral reinforced IXEF grades

Properties	Standards	Units	IXEF 2011	IXEF 2030
Volume resistivity	IEC 93/167	10^{15} Ω.cm	2	2
Dielectric strength	IEC 243	kV/mm	25	35
Dielectric constant (110 Hz)	IEC 250		4.4	4.8
Dielectric loss angle (110 Hz)	IEC 250		0.007	0.025
Comparative tracking index	IEC 112	V	570	600

B - Underwriters Laboratories and IEC 216

The Underwriters Laboratories (UL) organization has tested the following properties on the major IXEF compounds:

1 - Relative thermal index (RTI)

The relative thermal index (RTI) reflects the retention of certain properties (mechanical without impact, mechanical with impact, electrical) of a material after thermal ageing. It represents the temperature at which the compound will still retain 50 % of its initial property value compared to a reference material. This temperature is extrapolated on the basis of tests of shorter duration.

The thermal index “65 °C” is given by default to a polyamide-type material not tested by the Underwriters Laboratories.

2 - UL 94

There are 4 different UL classifications described in this manual for characterizing the self-extinguishing properties of a material based on the UL 94 test standards. The UL 94 HB category is applied to materials that burn in a horizontal position. The UL 94 V-2, V-1 and V-0 classifications describe the degree of self-extinguishing ability in a vertical position, by increasing order of severity.

3 - Hot wire ignition test (HWI)

This test, characterizing the flammability of the material, indicates the time in seconds necessary to ignite a specimen around which is coiled a wire dissipating a defined power. This test yields information on the resistance of a material at abnormally high temperatures caused, for example, by an electrical defect. It can be compared with the Glow Wire Test (see III.C.3.).

4 - High current arc ignition (HAI)

This measure indicates the number of electrical arcs which could be applied at a given rate to the surface of the material before it ignites. To reflect the practical conditions, the arcs used are low voltage but high current.

5 - High voltage-arc tracking rate (HVTR)

This test, important for components used in circuits over 15 W, yields information on the speed, in inches/min at which a tracking current develops on the surface of the material under given conditions.

6 - High-voltage/low intensity arc resistance

The time in seconds required for a leakage path to form across the surface of the material when it is subjected to an intermittent high-voltage, low current arc (ASTM D 495).

7 - Comparative tracking index (CTI)

See section III.A.4.

8 - Thermal stability following the standard IEC 216

This test, completed on thermally isolated materials, is used to determine the length of time, at a given temperature, for which the flexural strength at rupture of a material is reduced to half of its initial value (half-life).

Using the appropriate statistical methods, these values can give information on the long-term behaviour of the material at other temperatures.

The UL values of various IXEF compounds are included in table 14.

A certified external laboratory has completed these tests on the IXEF 1521 flame-retardant grade, on 4 mm thick samples.

The results are included in Table 13.

Table 13: Thermal Stability of the IXEF 1521 grade following the standard IEC 216

Exposure time	Temperature evaluated	Index T° with IEC 216
5 000 h	146	TI 5 kh/146
20 000 h	126	TI 20 kh/126

Table 14: UL classification of the main IXEF compounds (2001)

PLASTICS (QMFZ2)

SOLVAY SA — **E196025**
33 RUE DU PRINCE ALBERT, 1050 BRUSSELS
BELGIUM

Material Dsg	Color	Min. Thk mm	UL 94 Flame Class	HWI	HAI	RTI Elec	RTI Mech Imp	RTI Mech Str	HVTR	D495	CTI
Polyamide (PA), designated "IXEF", furnished as pellets											
IXEF 1022/#	All	1.5	HB	0	0	130	105	105	—	—	—
		3.0	HB	0	0	130	105	120	0	5	1
IXEF 1027/#	All	1.5	HB	1	1	140	115	115	—	—	—
		3.0	HB	0	1	140	125	125	0	6	1
IXEF 1501/#	All	1.5	V-O	0	3	130	105	105	—	—	—
		3.0	V-O	0	3	130	105	120	0	7	2
IXEF 1521/#	All	1.5	V-O	0	0	130	105	105	—	—	—
		3.0	V-O	0	0	130	105	120	3	6	1
IXEF 2502/#	BK	1.5	V-O	0	1	(65)	(65)	(65)	—	—	—
		3.0	V-O	0	1	(65)	(65)	(65)	0	6	2
IXEF 2530/#	BK	0.75	V-O	0	4	(65)	(65)	(65)	—	—	—
		1.5	V-O	0	4	(65)	(65)	(65)	—	—	—
		3.0	V-O	0	4	(65)	(65)	(65)	0	5	2

 # May be followed by a four digit number.
Marking: Company name or trade name (IXEF®) and material designation on container, wrapped or molded on finished part.

Note:
The 5 short term electrical properties and their associated values are also available on Internet: ***http://www.ul.com/database***
• customer: Solvay S.A. • UL File Number: E196025

C - «Fire» classification

This section summarises the «fire» characteristics of the flame-retardant IXEF grades (IXEF 1501, 1521 and 2530).

1 - According to UL 94

The classification of the main IXEF grades under the UL 94 standard is given in table 15 (see section III.B.).

2 - Limiting oxygen index

The limiting oxygen index (LOI) is a measure of the flammability of a specimen placed in an enclosed area flooded by a mixture of gaseous oxygen/nitrogen in controlled proportions. Combustion is ignited by a pilot flame in contact with the upper end of the specimen. The greater the concentration of 0_2 in the gaseous mixture that is required in order to keep the specimen burning, the better the material's flame retardancy.

Table 16 gives the LOI values for several IXEF grades.

Table 15: UL 94 classification

Grade	Thickness (mm)	UL 94 classification
IXEF 1022	1.5	HB
	3.0	HB
IXEF 1501	1.5	V-0
	3.0	V-0
IXEF 1521	1.5	V-0
	3.0	V-0
IXEF 2530	0.75	V-0
	1.50	V-0
	3.0	V-0

Table 16: Limiting Oxygen Index

Grade	Limiting Oxygen Index (%)
IXEF 1022	25
IXEF 1032	25
IXEF 1501	31.5
IXEF 1521	31.5
IXEF 1622	25
IXEF 2530	38.5

3 - Glow wire test

The glow wire test is performed to simulate the thermal stresses produced by heat sources such as overloaded resistance in an electrical circuit. An electrically heated wire (whose temperature is known) is placed in contact with a vertical plate of the material during a 30 second period. In addition to the height of any flame, one records the extinguishing time and the presence (if any) of burning drops after having withdrawn the wire. The results are included in table 17.

Table 17: Resistance to glow wire (according to the IEC 60695-2-11)

Grades	Temperature of the glow wire (°C) for 2 extinguishing times	
	time = 5 s	time = 30 s
IXEF 1022	650	750
IXEF 1032	750	750
IXEF 1521	960	960
IXEF 2530	960	960

4 - According to SNCF-RATP standards

The Société Nationale des Chemins de Fer (SNCF - the French national rail company) classifies the materials used in its passenger wagons by their reaction to fire (classification M and I) and by the characteristics of the fumes released (classification F).

According to measurements performed by Belgium's Institut Scientifique de Service Public, the IXEF 1521 grade is classified M3 (according to the FD P 92 507 standard), I3 (according to the NF F 16-101 standard), F3 (according to the GTM 000 standard).

5 - Aeronautics

The compounds IXEF® 1501 and 1521 have been tested by independant laboratories and have attained the classification conforming to the following standards.

- IXEF 1521 and 1501 conform to
  std. FAR 25.853 (b) mod 2532

- IXEF 1521 conforms to
  std. FAR 25.853 (d)
  std. ABD 0031

1 - Water resistance

The resin used in all IXEF compounds, contains amide functions. As with all polyamides (nylons), water acts as a plasticizer forming reversible complexes with the amide functions.

The speed (kinetics) with which IXEF compounds absorb water (C(t) - concentration of absorbed water as a function of time) depends on several parameters:

- D: diffusion coefficient (which depends on the temperature - table 18)
- C_S: water concentration at equilibrium under the conditions being considered, i.e. the relative humidity (RH). The value of C_S as a function of the RH rate is given in figure 20.
- S, V: surface area and volume of the specimen

The kinetics of water absorption can be described mathematically by Fick's Law:

$$\frac{C(t)}{C_s} = 2 \cdot \frac{S}{V} \cdot \sqrt{\frac{D.t}{\pi}}$$

The chart (figure 21) graphically represents this relationship.

Table 18: Diffusion coefficient of the water in various engineering compounds

Temperature (°C)	Diffusion coefficient (10^{-6} cm^2/h)		
	IXEF 1022	PA 66 GFR	PA 6 GFR
20	1	7.2	14.4
40	5.2	—	—
60	28	—	—
90	210	—	—
100	370	—	—

Note:
The coefficient of IXEF increases very slight with the level of reinforcement.

Figure 20: Water content of IXEF (1022, 1032, 1622) at equilibrium as a function of relative humidity

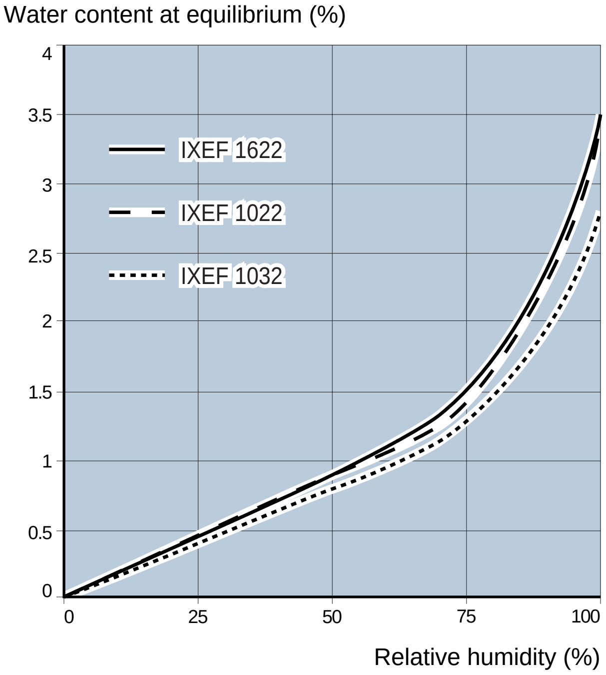
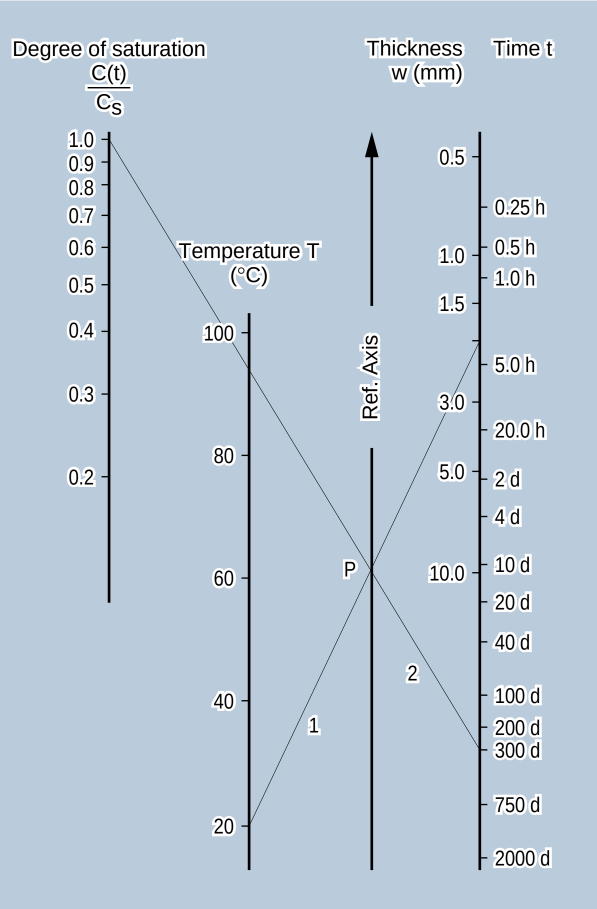


Figure 21: IXEF 1022 - FICK's chart for determining the state of parts in contact with water or water vapour



There are several important consequences of this water absorption which must be taken into account:

- a reduction of mechanical properties due to plasticizing (figures 22, 23 and 24).
- a dimensional change due to the swelling caused by water absorption (figures 21 and 22). This can be aggravated by the presence of glycol- or methanol-type additives.
- a decrease in the glass transition temperature (table 19). This can lower the creep resistance of the IXEF compounds and can also cause a post-crystallization of the resin injected into a mould whose temperature was below 120 °C (see section VI.A.2.). This will cause deformation of the part.

It is thus very important to carefully test, under the actual use conditions, every IXEF polyarylamide part which will be in continuous contact with water, in order to verify the absence of problems.

Table 19: Glass transition temperature for the IXEF 1022 grade

Product	Glass transition temperature (T_g) (°C)		
	Beginning	Middle	End
IXEF 1022 dry	50	85	110
IXEF 1022 saturated with water	7	25	80

Figure 22: IZOD impact strength of IXEF 1022 and 1622 as a function of their water content

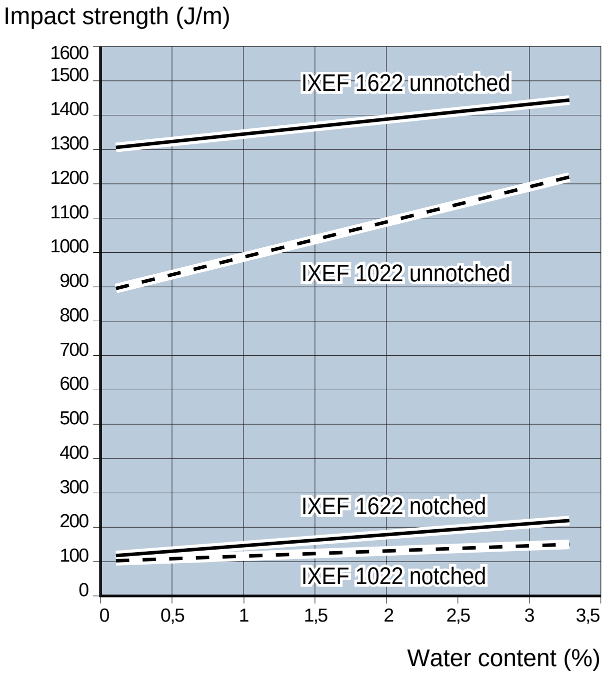


Figure 23: Tensile strength at equilibrium of IXEF 1022, 1032 and 1622 as a function of relative humidity

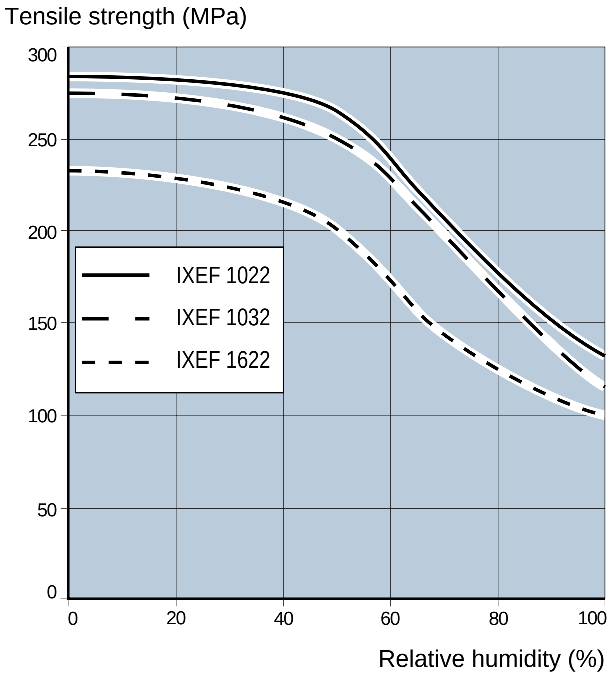


Figure 24: Tensile modulus at equilibrium of IXEF 1022, 1032 and 1622 as a function of relative humidity

