

Ixef[®]



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Ixef[®] PARA

Processing Guide

**SPECIALTY
POLYMERS**

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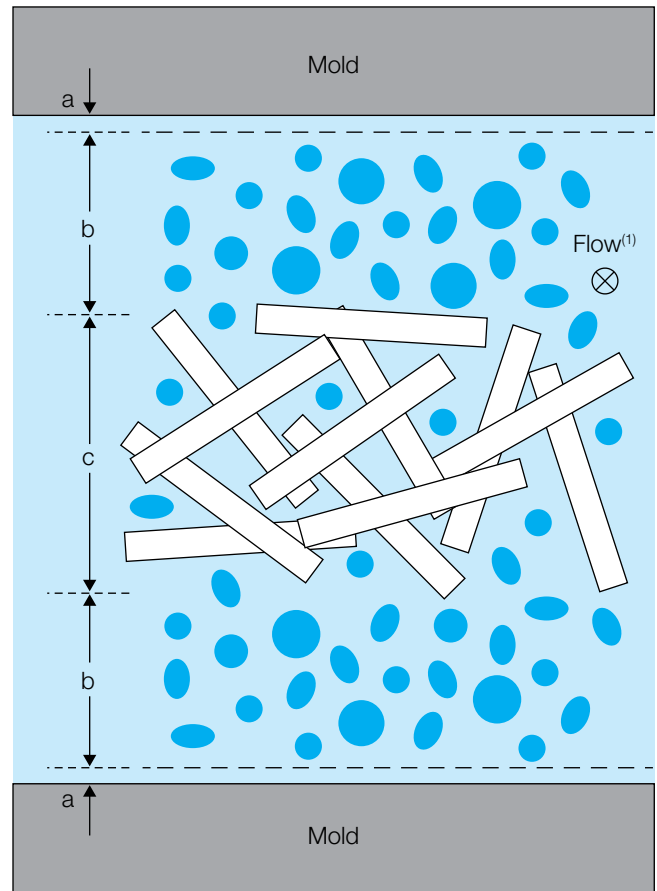
Ixef® Polyarylamide (PARA)

Ixef® PARA compounds are a family of thermoplastic products reinforced with glass fibers and/or mineral fillers.

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

- **Very high rigidity**
Tensile modulus up to 23 GPa at 20 °C (68 °F)
- **Excellent resistance to mechanical stresses**
Flexural strength can attain 400 MPa at 20 °C (68 °F)
- **Easy processing, also for thin-walled sections**
Good injectability and high productivity even with high fiber content
- **Low mold shrinkage, highly reproducible**
Precision molding, absence of sink marks and close dimensional tolerances can be achieved
- **Conception of miniaturized parts**
Rigidity, injectability of complex, thin shapes
- **Excellent surface finish**
Superb surface appearance for reinforced products, even with a high glass fiber content
- **Very low coefficient of linear thermal expansion**
Value comparable to that of metals
- **High thermo-mechanical properties**
Flexural modulus at 140 °C (284 °F) up to 7 GPa
- **Very low creep**
Deformation less than 1% after 1,000 hours under 50 MPa at 50 °C (122 °F), for example, for certain compounds
- **Slow rate of water absorption**
Like all polyamides, polyarylamide has a certain sensitivity to water. Even so, the semi-aromatic character of polyarylamide induces a lower and slower water absorption in Ixef® PARA compounds than that found in items molded in PA 6 and PA 6.6, which are more sensitive to humidity

Figure 1: Cross-section of injection molded part shown perpendicular to flow



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

Ixef® PARA compounds are composite materials. Injection molded parts are not isotropic, but instead exhibit a stratified structure (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 fibers 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 mold during injection.
- c = Finally, a core region where the fibers tend to orient themselves in a plane perpendicular to the flow direction (since the fibers 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 fibers are oriented in the flow direction.
- The rheological and thermal characteristics of the material. An increase of material temperature or of the mold increases the thickness of the skin zone, which improves the surface appearance.
- The processing conditions. The higher the injection speed, the more the fibers are oriented in the direction of the flow.

The resin used in all Ixef® compounds is polyarylamide (PARA), a high-performance semi-crystalline polymer. 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).

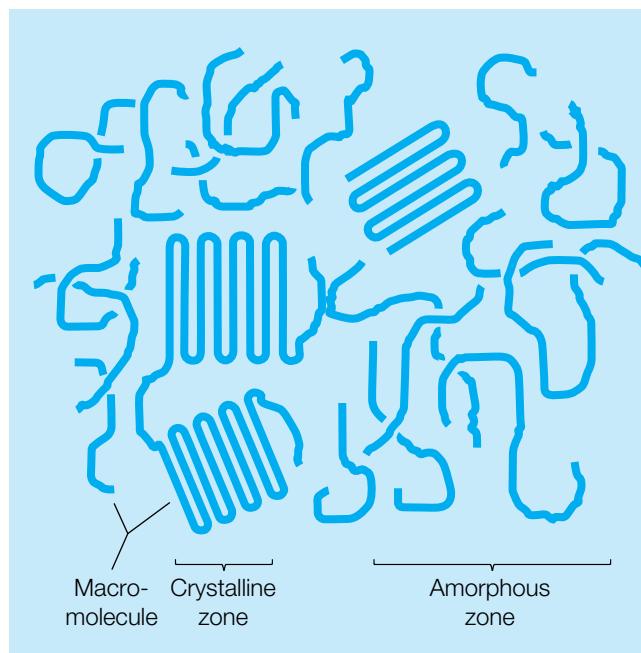
A solid semi-crystalline polymer can present different states depending on the temperature and/or the speed of stress:

- The vitreous state (zone below the glass transition temperature (T_g)), where the macromolecules are theoretically frozen, regardless of whether or not they belong to the amorphous or crystalline phases.
- The rubbery state (zone between the T_g and the melting temperature (T_f)): 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 molding parameters: processing temperature, mold temperature, molding cycle time, post-treatment after molding (annealing).

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



To develop a high crystallinity of Ixef® PARA compounds under normal injection molding conditions, it is essential to bring the temperature of