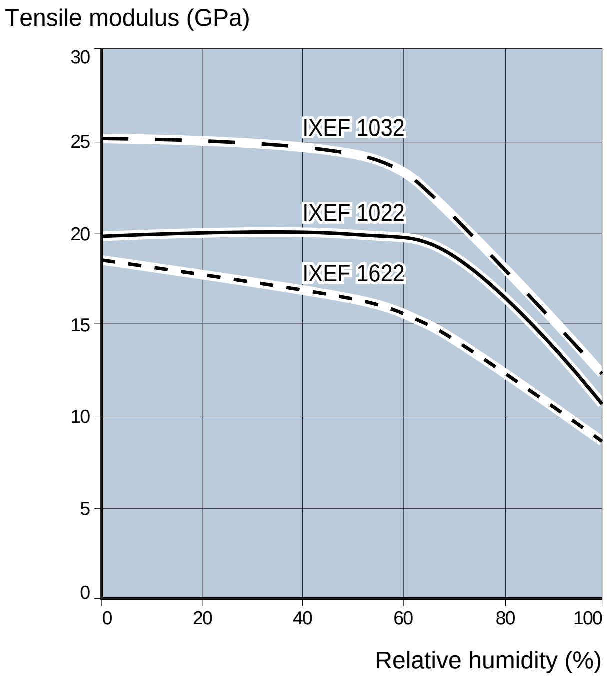
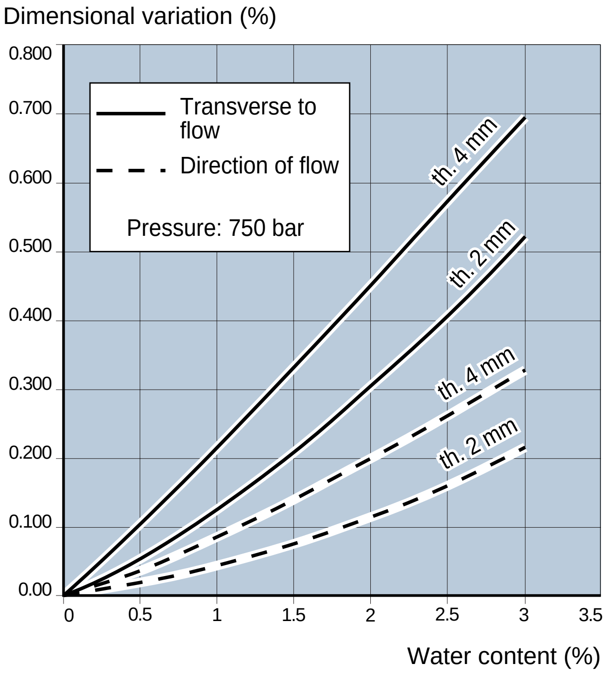


Figure 25: Dimensional variation of a 40x40x2 mm specimen and a 40x40x4 mm specimen of IXEF 1032 as a function of their water content



2 - Resistance to automotive fluids

In general, IXEF compounds display good resistance to the various fluids encountered in the automotive industry. Thanks in part to this good resistance, IXEF compounds have found many uses in the automotive market:

- rocker box covers (IXEF 1022)
- fuel pump bodies (IXEF 1022)
- door handles (IXEF 1022 and 1023 and 1025)
- headlamp components (IXEF 2011 and 2057)
- external rear-view mirror support (IXEF 2030 and 2035)
- lubricating racks (1022)
- clutch cylinders (1027)

Resistance to gasoline

The variations in the flexural properties and in the weight of specimens made of IXEF 1022 polyarylamide, polyamide PA 66 30 % GF and PA 6 30% GF submerged in a mixture of gasoline and ethanol at 40 °C are given in figures 26, 27 and 28. The proportions of the mixture are 80 % gasoline, 20 % ethanol by weight.

Figure 26: Chemical resistance of IXEF 1022 to a gasoline-ethanol mixture at 40 °C: flexural strength

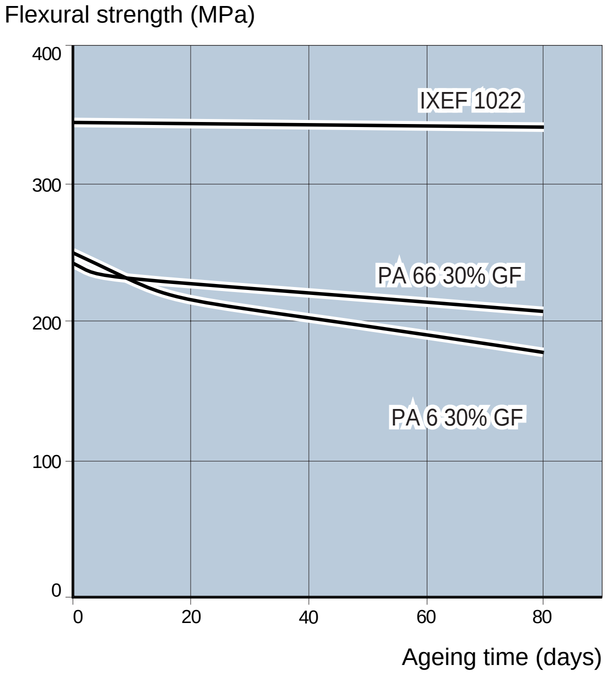


Figure 27: Chemical resistance of IXEF 1022 to a gasoline-ethanol mixture at 40 °C: flexural modulus

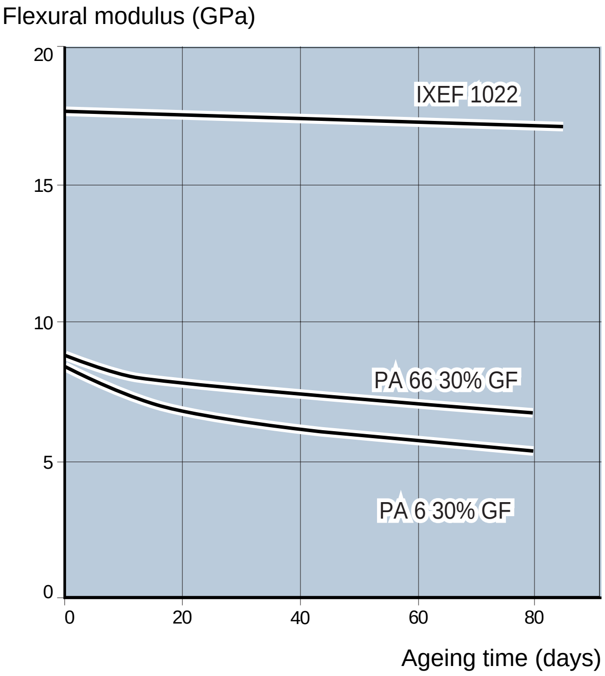
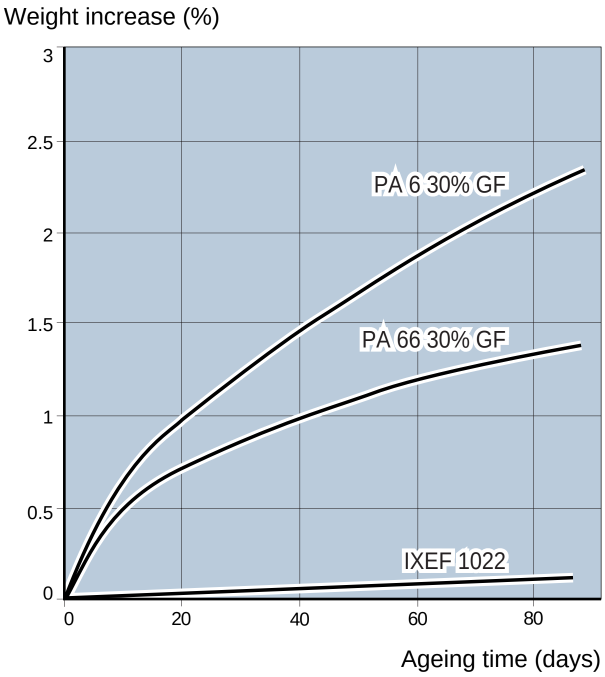


Figure 28: Chemical resistance of IXEF 1022 to a gasoline-ethanol mixture at 40 °C: weight increase



Resistance to motor oils

The variations in mechanical properties and in the weight of specimens made of IXEF 1002 polyarylamide submerged in motor oil at 120 °C are shown in figures 29 and 30.
Oil characteristics: SAE 10W30.

Figure 29: Chemical resistance of IXEF 1002 to a motor oil at 120 °C: tensile properties

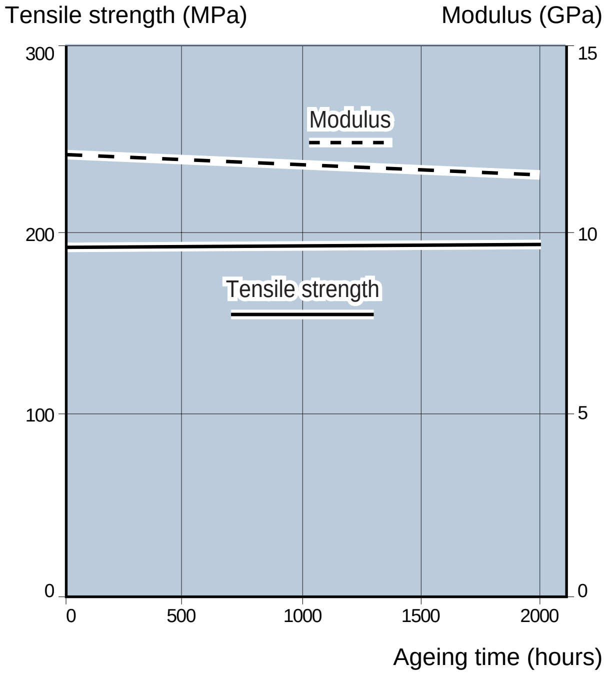
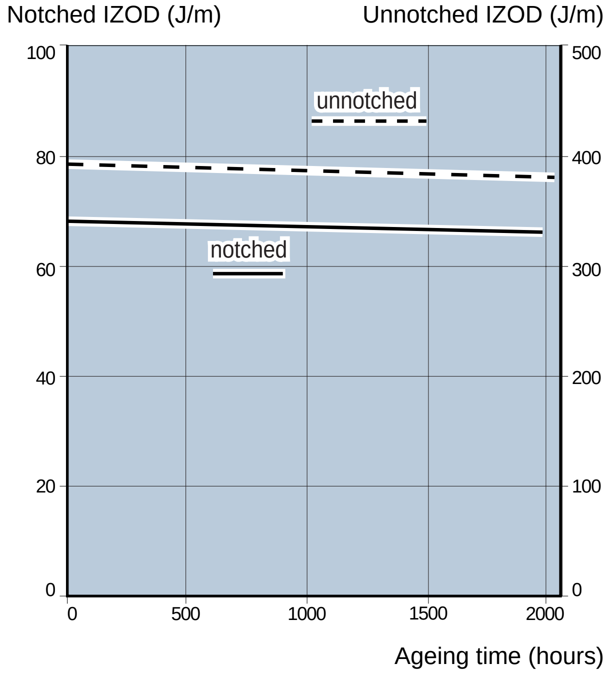


Figure 30: Chemical resistance of IXEF 1002 to a motor oil at 120 °C: IZOD impact strength



B - Various reagents

Table 20 compares the behaviour of the IXEF 1002 compound with that of several other thermoplastics after contact with various liquids.

In general, IXEF compounds display a good resistance to chemical reagents. However the amide function in the resin matrix makes them sensitive to certain chemicals.

It is very rapidly degraded by:

- powerful oxidants (0_3, Cl_2, ...)
- highly concentrated mineral acids (H_2SO_4, HNO_3, ...)

It is degraded at ambient temperature by:

- diluted mineral acids
- acetic acid and formic acid

It is degraded at high temperature by:

- strong bases (KOH, NaOH, ...)
- most organic acids
- formaldehyde.

By contrast, according to laboratory tests performed at 60 °C (or at boiling temperature if below 60 °C), IXEF polyarylamide is not affected by aliphatic hydrocarbons (white spirit, kerosene), aromatic hydrocarbons (benzene, toluene), ketones, esters, ethers, weak bases, aldehydes (except for formaldehyde) or alcohols (except for the light alcohols which plasticize polyamides like water does).

Comment:

The indications of resistance to chemical reagents and to solvents included in this section are helpful for recommending (or advising against) use of the glass fibre-reinforced IXEF compounds. When using a part made of IXEF polyarylamide in the presence of chemical agents, it is always necessary to verify the stability of the part in contact with these agents under the anticipated use conditions (including stress).

Table 20: Chemical resistance of various thermoplastics after ageing for 30 days at 23 °C in different chemicals

Reagents \ Polymers	IXEF 1002	PA 6 GFR	PA 11 GFR	PBTP GFR	PC GFR	OPP GFR
NH_4Cl, satured solution	—	—	0	+	0	0
Na_2CO_3, satured solution	+	—	0	+	0	0
$CaCl_2$, satured solution	0	0	+	+	0	0
Methanol	—	—	—	+	—	—
Propanol	+	—	—	+	+	0
Benzyl alcohol	+	0	0	+	—	0
Toluene	+	+	0	+		
Formaldehyde	0	—	—	+	+	0
Methylene chloride	+	—	—	—		
Perchloroethylene	+	+	—	+	—	
Acetone	+	+	—	0	—	—
Methyl ethylene	+	+	—	0		0
Benzene	+	+	—	+		
Trichloroethylene	+	0	—	—		
Methyl acetate	+	0	—	+	—	
Tetrahydrofuran	+	+	—	0		
Olive oil (at 40 °C)	+					
Brake fluid	+	+	+	+	—	0
Gasoline + CH_3CH_2OH (80/20)	+	—	—	+		
Gasoline + CH_3CH_2OH (90/10)	+	—	—	+		
Super gasoline	+	0	+	+	0	—

Selection criterion:

+: variation of weight below 1%, and variation of breaking strength less than 10%.
0: only one of the two criteria met.
—: neither of the 2 criteria met.

C - Thermal ageing

Ageing at high temperatures in an inert atmosphere (e.g. in motor oil) does not significantly alter the properties of IXEF compounds (at least for periods lasting several months). By contrast, ageing at high temperature in air results in a surface oxidation and a loss of properties over time.

During this ageing, there appears in succession:

- a surface oxidation several microns deep, leading to yellowing and micro-cracking
- core oxidation, the rate of which is limited by the diffusion of oxygen, leading to a reduction of flexural strength and elongation
- ultimately, destruction of the oxidized specimen throughout its thickness. Dicke.

The thickness of the wall plays a fundamental role in the loss of mechanical properties, since it determines the concentration of the oxygen at the core of the part.

The thermal ageing of the IXEF 1022 grade is expressed in figure 31 by the time required for the tensile strength and tensile impact values to fall to 50 % of their initial values (DAM), plotted as a function of the test temperature.

The laboratory results obtained by ageing different IXEF grades at high temperature in a ventilated oven are summarized in figure 32.

Figure 31: Half-life of tensile specimens (3.2 mm) made of IXEF 1022 in accordance with the UL 746B method

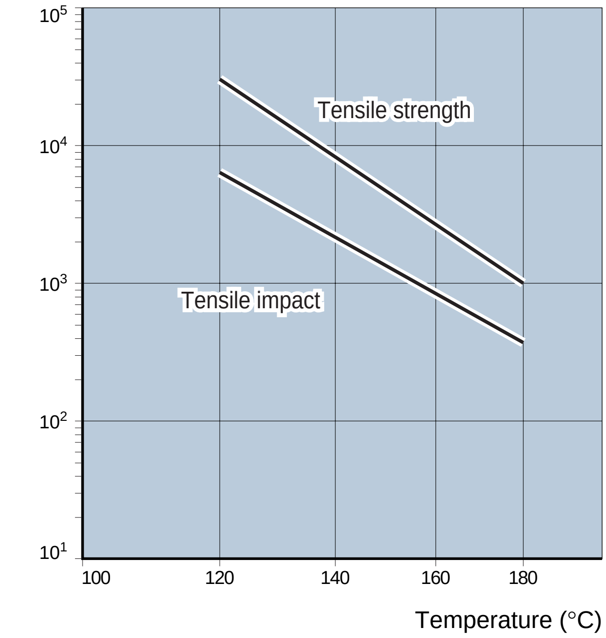
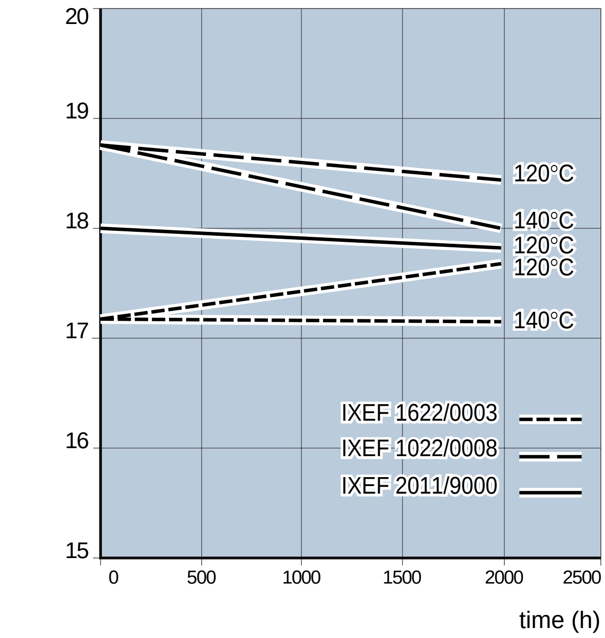


Fig. 32: Thermal ageing in a ventilated oven at 120 °C and 140 °C: flexural modulus



D - Natural ageing

Specimens were exposed at the Hiratsuka Test Station over a 4 year period (average temperature 23 °C, average precipitation 130 mm/month, solar radiation of 500 kJ/year/cm^2).

The results obtained on 3.2 mm thick specimens show:

- a reduction of flexural strength of around 30 %, corresponding essentially to reversible plasticizing by water (figure 33)
- unchanged modulus
- an increase of roughness due to surface photo-oxidation.

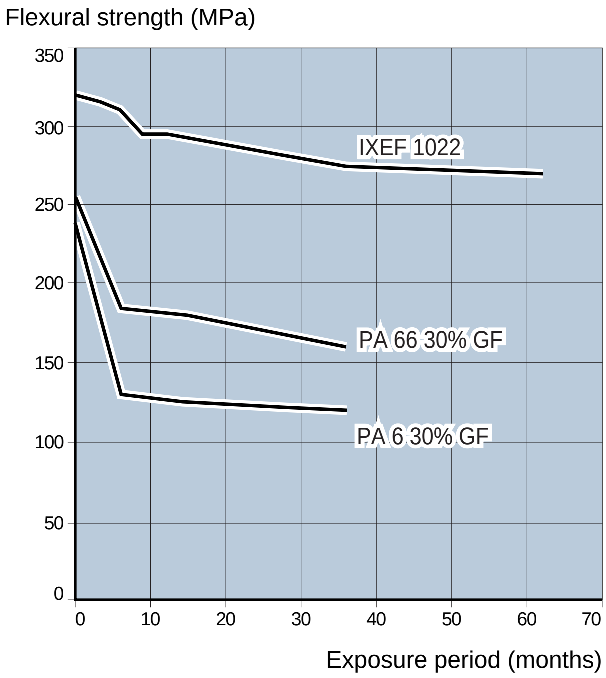
The surface of a part made of IXEF polyarylamide is composed of a layer of pure polymer around one µm thick. This layer makes it possible to obtain a very high gloss finish. If photo-oxidation occurs, an alteration of this layer can cause increased surface roughness (eg. from surface rugosity of Ra = 0.15 µm to Ra = 0.2 µm). Oxidation, affecting a minute quantity of matter, thus leads to a change in surface appearance (gloss and colour) without significantly affecting the mechanical properties of the material.

In choosing the surface appearance of parts subject to U.V. radiation, it is therefore useful to avoid excessively low roughnesses which will be sharply affected by even very superficial photo-oxidation.

Certain IXEF grades have been developed to increase their resistance to the photo-oxidation phenomenon.

The variation of surface rugosity in these grades under UV is notably improved.

Figure 33: Natural ageing: flexural strength



E - Accelerated ageing

In order to evaluate the effects of ageing within reasonable delay, the tests for accelerated ageing were carried out on IXEF samples using the test method DIN 53387/1.

The change in properties of the products after 2000 hours of exposure are shown in table 21.

Table 21: Accelerated ageing - Flexural properties of IXEF grades after 2000 hrs of exposure (DIN 53387/1)

Grades	Residual modulus (% initial value)	Residual strength (% initial value)	Residual elongation at break (% initial value)
IXEF 1022	97	90	94
IXEF 1622	96	93	95
IXEF 1028	98	96	95

F - Food and water contact approvals

This section describes the various food and water contact approvals obtained for the natural IXEF 1022/0006 and black IXEF 1022/9006 compounds (the last 4 figures correspond to the food contact grade).

It is important to note that these tests were performed on laboratory specimens. They do not replace tests on finished parts under actual use conditions performed by the end-user.

1 - NSF 51 (USA)

The American National Sanitation Foundation (NSF) tested the IXEF 1022/0006 IXEF and 1022/9006 compound according to its method 51 - Plastic materials and components used in food equipment. These grades have received NSF 51 approval for contact with dry and aqueous food products up to a temperature of 100 °C.

2 - BS 6920 - Tests of effect on water quality (UK)

The IXEF 1022/0006 and IXEF 1022/9006 grades were tested by the Water Quality Centre (UK) in accordance with the BS6920 method at 85 °C. According to these results, the Water Byelaws Scheme (UK) finds that these compounds can be used in contact with drinking water.

3 - European standards

The monomers used for the manufacture of the resin based on the polymer (PA MXD6) are included in the positive list of the European Union (Directive 90/128/EEC). After extraction in distilled water or olive oil for 10 days at 40 °C, the concentration of monomers which have migrated meets the limits described in the Directive 90/128/EEC.

The global migration test is designed to determine the total quantity of product migrating from the plastic material into the simulant (extraction liquid) with which the material is in contact. This quantity must be below the limit set in Directive 90/128/EEC. The IXEF 1022/0006 grade meets this criterion when the simulant is distilled water or olive oil. The criterion is not satisfied when acetic acid (3 % in water) or ethanol (15 % in water) is used as a simulant.

G - Other certifications

1 - Microbial cultures

The German BAM organisation (Bundesanstalt für Materialforschung und -prüfung) tested the IXEF 1501 and 1521 grades according to the MIL-STD-810 method (American military standard) using the following fungi: chaetomium globosum, penicillium funiculosum and aspergillus flavous, niger and versicolor. No signs of microbial growth were observed.

2 - Automotive certifications

IXEF compounds are used in various automotive applications by several car manufacturers (PSA, GM, VW, Fiat, Renault, Daimler Chrysler, Ford, BMW, ...). Some of these manufacturers have approved several IXEF compounds and given them a code which is listed in their plastic materials approval handbooks.

The following list gives the codes of these IXEF grades:

OPEL	:	IXEF 1022/9007 QK 000686 IXEF 1002 QK 000689
FIAT	:	IXEF 1022/0003 PA-A 220.100 IXEF 2010/X914 PA-A 130.35 IXEF 2030/X003 PA-A 220.50
BMW	:	IIXEF 1002 PAA-GF 30 IXEF 1022 PAA-GF 50 IXEF 1032 PAA-GF 60 } BMW N 601 00.0

3 - ISO 9002

The resin used in IXEF compounds is polymerized in a ISO 9002 certified facility.
(Certificate 92038C, 4th May 2001, delivered by AIB-VINÇOTTE (B)).

Compared to other thermplastics, IXEF compounds offer several interesting advantages:

- a very high tensile modulus (up to 24 GPa for some grades, e.g. IXEF 1032)
- a very good surface finish, even for filler contents of 60 % (IXEF 1032). Due to their excellent surface appearance, the IXEF 2011 and IXEF 2057 grades (mineral fillers only) are used in the manufacture of headlamps.
- excellent creep resistance
- easy processing. The spiral length of the IXEF 1022 grade (50 % glass fibres) is close to that of a polyamide 6.6 filled with 30 % glass fibres.
- a very low water pickup which does not necessarily require granule drying prior to injection moulding.

Table 22 compares the physical and mechanical properties of IXEF compounds with those of other glass fibre-reinforced compounds (data purely indicative).

Table 22: Comparison of the mechanical properties of various glass fibre-reinforced thermoplastics

Properties	Units	IXEF 1022		IXEF 1032		PA 66 50% GF		PA 6 50% GF		PBT 30% GF
Density	g/cm^3	1.64		1.77		1.55		1.55		1.68
Water absorption (24h/20 °C)	%	0.16		0.13		1.2		1.5		-
Water pickup at saturation (23 °C)	%	3.3		2.8		4		4.8		0.45
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	
Tensile										
Max. strength	MPa	255	190	280	215	230	180	235	160	135
Modulus	GPa	20	17	24	21	17	1.3	16	11	11
Elongation	%	1.9	1.8	1.8	1.7	2.5	3.5	3	5.5	2.2
Flexural										
Max. strength	MPa	380	300	400	305	-	-	330	260	190
Modulus	GPa	18	15	21	18.5	-	-	13	10	11
HDT/A	°C	230		230		250		215		210

(a) dry
(b) after water pickup (65% R.H.).

B - Light alloys

For many applications the mechanical properties of IXEF compounds are sufficient to replace light alloys (aluminium, magnesium, MAZAK). Among glass fibre-reinforced thermoplastics, the modulus of the IXEF grades is probably closest to that of the light alloys.

Compared to light alloys, IXEF compounds offer several advantages:

- the moulding of IXEF polyarylamide parts does not require subsequent machining.
- the surface finish of IXEF polyarylamide parts is often better than that of light alloys.
- the maximum stress that an IXEF 1022 test specimen can withstand in an undulating flexural fatigue test is higher than that of light alloys.

Table 23 compares the mechanical and physical properties of IXEF 1022 and several grades of light alloys.

Table 23: Comparison of IXEF compounds and light alloys (data purely indicative)

Properties	Units	IXEF 1022	IXEF 1032	Cast metal alloys of Al		of Zn	of Mg
				AG6	AS9U3	MAZAK *	AZ91D
Density Melting temperature Thermal conductivity Heat capacity	g/cm^3 °C W/m.K J/g.K	1.64 235 0.4 1.7	1.77 235 0.4 1.6	2.7 660 110 1	2.9 660 95 1	6.6 390 110 0.4	1.83 470 51.2 -
Max. tensile strength E-modulus Elongation before deformation	MPa GPa %	255 20 1.7	280 24 1.7	220 65 0.2	200 72 0.2	280 85 0.2	235 45 3
Cyclical flexural strength at 10^7 cycles	MPa	70	100	~ 35	~ 35	~ 50	~ 50

** at 4% Al; 0.04% Mg*

A - Injection moulding

Table 24 summarizes the processing parameters recommended for IXEF compounds. The following sections contain a more extensive discussion of these conditions.

Table 24: Injection moulding parameters for IXEF compounds

Temperatures	
Cylinder temperature (°C)	
• Feed zone	250 - 280
• Compression zone	250 - 280
• Homogenisation zone	250 - 280
• Nozzle zone	260 - 290
Temperature of the material (measured on purged material) (°C)	
• Standard grades (e.g. IXEF 1022, 2030)	280
• Flame-retardant grades (e.g. IXEF 1521, 2530)	< 270
• Impact modified grades (IXEF 1622)	< 270
Mould temperature (°C)	> 120
Plasticizing	
• Peripheral screw speed (m/min)	3 - 10
• Hydraulic back pressure (bar)	0 - 10
Injection	
• Injection speed	high
• Material injection pressure (bar)*	500 - 2500
Holding and Cooling	
• Material holding pressure (bar)	300 - 1500
• Holding time* (s)	3 w *(w = wall thickness in mm)*
• Cooling time* (s)	2.5 w^2 *(w = wall thickness in mm, w ≥ 2 mm)*
** indicative*	

More details are available on the internet address: **www.solvay.com/IXEF**

1 - Water content and drying

IXEF compounds are delivered in granular form (bulk density around 0.7 g/cm^3) usually in 25 kg bags or 1 tonne octabins. Both package types are sealed and water-tight, so it is not necessary to dry the product before processing. If the packaging is left open in a humid atmosphere or if regrind is used, the product absorbs moisture at a rate which depends on the environmental conditions. For example, if a layer of granules 2 cm thick left at 20 °C in an atmosphere with a 65 % relative humidity, it will absorb water at a rate illustrated in figure 34 (IXEF 1022).

If the water content of the granules exceeds 0.3 % (e.g. after 4 hours under the conditions mentioned above), it becomes necessary to dry the product.

One can use hot-air drying at 80 °C for 12 hours. A drier with dehumidified air will of course be more effective. To avoid surface oxidation (which causes yellowing), air temperatures above 90 °C should not be used.

Drying under vacuum is not only intrinsically more effective, but also makes it possible to work at higher temperatures. We recommend using a temperature of 120 °C. Under these conditions, for a layer of granules 3 cm thick and a reduced pressure of P = 2-3 mm Hg, the drying rate described in figure 35 is observed.

Figure 34: Water pickup of IXEF 1022 granules

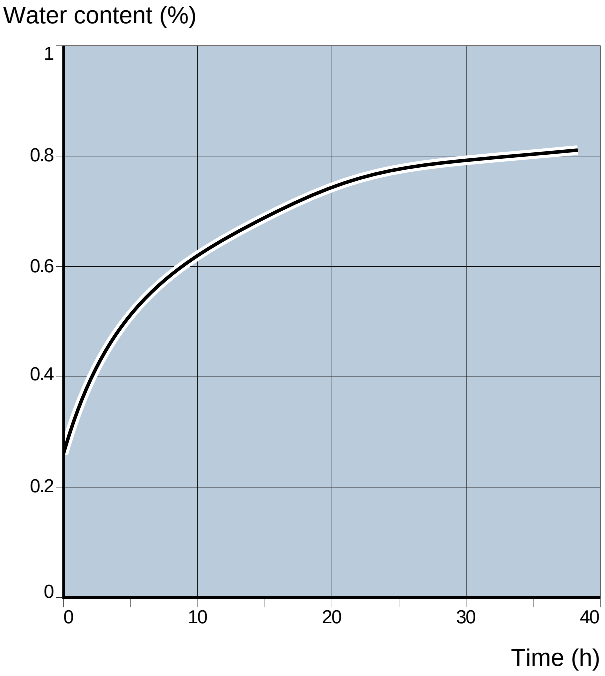
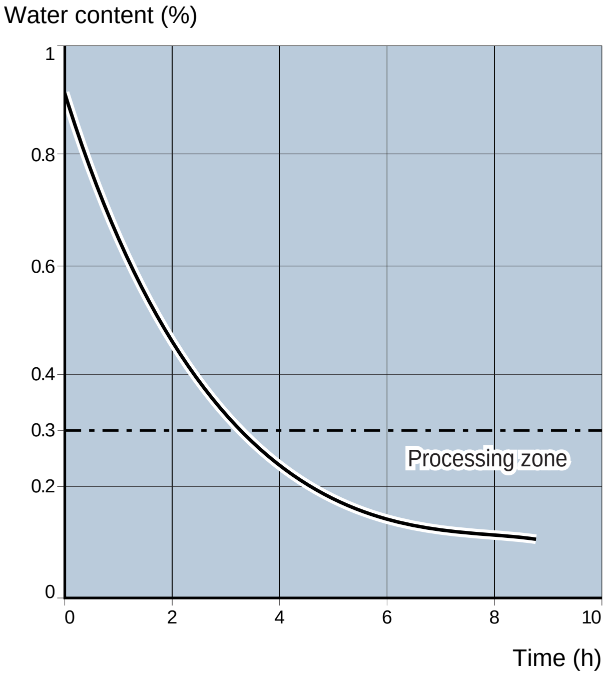


Figure 35: Moisture loss during vacuum drying (at 120 °C) of IXEF 1022



2 - Equipment temperature

As discussed in Chapter I, the resin matrix of IXEF compounds, polyarylamide is a semi-crystalline polymer. The physical properties, the dimensional precision of the parts and the properties at high temperatures are determined by the level of crystallinity which is actually attained. It is thus very important to obtain the maximum crystallinity during the processing of the product.

A semi-crystalline material can only crystallize at a temperature above its glass transition temperature. The minimum temperature of the material during injection corresponds to the temperature at the surface of the mould cavity.

The glass transition temperature of the resin used in IXEF compounds is 85 °C. It is thus necessary to use a mould temperature that is well above 85 °C. Tests conducted on a 3 mm thick specimen have made it possible to measure the relative level of crystallinity at the core and at the surface of the part, as a function of the mould temperature (figure 36). These results show that a mould temperature of the order of 120 °C is necessary (above all for low thicknesses) in order to maximize the crystallinity level during processing.

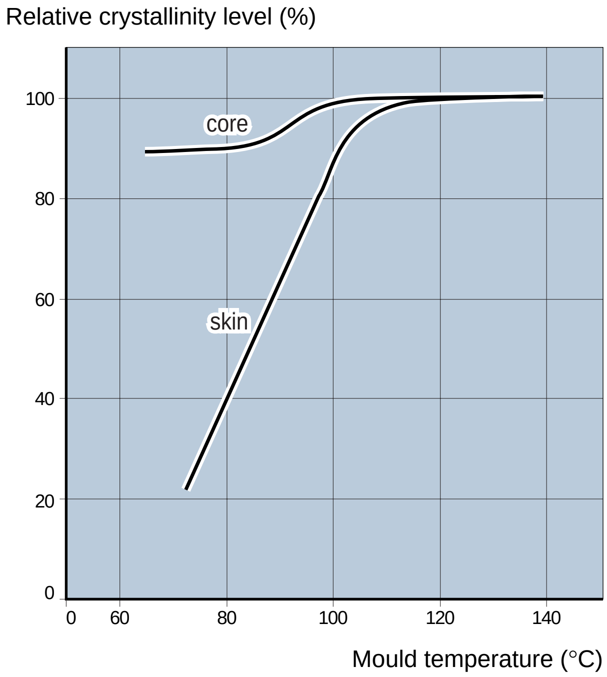
There is a simple analytical test which can determine if the part has been injected with the right mould temperature: the DSC analysis (Differential Scanning Calorimetry).

A small piece of the injected part is slowly heated (20 °C per minute) and the amount of heat liberated is registered (see page 7, figures 3 and 4).

If the product has not attained its maximum level of crystallisation, it will undergo post-crystallisation during the heating phase.

This crystallisation process liberates heat and a negative peak (exothermic around 80-120 °C) appears on the DSC graph.

Figure 36: Crystallinity as a function of the mould temperature



A part that does not reach the maximum crystallinity level during processing (mould temperature too low) can suffer from the following defects:

- **The water pickup of parts moulded in a cavity whose temperature was below 120 °C will be higher** than that of parts moulded at 120 °C (figure 37). This is due to a larger amorphous region.
- **Parts moulded at a mould temperature lower than 120 °C risk undergoing post-crystallization and thus distortion after moulding.** This is caused by a drop of the glass transition point due to water pickup.
- **The creep of «cold» moulded parts is higher** than that of parts moulded at the correct tool temperature (figure 38).
- **A low mould temperature will produce an irregular surface** with both smooth and rough zones, or with fibres on the surface. A mould temperature above 120 °C is necessary to obtain an excellent surface finish.
- **Injection into a mould cavity below 80 °C will result in very low shrinkage**, which can cause problems during part ejection.

Figure 37: Water absorption of specimens of IXEF 1002 injected at mould temperatures of 75 °C and 130 °C

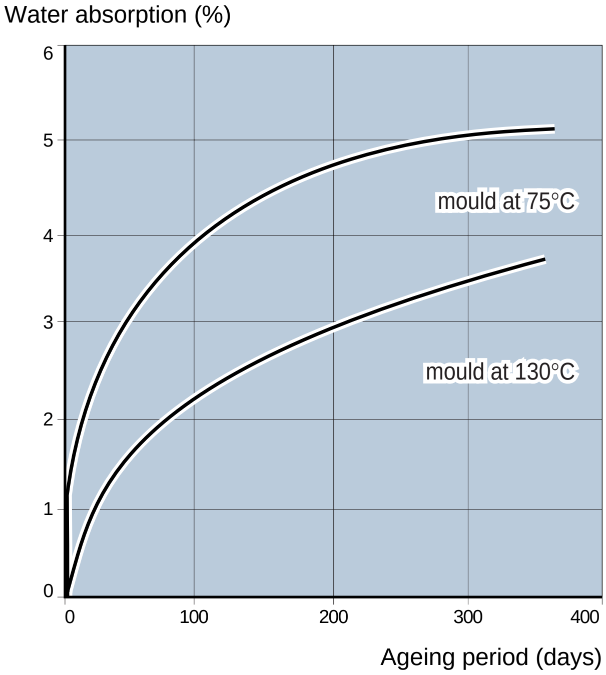
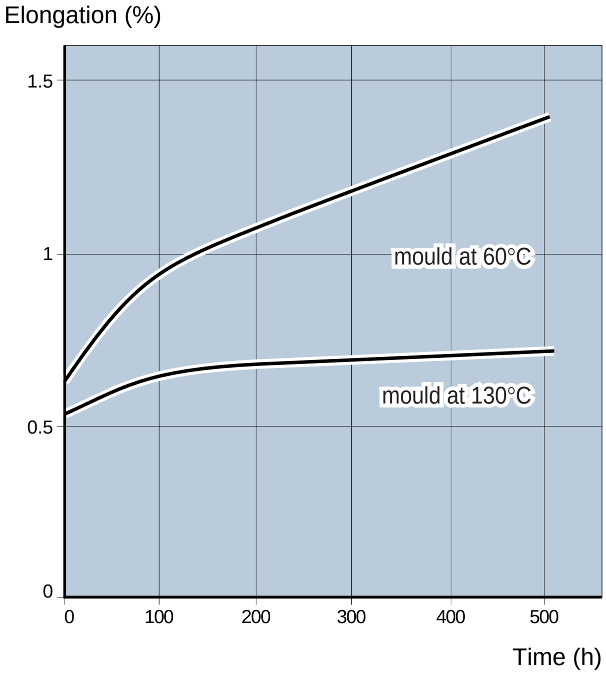


Figure 38: Tensile creep (23 °C, 120 MPa) of IXEF 1032 at two different mould temperatures



3 - Plasticizing phase

The plasticizing phase is intended to melt the volume of material necessary for injecting the part and bring it up to the injection temperature.

Temperatures

A material temperature in the order of 280 °C (270 °C max. for the flame-retardant or impact modified grades), is required. The temperature profile should increase steadily from the hopper to the nozzle, with 250 °C at the feed zone.

Because IXEF compounds begin to oxidize at 300 °C causing discoloration of the material, one must verify the actual material temperature by purging some of the material outside the mould. The shearing done by the screw and the high-speed flow produce an increase of temperature (normally estimated at 20 °C) which can sometimes be excessive. Nevertheless, the standard IXEF grades do not display any degradation likely to create a danger for the user below 310 °C.

IXEF compounds crystallize near 200 °C, it is therefore necessary to limit heat losses from the barrel nozzle to the tool to prevent material freeze off.

Screw speed

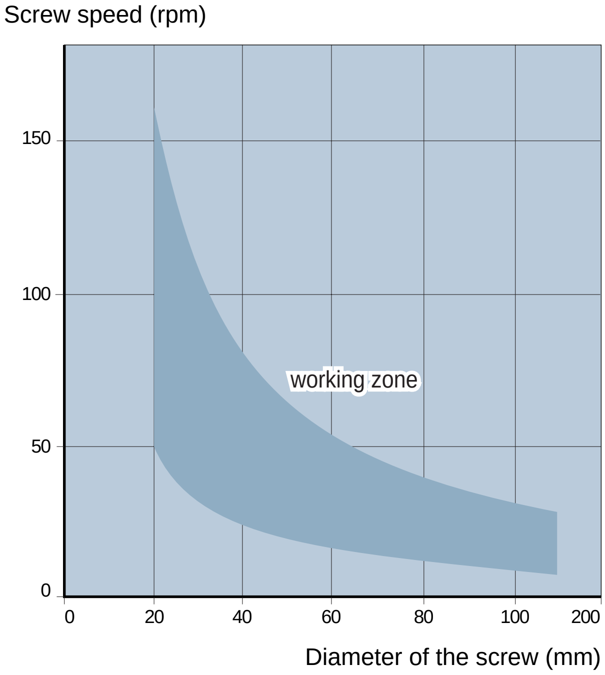
The screw speed must be such that the peripheral speed is between 3 and 10 m/min. Figure 39 gives the range of screw speeds as a function of the diameter of the screw.

For a peripheral speed above 10 m/min, the mixing becomes too intense and can cause damage to the glass fibres.

Back pressure

The back pressure on the screw must be low and can even be zero (hydraulic pressure from 0 to 10 bars). A slight back pressure is sufficient to obtain good homogeneity of the molten material.

Figure 39: Screw speed as a function of its diameter



4 - Injection phase

The settings of the injection phase cannot be carried out until the mould temperature and material temperature are correct and verified.

The hydraulic unit in an injection moulding press allows pressure to be applied to the molten material and permits transfer of the material from the barrel to the mould cavity. The mould fitting can be done at a constant flow rate (and even a flow rate set as a function of time) or at a constant pressure.

The pressure on the material (generally there is chart on the machine showing the effective pressure on the material in the barrel as a function of the pressure on the oil circuit) depends on the geometry of the mould, the speed of injection, and the temperature of the material. Increasing this pressure increases the lengths of flow as shown by the spiral mould injectability tests in figures 40 and 41.

The part and surface quality depend largely on the cavity filling phase. In order to ensure complete filling of the cavity and obtain uniform parts, the injection pressure and speed must be as high as possible without producing burning by the diesel effect, or causing flows that reduce the part surface quality.

The injection phase is followed by the holding phase. Particularly attention must be made to insure that the change over point is situated between these two phases.

Figure 40: Spiral length as a function of the injection pressure for a thickness of 1 mm of various IXEF grades

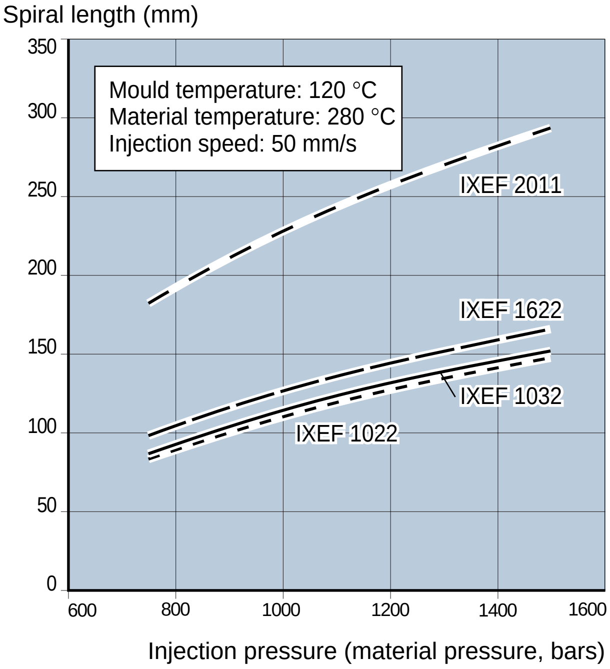
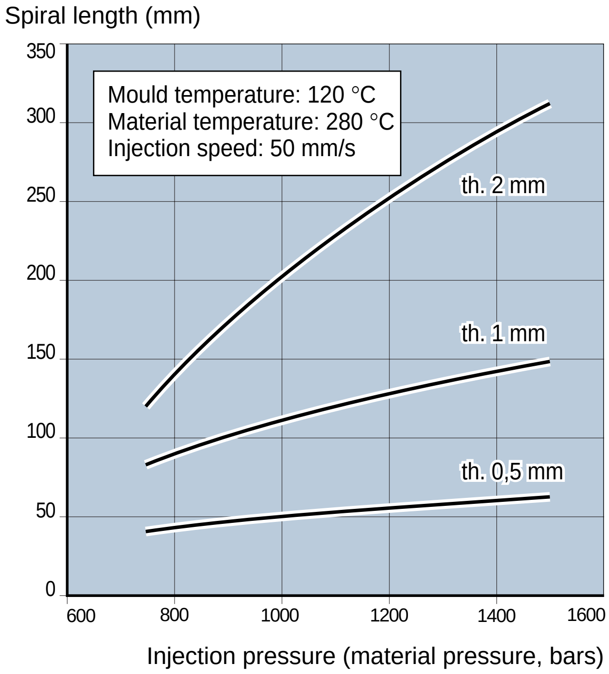


Figure 41: Spiral length as a function of the injection pressure for various thicknesses of IXEF 1022



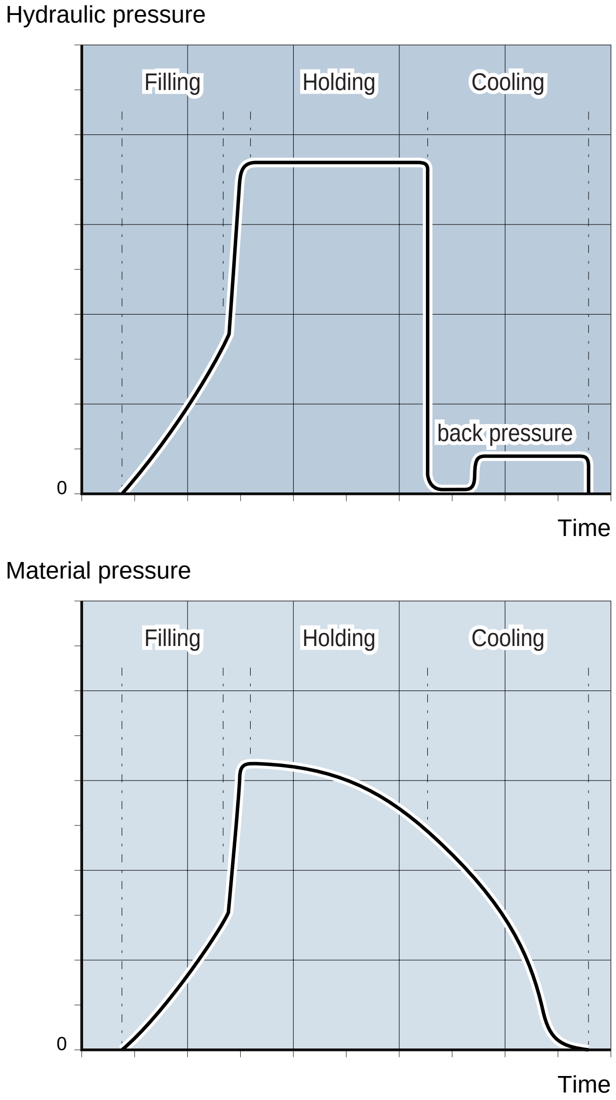
5 - Holding phase

The holding phase, which follows injection (figure 42), completes the filling of the part and compensates for the decrease of the specific volume (caused by a reduction of the temperature and crystallisation) by adding more material: the flow rate is low but the pressure is high.

Dimensional precision and stability as well as surface appearance are influenced by the value of the holding pressure. Depending on the tolerances desired, we recommend applying a material pressure between 300 and 1500 bars. A holding pressure which is too high can lead to overfilling and difficulty during ejection.

The application time can be estimated at 3 s per mm of thickness (w ≥ 2 mm). Nevertheless, one must verify during the first mouldings that the time selected allows the maximum weight of the part to be attained (the weight must not increase significantly if one increases the holding time). An incomplete part results not only in surface defects but also in a loss of mechanical properties.

Figure 42: Hydraulic pressure and material pressure during a moulding cycle



6 - Cooling phase

In order to make the first settings for the injection of a new part, the cooling time (t_c) can be estimated on the basis of the maximum wall thickness of the part (w in mm for $w \geq 2$ mm):

$$t_c = 2.5 \times w^2$$

For a piece which is difficult to eject, it can be necessary to increase this time estimation especially with IXEF impact modified grades.

The cooling time needs to be refined to optimise the cycletime.

The part can be injected from the tool as soon as it can withstand the stress applied by the ejectors. By way of example, IXEF 1022 is solid at 180 °C, a temperature at which its modulus is 5 GPa.

7 - Additives

Lubricants

Problems of part distorsion during ejection or parts hanging up in the mould are often caused by the mould design or the injection moulding conditions. If the modification of these parameters is not possible or does not solve the problem, IXEF compounds containing increased levels of lubrication can be used.

There are two IXEF 1022 compounds which contain increased levels of mould release agents: the grades IXEF 1022/X005 (natural) and IXEF 1022/X925 (black). These two products reduce the ejection force required to remove the part from the mould.

These lubrificated compounds, which present slightly lower mechanical properties compared with standard grades, are often used to decrease the moulding cycle time.

Coloured master batches

Although Solvay sells several grades of IXEF moulded in colour, it is possible to use coloured master batches to produce tinted parts.

For the IXEF grades, we recommend (among others) coloured master batches based on polyamide (PA 66).

Coloured master batches containing TiO_2 should be avoided because they can cause a significant decrease in mechanical properties.

Blowing agents

Parts of relatively constant thickness can be expanded up to 30 % by adding a blowing agent which can be used at 240-270 °C (e.g. Expandex® 5NPT). In this case, one must observe the following conditions:

- mix around 0.5 % blowing agent with the dry granules
- adjust the material temperature to a maximum of 240-250 °C
- use a shut-off nozzle (the material must be kept under pressure in the barrel)
- adjust the shot volume to plasticize the exact mass of the material that one wishes to inject.
- inject at high speed.

The exact injection conditions should be optimised in accordance with the initial moulding results.

8 - Recycling

The regrind (sprues, runners, etc.) can be recycled with virgin compound excluding any contamination (oil, release agents, other additives, ...) .

As an indication, figures 43 and 44 show the variation of the tensile strength, modulus and elongation at break of the IXEF 1022/0003 grade (natural) as a function of the number of recyclings at 30 % (the compound used in each cycle corresponds to 70 % virgin compound mixed with 30 % regrind from the preceding cycle).

We find very little change in these three mechanical properties. The successive recyclings can cause a slight change in colour.

The successive recycling of IXEF 1022 grade at 30 % leads to a stable colorimetric variation (ΔE) of the order of 5. It is thus important to confirm experimentally the recycling rate in order that the finished part continues to meet the specifications.

We recommend drying the regrind prior to injection unless they are ground and reinjected at the press.

We recommend that parts be marked to facilitate after use recycling. See table 25.

Table 25: Marking of IXEF polyarylamide parts following ISO 1874

Grade	Marking
IXEF 1002	> PA MXD6 - GF 30 <
IXEF 1022	> PA MXD6 - GF 50 <
IXEF 1032	> PA MXD6 - GF 60 <
IXEF 1501	> PA MXD6 - GF 30 <
IXEF 1521	> PA MXD6 - GF 50 <
IXEF 1622	> PA MXD6 - GF 50 <
IXEF 2011	> PA MXD6 - MF 41 <
IXEF 2030	> PA MXD6 - MF/GF 55 <
IXEF 2057	> PA MXD6 - MF 45 <
IXEF 2530	> PA MXD6 - MF/GF 55 <

Figure 43: Evolution of the tensile properties of IXEF 1022 during successive recyclings at 30%

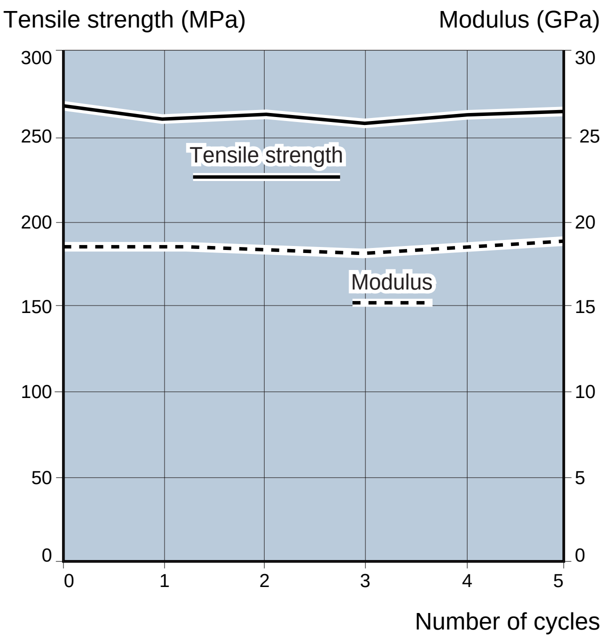
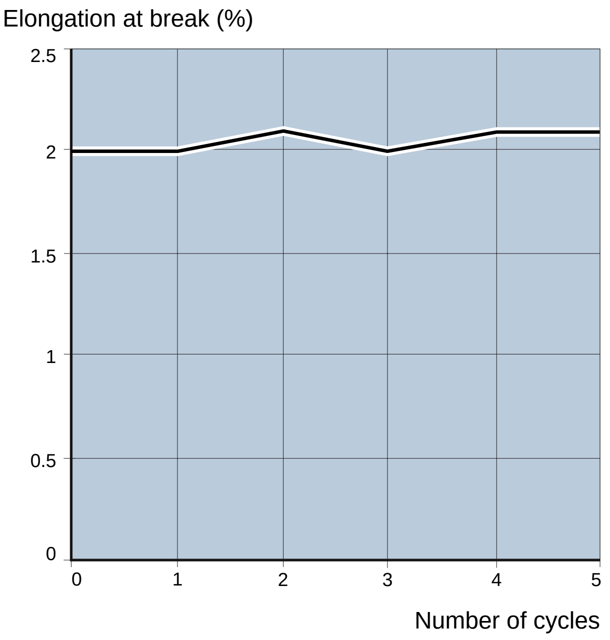


Figure 44: Evolution of the tensile properties of IXEF 1022 during successive recyclings at 30 %



9 - Solutions for common processing problems

(for more details: **www.solvay.com/IXEF**)

Table 26

Problems	Possible remedies
greasy spots on the parts and mould (signs of degradation)	• reduce material temperature (screw and/or hot runners)
whitish spots (same phenomenon but with cold mould)	• increase mould temperature • reduce material temperature (screw and/or hot runners) • release agents, lubricants
bad surface appearance	• increase mould temperature • increase injection speed • verify holding time and pressure
glass fibres visible on surface	• increase mould temperature • increase injection speed • increase runner dimensions • increase material temperature
jetting	• modify injection point position • reduce the initial injection speed • increase the cross-sectional area of the injection point
burning	• increase venting • reduce injection speed at end of filling
incomplete part	• increase shot volume • increase injection pressure and speed • increase runner dimensions • increase material temperature • increase venting
deformed part	• increase the temperature of the mould • modify the part design, avoiding major thickness differences • increase holding pressure to reduce shrinkage • modify position and dimension of the injection gate • increase the cooling time
the part or the sprue sticks in the mould	• reduce holding time • reduce holding pressure level • increase the draft angle of the mould cavity
sink marks	• increase the holding time and pressure • change the position and dimension of the injection point

B - Injection moulding equipment

1 - Injection unit

IXEF grades do not require special injection moulding equipment for their processing, provided that it is adapted to reinforced or filled materials. The screw-type machines are the most commonly used, offering a good compromise between melting capacity, control of the molten material temperature, and injection speed and pressure.

Clamping force

One can estimate a maximum clamping force corresponding to a material pressure of 800 to 1000 bar at the head of the screw that means 0.8 to 1 t per cm^2 of projected surface area (for example a press of 120 t for a surface area of 120 cm^2).

Nevertheless, experience has shown that on the modern presses with programmable injection speed or pressure half of this value is often sufficient.

Barrel

Since the barrel is subjected to abrasion, it is preferable to use a bi-metal type barrel to increase service life.

This technique offers a wide range of combinations between the basic metal (providing mechanical strength) and the internal coating which protects the barrel (see for example BERNA AG, CH; XALOY, USA; BROOKES Ltd, UK; etc.).

Screw

IXEF compounds, based on semi-crystalline polyarylamide resin, possess a sharp melting temperature. Plasticizing of the material can be easily achieved using a universal-type screw (compression ratio: 2.7 to 3, length/diameter ratio 15 to 20).

Preferably, new or renovated screws will be covered by a Stellite® alloy (on the sides and the thread crests), or a core-hardened alloyed steel with a high chrome content (high hardness and constant thickness).

Nitride-hardened screws are not recommended for the injection moulding of highly filled materials because, despite their high surface hardness, the depth of treatment is inadequate.

Check valve

This part plays an important role in building up the pressure. It must seat correctly in order to maintain this pressure during the injection and holding phases (figure 45).

The valve is subject to heavy wear caused by the high shear rates of the material; a solution to wear is offered by protectively treating the surface with a gas-phase chemical deposit.

Material back flow can be caused by either wear or a deposit of degraded material. Backflow makes it impossible to maintain a cushion of material during the packing phase. In case of an irregular shot volume of the material, it is thus imperative to dismantle the head of the injection unit in order to inspect the check valve.

Nozzle

The nozzle, located at the end of the barrel, is the point of contact with the mould. It must be heated to compensate for the heat lost to the mould, which is cooler (figure 46).

A shut-off nozzle is not indispensable, but it does offer the advantage of eliminating any drooling. All types of shut-off nozzle can be used; the systems using spring-loaded needles are preferable due to their good impermeability and the absence of stagnation zones.

A nozzle without shut-off will give good results if one properly adjusts the temperature of the nozzle to eliminate the melt drooling.

Given the great fluidity of IXEF compounds when melted, it is important to firmly screw the nozzle into the barrel to prevent any material infiltration

Figure 45: Check valve

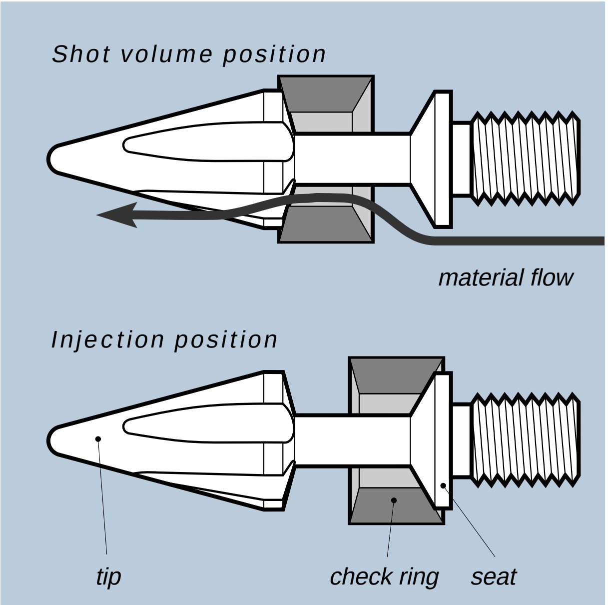
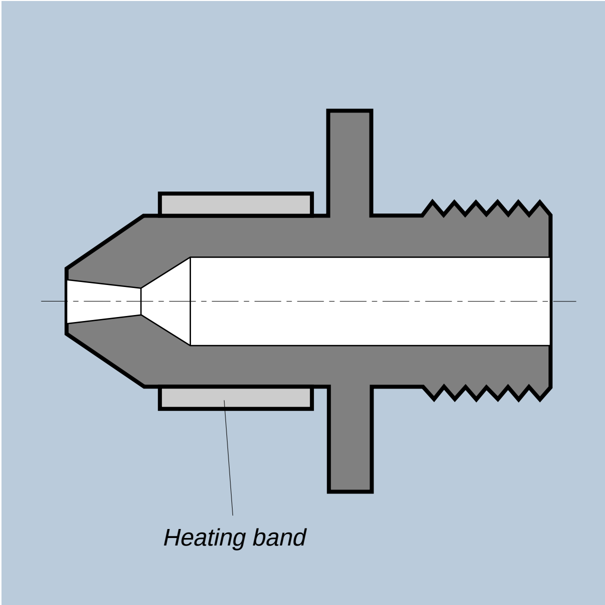


Figure 46: Open nozzle



2 - Mould

Construction materials

The steels used for constructing moulds must meet certain criteria such as machinability, suitability for polishing and heat treatments as well as resistance to stress, abrasion and in certain cases corrosion. The degree to which these different requirements are respected depends on the composition of the steels. Carbon favours quench hardening; chrome improves resistance to wear abrasion and corrosion, sulphur offers better machinability. However the last two components reduce the suitability for polishing.

Due to the processing of polyarylamide IXEF® we recommend the use of through-hardened steels to obtain a hardness of between 54-60 HRC after heat treatment.

A few examples:

- AFNOR Z160 CDV 12-DIN X155 Cr Vmo 12.1 - W. Nr 1.2379 AISI D2 (this self-hardening grade with 12% Cr is resistant to abrasion and easily superficially hardened by nitration).
- Aubert & Duval S.M.V. 5W (Wear resistant grade with a fine grain structure) and XDBD (corrosion resistant)
- AFNOR Z40 CDV5 – DIN X40 Cr MoV 5.1- W.Nr 1.2344 AISI H13 (this type of steel is used where a highly polished surface is important.
- UDDEHOLM: STAVAX ESR, ORVAR and ELMAX

For the flame-retardant IXEF® grades (IXEF® 1501,1521 or 2530), in addition to the hardness criteria (54-60 HRC), it is recommended to choose corrosion resistant steels.

A few examples:

- AFNOR Z40 C14 – DIN X42 Cr13 – W.Nr 1.2083 AISI 420
- Aubert & Duval X.D.B.D.W (wear and corrosion resistant with a fine grain structure)

Heat regulation

IXEF compounds require a mould temperature of at least 120 °C.
The surface temperature of the cavity wall must be as uniform as possible, with a deviation of no more than 5 °C to conserve an optimum quality. One must take this into account when designing the cooling channels and determine the proper distance between the channels and the cavity walls.

We recommend thermal regulation using a heat-exchanging fluid («hot oil») which offers good temperature uniformity. The heating power of the thermal regulation device must be sufficient to allow the working temperature to be reached quickly, while the machine is stopped (i.e. without using the heat capacity of the molten IXEF compound).

The power required by the heat regulator can be estimated from the weight of the mould as follows:

- around 100 kg: 3 to 6 kW
- around 1000 kg: 6 to 9 kW
- around 2000 kg: 9 to 12 kW

We do not recommend using heating cartridges alone, since they do not provide adequate temperature control.

It is also necessary to thermally insulate the mould to limit heat transfer to the mould platens. The manufacturers of mould accessories (such as HASCO, DME, etc.) can be consulted on this subject.

Runners

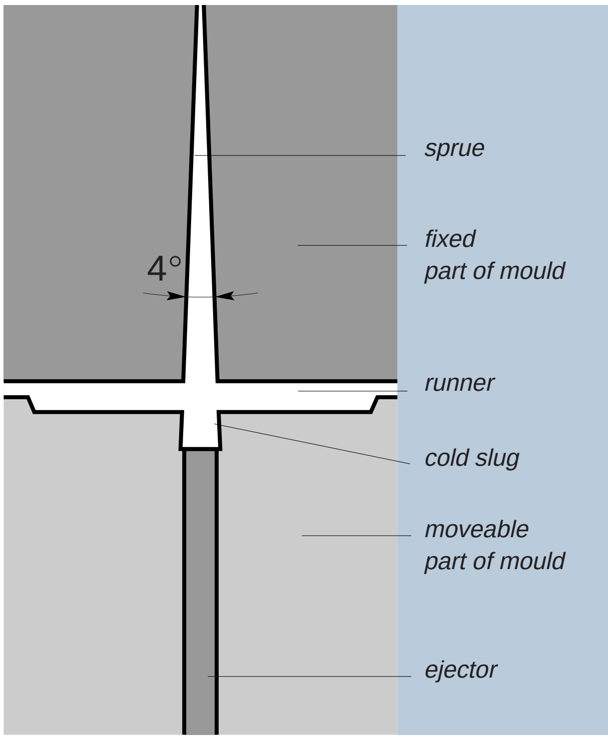
The sprue, which leads the molten material from the nozzle of the injection unit to the mould parting line, must have a sufficient **draft angle** and a **polished surface** to prevent the sprue sticking to tool. The total draft angle must be between 3 and 4° (figure 47).

The cold slug has a taper which is inverse to that of the sprue; its length must be approximately equal to its diameter. The average diameter of the sprue must be adapted to the volume of the part; for example, it is 4 mm for a volume below 50 cm^3 and 8 mm for a volume above 150 cm^3.

The sprue feeds a network of runners. When designing these runners, it is best to under-dimension the cross-sectional areas of the runners. They can later be enlarged if filling difficulties are encountered. To obtain parts with precise dimensions in the case of a multi-cavity mould, a balanced feed system must be provided which fills all cavities at the same speed and pressure.

The cavities can be fed with IXEF material by means of hot runners, which offer the advantage of saving both material and energy. We can recommend the Mold Master Husky, INCOE and Eurotool companies, among others. It is important to precisely regulate the temperature of any hot runner system.

Figure 47: Cold slug



Injection gates

The position and cross-sectional area of the gates are of fundamental importance. These parameters determine:

- orientation of the fibres, absence of jetting, weld line position; important points for the part's mechanical strength
- effective time of the holding phase prior to crystallization of the material at the gate; this ensures dimensional precision
- homogeneity of cooling; necessary for good thermal stability
- aesthetic aspect of the part. The injection point leaves a mark on the surface of the part; it should therefore be located on a non visible surface.

The cross-sectional area and the position of the gates must thus be studied with care, taking into account the final properties of the part and not focusing primarily on easy mould construction.

In the case of a cold gate, the thickness (d) of the gate is related to the wall thickness (w) of the part. For example, we suggest:

- d ≈ w for a direct feed
- d ≈ 0.7w for a lateral feed
- d ≈ 2w for a thin part.

The injection gate must be positioned as a function of the mechanical and aesthetic requirements of the part. The IXEF technical assistance department, with its wide experience and tools such as MOLDFLOW, can help you.

In general, the injection gates must be positioned as follows:

- in the thickest area of the part (figure 48).
- at the end of long parts so that the orientation of the glass fibres is as uniform as possible (see figure 48).
- avoiding weld lines, or moving them towards zones subject to less stress.
- in such a way that the various extremities of the part cavity are filled simultaneously.

Figure 48: Placement of the injection point

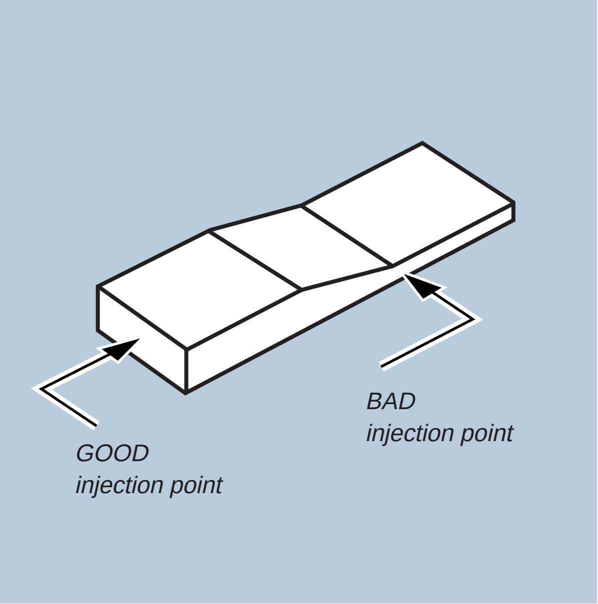
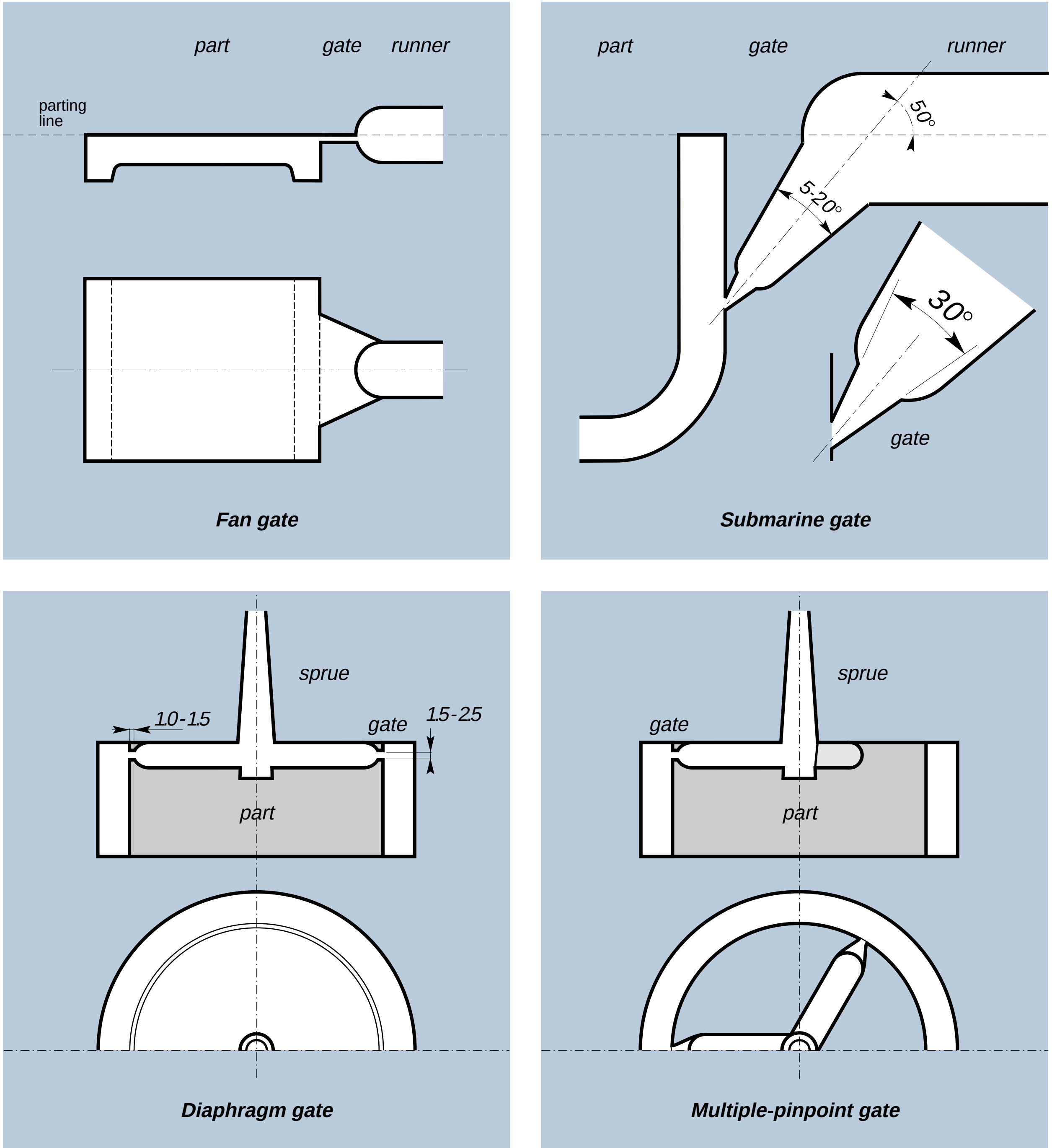


Figure 49 : Examples of different injection gates



Vents

Moulding parts with IXEF compounds requires the presence of vents in the mould. They must be designed to allow the evacuation of air in the mould when filling the cavity (see figure 50).

Inadequate vents can result in underfilling of the cavity, sink marks and sometimes even burn marks on the part (diesel effect).

The principal vent is constituted by the mould parting line. It is often necessary to machine additional vents either on the parting line (on the side opposite the entry), on the ejectors, or on mould inserts.

Wide but thin vents are recommended; in general, the width is from 6-10 mm and the thickness should not exceed 0.010 - 0.015 mm, to avoid flashing. At a distance of 5 - 6 mm from the cavity, it is useful to increase the thickness of the vents to 1 - 2 mm.

Ejectors

The low shrinkage during moulding and the rigidity at high temperatures of IXEF compounds make it important to design the ejectors with a sufficient power.

It is necessary to distribute them around the part to facilitate ejection and to prevent part deformation.

Split line

To assure a good closing of the mould, we recommend to check the aligment of the split line (blue marking) under a force corresponding to 15 % of the clamping force used in production.

The use of IXEF compounds does not pose any health danger provided that they are handled and processed as recommended.

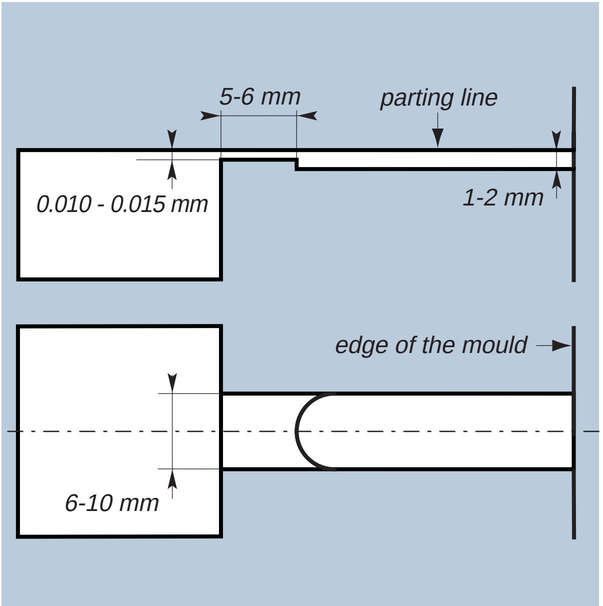
It is particularly recommended that the processing site be correctly ventilated during moulding and that the ventilation be placed directly above the injection nozzle. Operators should wear safety goggles and insulating gloves.

For long stops, it is recommended to empty the injection unit and reduce the cylinder temperature to around 180 °C. The cylinder can be reheated to 250-280 °C just before resuming moulding.

For brief pauses (less than 10 minutes) at the recommended processing temperature, it is not necessary to reduce the barrel temperature (except for sensitive colours).

During a definitive shutdown, it is recommended to completely empty the barrel and purge the cylinder several times with a medium-density, high viscosity polyethylene (e.g. ELTEX® B 5920 from SOLVAY).

Figure 50: Vents



A - Estimation of stresses

The design of thermoplastic parts must take several factors into account:

- **the mechanical stress** on the part. Section VII.A. describes several techniques which can be used to estimate the stress.
- **the environment** (thermal, chemical, etc.) which the part must withstand (see chapters I. and IV).
- **the electrical and flame retardancy requirements** of the part (see chapter III. and UL standard 746C),
- **the form of the part**. The form can influence the dimensional stability, the moulding cycle time and the level of stress in the part. These topics are dealt with in section VII.B.
- **shrinkage of parts** after moulding. This is very important in designing the mould and is described in section VII.C.
- **assembly techniques**, which are dealt with in section VII.D.
- **decoration techniques**. This subject is discussed in section VII.E.

External loads produce stresses in a part. These stresses may cause the part to break or result in too high a deformation, depending on the form and the material chosen.

The stresses (σ) and the deformations (ε) can be estimated from the mechanical equations based on Hooke's Law and the modulus of the material (E):

$$\sigma = E.\varepsilon$$

It is impossible here to describe all possible modes of deformation, so we have chosen to concentrate on tensile (VII.A.I.) and flexural loadings (VII.A.2.). For other types of stress, or for complicated parts, the IXEF technical assistance department can help you.

1 - Tensile stress

Tensile stresses can be estimated using the following equation:

$$\sigma_T = \frac{F_T}{A}$$

where:

σ_T = tensile stress (MPa)

F_T = tensile force (N)

A = cross-sectional area (mm^2)

2 - Flexural stress in beam

The flexural stress in a beam can be estimated with the following equation:

$$\sigma_f = \frac{M_f \cdot C}{I}$$

where:

σ_f = flexural stress (MPa)

M_f = flexural moment (N.mm)

C = distance from the neutral axis to the outer fibre (mm)

I = moment of inertia (mm^4)

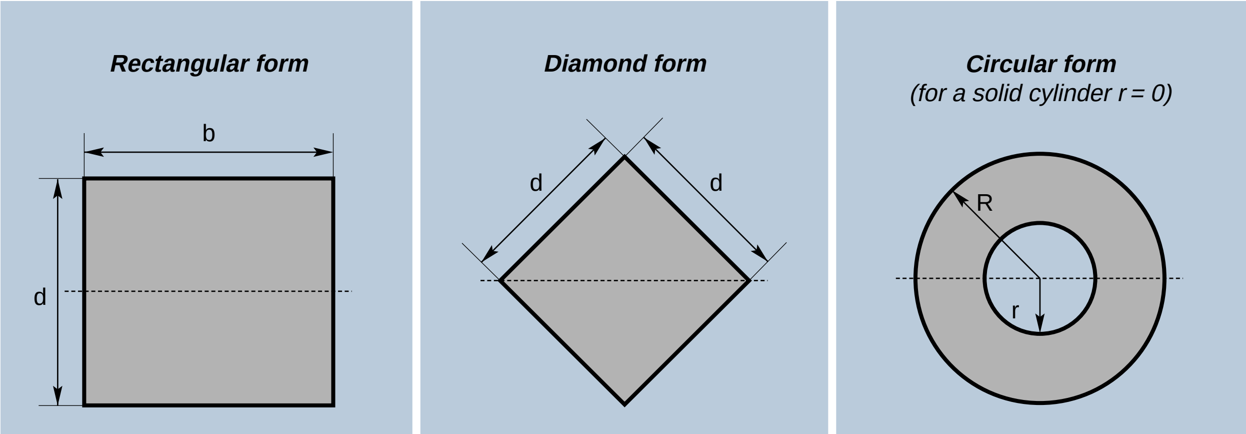
These factors depend on the form of the beam (C and I), the position of the load (M_f) and the mode of attachment (M_f).

Figure 51 gives the moments of inertia (I) and the distance from the neutral axis to the outer fibre (C) for beams of different sections.

Figure 52 gives the flexural stress (σ_{max}) and the maximum deflection (Y_{max}) for different types of attachment and loading.

Of course, there are other types of loading and attachment. The interested reader should refer to books on the strength of materials (e.g. Formulas for Stress and Strain, Roark and Young, McGraw-Hill Publishers).

Figure 51: Moments of inertia around the axis of symmetry of different geometric forms

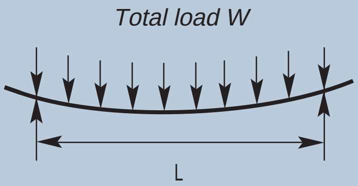
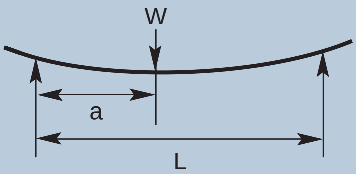
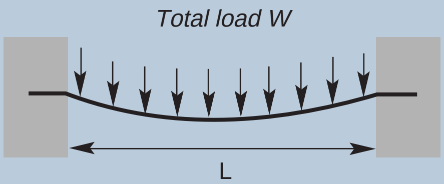
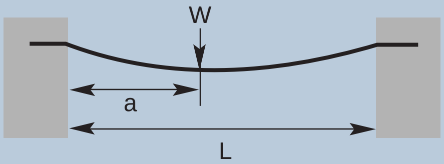
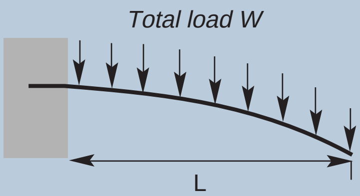
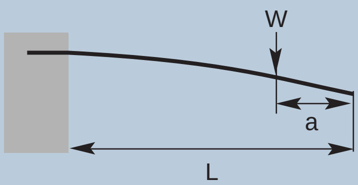


Rectangular form: $I = \frac{bd^3}{12}$ $C = \frac{d}{2}$

Diamond form: $I = \frac{d^4}{12}$ $C = 0.707d$

Circular form: $I = \frac{\pi (R^4 - r^4)}{12}$ $C = \frac{R}{2}$

Figure 52: Maximum stress (σ_{max}) and deflection (Y_{max}) as a function of the type of load

Uniform load	***Load at one point***
 $\sigma_{max} = \frac{WLC}{8\,I}$ $Y_{max} = \frac{-\,5WL^3}{384\,E\,I}$	 $\sigma_{max} = \frac{Wa(L-a)C}{L\,I}$ $Y_{max} = \frac{-\,Wa}{3\,E\,I\,L}\left(\frac{L^2-a^2}{3}\right)^{3/2}$
 $\sigma_{max} = \frac{-\,WLC}{12\,I}$ $Y_{max} = \frac{-\,WL^3}{384\,E\,I}$	 $\sigma_{max} = \frac{-\,Wa(L-a)^2\,C}{L^2\,I}$ $Y_{max} = \frac{-2Wa^3}{3\,E\,I}\left(\frac{L-a}{L+2a}\right)^2$
 $\sigma_{max} = \frac{-\,WLC}{2\,I}$ $Y_{max} = \frac{-\,WL^3}{8\,E\,I}$	 $\sigma_{max} = \frac{-\,W(L-a)C}{I}$ $Y_{max} = \frac{-\,W}{6\,E\,I}(2L^3 - 3L^2a + a^3)$

B - Design of the part

The design or form of the parts must not only satisfy the functional constraints but also the technological constraints imposed by the injection moulding process described below:

- wall thickness as uniform as possible (section VII.B.1.)
- design of draft angles allowing ejection from the mould (section VII.B.2)
- no sharp angles (section VII.B.3)
- design of bosses, holes and ribs (section VII.B.4)

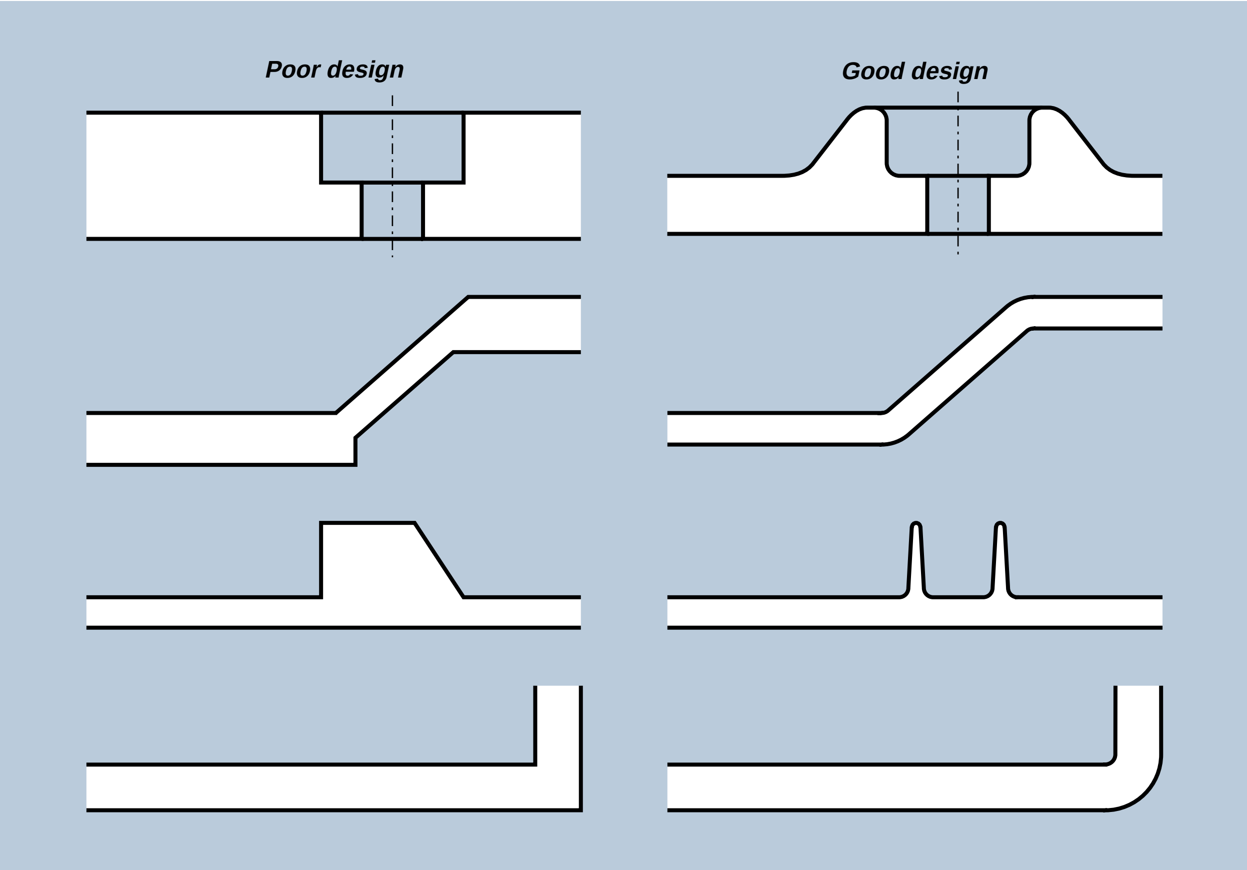
These basic rules, which are not specific to the IXEF compounds (which often tolerate more liberty than most thermoplastics), are discussed in more detail in the following sections.

1 - Wall thickness

In general, IXEF compounds permit wall thicknesses between 0.5 mm and 12 mm. Large thickness variations can cause of distortion, hesitation and dimensional problems (figure 53).

Moreover, if w (in mm) is the part wall thickness, the injection moulding holding time is of the order of 3 w (in seconds) and the cooling time is of the order of 2.5 w^2 (in seconds, $w \geq 2$ mm) (see chapter VI). It is thus of interest to reduce the wall thickness by making use of reinforcing ribs.

Figure 53: Examples of how to achieve a uniform wall thickness



2 - Draft angles

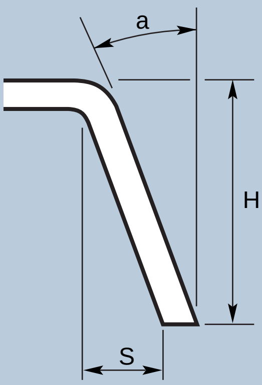
Since IXEF compound undergoes relatively little shrinkage, a draft angle of 1 to 2 degrees (1.7% - 3.4%) is generally necessary to facilitate ejection of the part from the mould.

Several different cases are described below (figure 54).

Figure 54: Draft angles

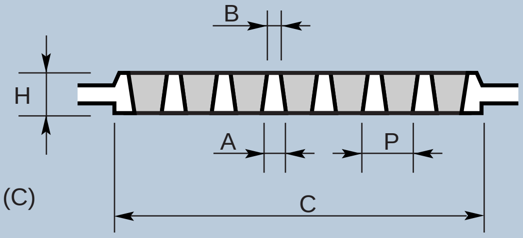
Smooth flat wall:
for H < 100 mm, a = 3% - 3.5%
for H > 100 mm, a = 1.7%

Textured flat wall:
S/H = 1/5 - 1/10, a = 10% - 18%



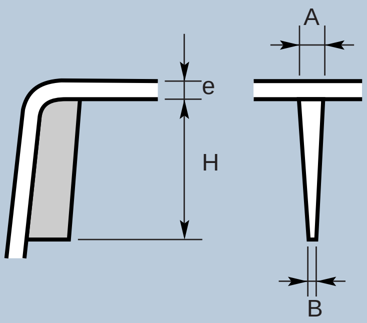
Grill:
(A - B)/(2.H) = 11% - 9%

If the pitch (P) of the grill is less than 4 mm, use a draft angle of 1/10.
The draft angle can be increased as the dimension (C) of the grill increases.



Vertical ribs:
(reinforced sides)
(A - B)/(2.H) = 0.3% - 0.5%

Horizontal ribs:
(reinforced bottom)
(A - B)/(2.H) = 0.7% - 1%



3 - Internal corner radii

Internal corners with sharp angles or very short radii and notches are one of the main causes of failure under load of parts made in plastic, and notably IXEF compounds.

It is necessary to calculate the stress concentration created by an internal corner in order to verify that the strength of the material is adequate in this region. The mathematical formulae used to estimate the stress concentration factor for different geometries can be obtained from strength of materials handbooks. As an example, figures 55 and 56 present the stress concentration as a function of the ratio of internal corner radius.

A good rule of thumb consists of choosing an internal corner radius equal to or greater than one-half of the thickness of the part, and at least equal to 0.6 mm.

Figure 55: Internal corner radii

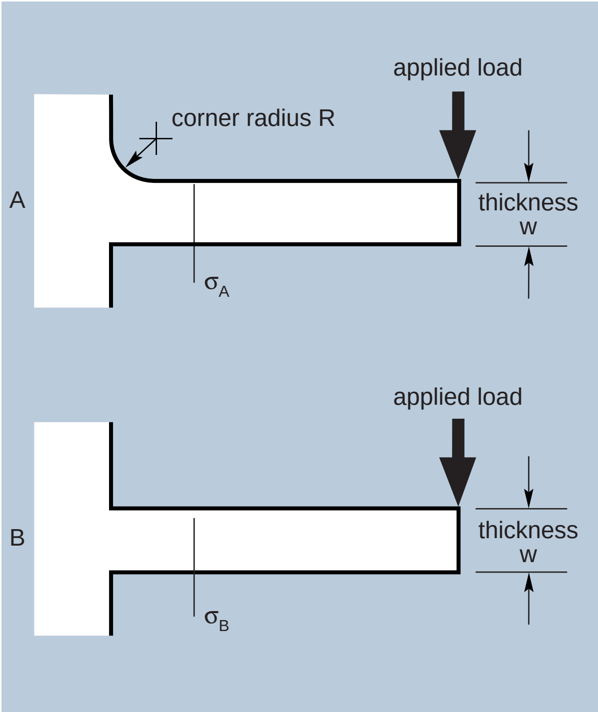
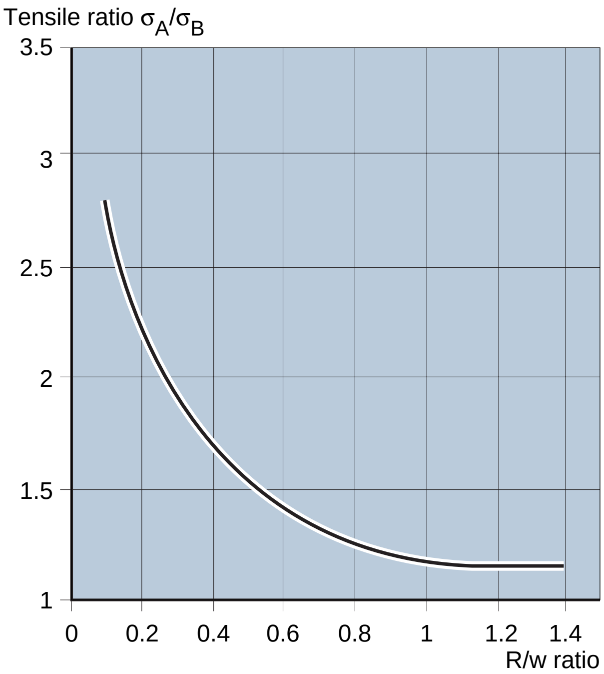


Figure 56: Stress concentration due to an internal corner



4 - Ribs, bosses, holes

Ribs

Ribs increase the rigidity (higher moment of inertia) and strength of parts with little increase in weight. By avoiding too large and widely distributed thicknesses, one can thus reduce the weight and the cycle time. The recommended rib dimensions are given in figure 57.

Because of their low shrinkage, IXEF compounds minimize the sink marks caused by thick ribs. If sink marks are unacceptable on the opposite wall, they can be masked by a grained texture at the site of the sink mark.

Bosses

Bosses are used to permit the assembly of parts or to reinforce holes. As a general rule, the external diameter of the boss must be double the diameter of the hole to be reinforced, and the wall thickness of the boss may not exceed that of the part. Figure 58 offers several design possibilities.

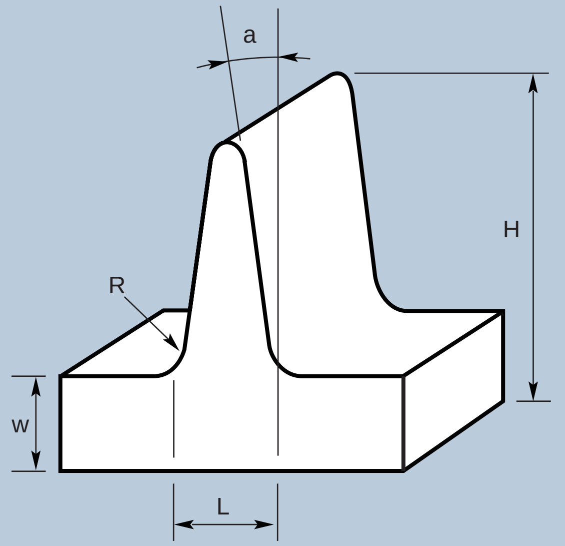
Holes

The moulding of holes does not pose any problems, but it does create a weld line which constitutes a mechanical weak point.

When designing holes, the following basic rules should be observed:

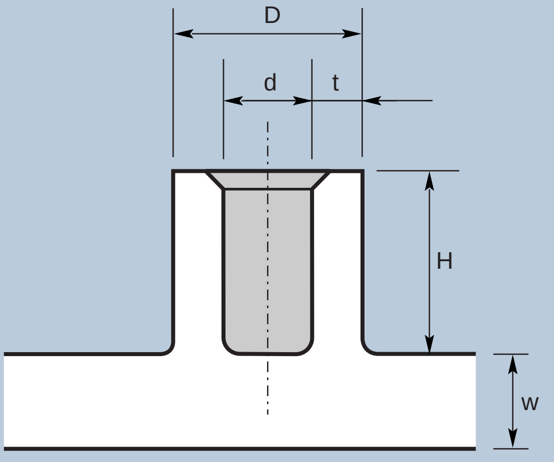
- the distance between the axes of two holes must be at least greater than the sum of their diameters.
- a blind hole whose axis is perpendicular to the flow direction must have a depth less than twice its diameter: beyond this ratio there is a risk of bending the stem during injection.
- in the case of aligned holes, one can tolerate a decentrage if the diameter of one of the holes is slightly greater than that of the other.
- an overflow tab can be used in certain cases to improve the mechanical strength of the weld line.

Figure 57: Rib design



R = w/4
H = 4 w
L = 0.4 w in order to minimize sink marks
L = 0.6 w in order to maximize strength
L = w in case of expanded moulding

Figure 58: Boss design



D = 2d
t = 0.6 w
H = 2 to 3 d
edge bevelled at 45°
Radii = 0.8 to 1.5 mm

C - Shrinkage and tolerances

1 - Shrinkage of IXEF polyarylamide

IXEF compounds are characterized by a low level of shrinkage during moulding. The IXEF 1022 grade for example has an average shrinkage of only 0.3 %. Although the dimensions of a mould must always be adjusted depending on the results obtained from the first moulding trials, one can use the nominal values contained in table 27.

The actual skrinkage obtained depends, in addition to the IXEF grade used, on the geometry of the part (notably its thickness), the position of the gates as well as the packing during cooling. The nominal values in the table below were measured on injection-moulded parallelepiped-shaped specimens with 20 x 40 surfaces and a thickness of 1, 2 or 4 mm.

At a temperature above the glass transition point, a very slow post-moulding crystallisation can cause the part to develop sink marks over time. Water pickup, very slow at low temperature, can result in expansion. In practice, one may assume that these two phenomena cancel each other out.

Table 27: Shrinkage of IXEF compounds

Compound	Thickness (mm)	Holding pressure (bar)	Shrinkage in flow direction (%)	Shrinkage transverse to flow (%)
IXEF 1022 **IXEF 1028** **IXEF 1622**	1 2 4	750 750 750	0.1 0.1 0.2	0.3 0.3 0.5
IXEF 1032	1 2 4	750 750 750	0.1 0.1 0.2	0.3 0.3 0.3
IXEF 1521	1 2 4	750 750 750	0.1 0.1 0.2	0.3 0.3 0.5
IXEF 2011	2 4	750 750	0.1 0.3	0.4 0.6
IXEF 2030	1 2 4	750 750 750	0.1 0.2 0.3	0.4 0.4 0.5
IXEF 2057	2 4	750 750	0.4 0.5	0.5 0.7

Mould temperature: 120 °C .
Material temperature: 280 °C (270 °C for the flame-retardant or impact modified grades).

2 - Dimensional tolerances

The dimensional tolerances or the precision of the parts made with glass fibre-reinforced thermoplastics (the class to which IXEF polyarylamide belongs) depend on several factors. A partial list includes:

- **the form of the part**. The presence of different thicknesses or weld lines for example can increase the achievable circularity or flatness tolerances.
- **design of the mould**. Wear, too much play between the fixed and the moving parts of the mould, or an improper temperature regulation can cause significiant dimensional variations.
- **processing conditions**. A variation of the processing conditions over time (temperature of the material or the mould, holding phase, injection rate, etc.) can lead to a dimensional variation.
- **variations among the different batches**. To reduce such variation, the IXEF compounds are manufactured and checked in accordance with the ISO 9002 standards (see page 37).
- **working conditions**. Water pickup and post-shrinkage phenomena can also influence the tolerances that can be attained.

Due to these factors, it is difficult to precisely predict the dimensional tolerances for a thermoplastic part. However, it should be noted that IXEF is used in many applications requiring low tolerances.

For example, on the basis of typical shrinkage variations, it is possible to estimate the tolerances achievable on lengths (e.g. distance between two axes). When the general moulding recommendations are observed, we can consider linear tolerances:

$$\Delta l = \pm\ 0.05\%$$

For typical tolerances for flatness, circularity, etc., please contact the IXEF technical assistance department.

It is also recommended, when machining mould cavities, to «leave some metal on» in the dimensionally critical zones so as to be able to make the necessary adjustments after the first injection trials.

1 - Mechanical assembly techniques

Insert moulding

IXEF compounds can be injected either around metal inserts or onto parts already moulded from IXEF compounds.

If thin-walled parts are to be produced, the insert should always be heated to the temperature of the mould.

Snap-fit assembly

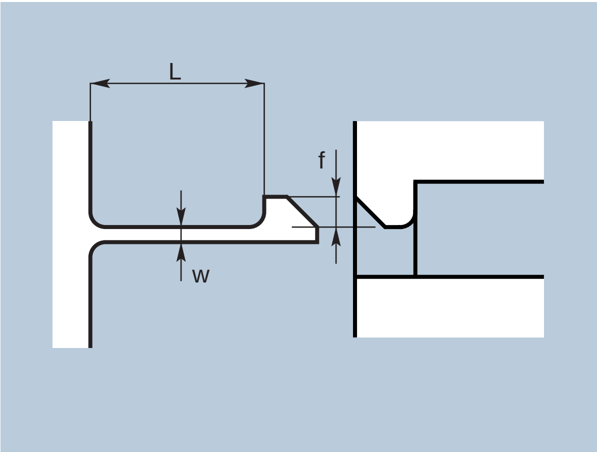
Snap-fitting allows two items to be clipped together, using the elasticity of one or both components. As can be seen in the diagram (figure 59), the male part contains a lug which is inserted after deformation into the female part.

Using the geometry of the clip defined by this diagram, the following value can be assumed for f using the standard IXEF 1022 grade:

$$f = 0.005 \frac{L^2}{w}$$

Given the high rigidity of IXEF grades and their elongation at break, this type of assembly is not recommended without prior study of the geometry of the clip.

Figure 59: Clip design



Screw assembly

The maximum tightening torque that an IXEF polyarylamide plate can withstand and the extraction force which a screw can resist (figure 60) are outlined in table 28 for the IXEF 1022 grade.

Figure 60: Measurement of the maximum torque and the extraction force

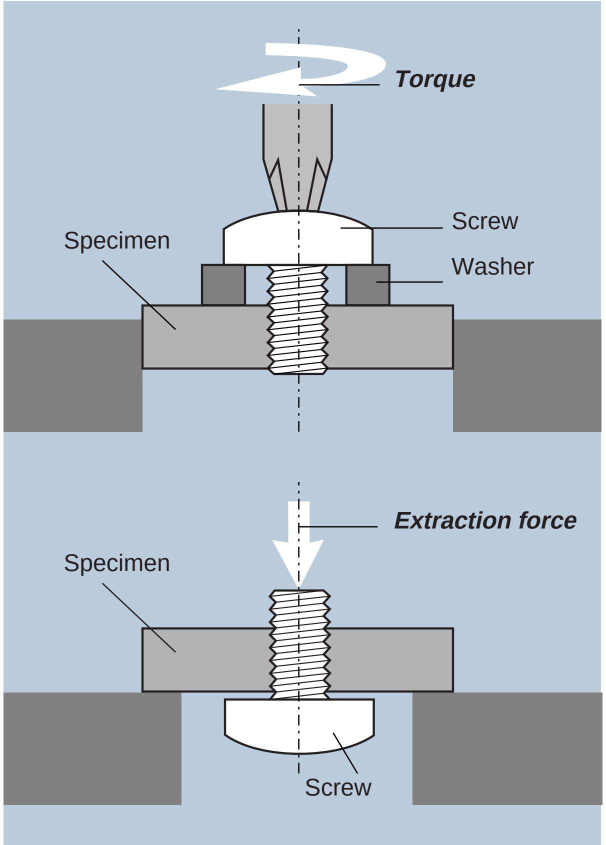


Table 28: Screw assembly in an IXEF polyarylamide part

Screw type	Diameter of the hole (mm)	Maximum torque (N.m)	Extraction force (kN)
M 2.6 X 0.45	2.2	> 1.0	> 1.7
M 3.0 X 0.5	2.5	> 1.5	> 3.6
M 4.0 X 0.7	3.4	> 4.5	4.6
M 5.0 X 0.8	4.3	7.5	6.1
M 6.0 X 1.0	5.1	> 6.5	7.7

2 - Assembly by welding

Ultrasonic welding is one of the most widely used methods for assembling moulded parts.

The principle of ultrasonic welding is as follows: vibrational energy emitted by a sonotrode is transmitted through the two parts to be assembled. This energy melts resin in the joint areas. The bond between the two parts is then obtained by applying pressure at the moment of solidification.

In general, IXEF compounds are more rigid than other reinforced thermoplastics; as a result, the vibrational energy is transmitted more easily through the moulded parts and the quality of the weld is correspondingly higher.

Different results of ultrasonic welding tests performed on IXEF compounds and on other materials are given in table 29.

Test conditions:

A Shimad Physical Chemistry Ind. Co. Ltd. welding machine (Type No. USW-63A) was used:

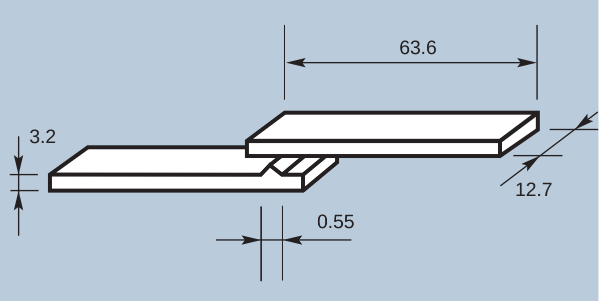
- frequency: 18,000 Hz
- power: 1.2 kW maximum
- welding time: 0.8 seconds
- holding time: 0.25 to 5 seconds
- pressure applied on the sonotrode: 580 N

Specimens: figure 61.

Table 29: Resistance to shearing of ultrasonically welded joints

Products	Breaking strength under a shear force (MPa)
IXEF 1002	26
IXEF 1022	19
IXEF 1501	19
PA 6 30% GF	21
PA 66 30% GF	22
PBT 30% GF	13
PC 30% GF	23

Figure 61: Dimensions (mm) of the specimens used in welding tests



3 - Assembly by bonding

The IXEF compounds can be assembled by bonding without any difficulty.

Four main types of adhesives have been evaluated for bonding IXEF on IXEF and IXEF on steel:

- **Cyanoacrylates**
  - Single Part Fast Curing Adhesives
  - Ideally suited for small part bonding
  - Toughened grades available
  - Optimum Gap Fill ≤ 0.15 mm
  - Maximum Temperature 80-110 °C (Depending on grade)
- **Two part Acrylics**
  - Tough, and semi-flexible
  - Good adhesion to many substrates
  - Optimum Gap Fill ≤ 1 mm
  - Maximum temperature 100-120 °C (depending on grade)
- **Modified Silane Adhesive/Sealants**
  - Very flexible
  - Slow Cure
  - Excellent gap fill (3-4 mm)
  - Good Water resistance
- **Epoxies**
  - Good shear and impact resistance
  - Optimum Gap Fill ≤ 2 mm
  - Maximum Temperature 100 °C

Table 30: Results of bonding tests (IXEF/IXEF and IXEF/Steel)

Adhesive		Typical Tensile Shear Strength (N/mm^2)				
			IXEF 1022 / IXEF 1022		IXEF 1022 / Steel	
		Cure speed	As Received #	Abraded 4-5 Ra ##	As Received #	Abraded 4-5 Ra ##
Cyanoacrylate	Loctite® 406	5-20 s	4 - 6	5 - 8	Not recommended	5 - 7
Toughened Cyanoacrylate	Loctite® 480	20-80 s	3 - 7	8 - 10*	3 - 6	7 - 10*
Two part Acrylic	Loctite® 3295	10-30 min	3 - 5	3 - 6	3 - 5	4 - 7
Two part Acrylic	Dexter® H 3101	8-20 min	2 - 4	2 - 5	2 - 4	3 - 5
Epoxy	Loctite® 3425	1.5 hour	3 - 6	4 - 7	3 - 6	4 - 6
Modified Silane Adhesive/Sealant	Loctite® 5069	3.5 mm/24 h (skin over 30 min)	2 - 4	2 - 4	2 - 4	2 - 4

* Substrate Failure of IXEF # Surface Finish 1-2 Ra ## Abraded with 60 Grit paper (4-5 Ra)

These tests allow to set the following main important recommendations:

Joint Design

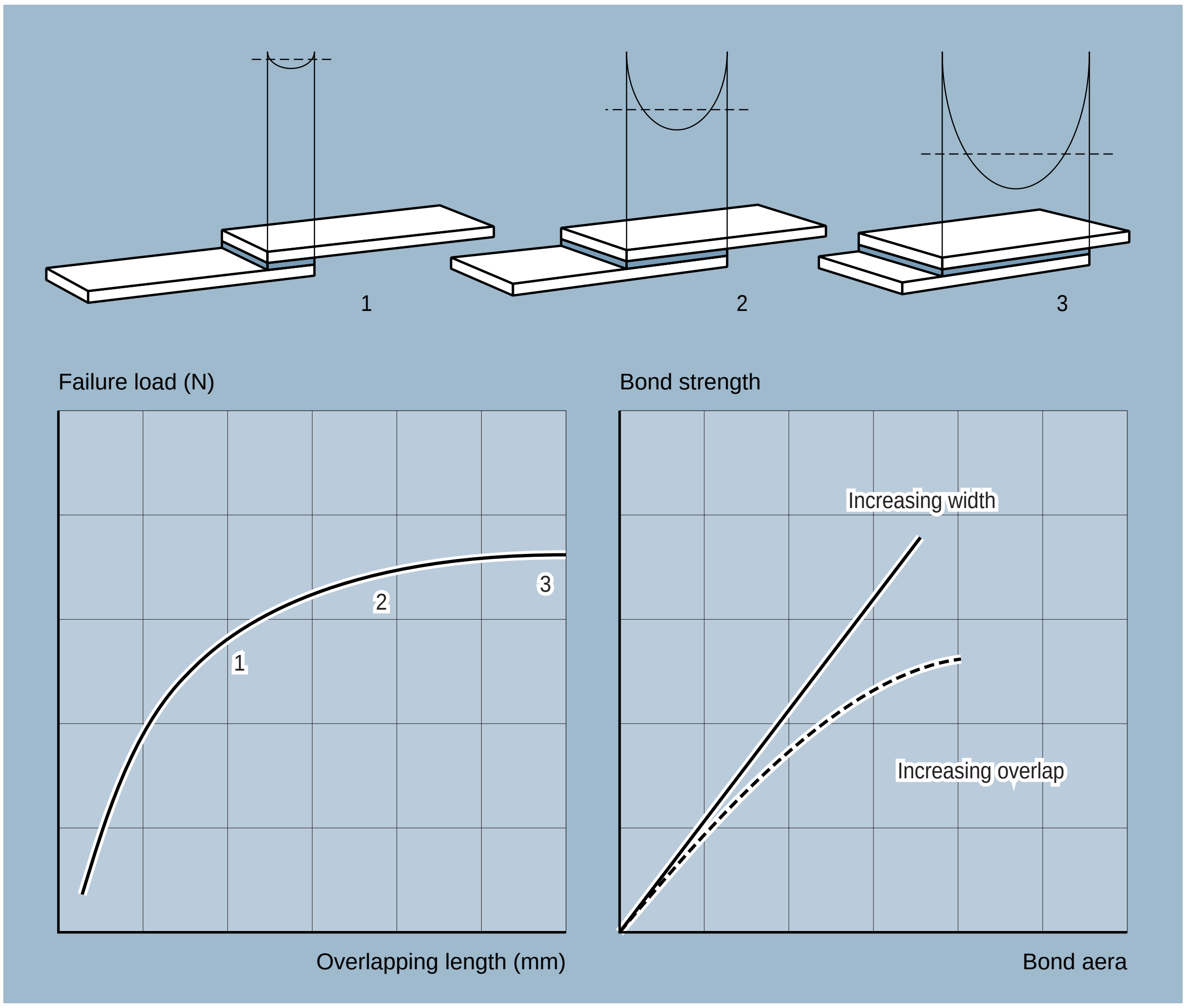
- Keep bond line gaps small
- Maximise bond area where possible an optimise the joint overlap (see figure 62)

Surface Finish/Preparation

- Avoid sacrificial mould release agents
- Clean any residues prior to bonding
- 3 to 8 Ra surface rugosity is needed.

Table 30 presents the shear strength results (IXEF 1022/IXEF 1022 and IXEF 1022/steel) for various bonding tests and adhesives.

Figure 62: Influence of the overlapping length and the bond width on the bond strength



E - Decoration techniques

1 - Painting

Many automobile body applications require a very good surface quality and paint adhesion. Because of their excellent surface finish (even with high glass fibre content levels) and good paint adhesion, IXEF compounds are used in many exterior painted applications, such as car door handles and rear-view mirror supports.

IXEF compounds also have high HDT values, thus allowing them to be baked at temperatures of 180 °C for as long as 30 minutes.

In addition, when using standard paints it is not necessary to perform adhesion promoting surface treatment (sand blasting, plasma or flame treatment, etc.). Because of the chemical nature of the organic matrix, most common primers adhere very well to the IXEF compound surface.

Adhesion tests were performed on the IXEF 1022 grade by the «Motor Industry Research Association» (MIRA UK). Three types of paint were used:

- polyester/isocyanate
  bake time 30 minutes
  bake temperature 80 °C
- acrylic/isocyanate
  bake time 30 minutes
  bake temperature 80 °C
- polyester/amino
  bake time 20 minutes
  bake temperature 140 °C

The painted specimens were submerged in water at 40 °C for 21 days and also subject to heat cycles between -40 °C and 100 °C. The adhesion was tested by measuring the quantity off paint removed when an adhesive tape is ripped off (Tape Test - ASTM D3002).
No delamination was observed.

2 - Metallisation

IXEF parts can be metallised for aesthetic, functional and electronic shielding requirements, directly replacing applications in metals and alloys.

There are a variety of techniques for the metallisation of IXEF grades

- Lamination
- Paints and spray-on coatings
- Vacuum disposition
- Electroplating

The most commonly used procedure is electroplating, especially for obtaining a decorative surface, as for the automotive industry.

New procedures have been developed (TECSEN), which are environmentally friendly and can also selectively plate onto IXEF parts. These plate procedures are successfull with any IXEF grade (till 60 % glass fibre reinforcement).

Adhesion and thermal shock tests have produced excellent results for these metallic coatings.

3 - Compounds moulded in colour

Several IXEF compounds are delivered moulded in colour, in accordance with the customer's specifications.

For large quantities, it is normally possible to prepare an IXEF compound moulded in colour according to the customer's colorimetric reference.

F - Machining IXEF compounds

Machining IXEF compounds does not cause any particular problems. Surfaces of quality N7 to N8 without lubricant and N6 with lubricant were obtained under the conditions set out in the table below.

Table 31: Operating conditions for machining IXEF parts

<table>
<tr><td rowspan="14">OPERATING CONDITIONS</td><td rowspan="5">Turning or milling tool</td><td rowspan="2">Recommended type</td><td colspan="2">A: high speed steel</td><td rowspan="3">5-6°</td></tr>
<tr><td colspan="2">C: metal carbide</td></tr>
<tr><td rowspan="3">Characteristics angles</td><td colspan="2">Dépouille</td></tr>
<tr><td rowspan="2">Grinding angle</td><td>High speed steel</td><td>20-25°</td></tr>
<tr><td>Carbide</td><td>12-15°</td></tr>
<tr><td colspan="2" rowspan="5">Cutting speeds (m/min)</td><td rowspan="2">Turning and milling</td><td>Rapide steel</td><td>90-150</td></tr>
<tr><td>Carbide</td><td>90-200</td></tr>
<tr><td>Sawing</td><td>Fritted CW blade</td><td rowspan="3">200</td></tr>
<tr><td>Drilling</td><td>High speed steel</td></tr>
<tr><td>Tapping</td><td>CW</td></tr>
<tr><td colspan="2" rowspan="4">Lubrication</td><td colspan="2">Turning and milling</td><td rowspan="4">Oil + water emulsion</td></tr>
<tr><td colspan="2">Sawing</td></tr>
<tr><td colspan="2">Drilling</td></tr>
<tr><td colspan="2">Tapping</td></tr>
<tr><td colspan="6">Classe N7-N8 without lubrification, N6 with lubrification.</td></tr>
</table>

This brochure annuls and replaces the brochure Br 1563c-IXEF-Technical Manual-July 2000.

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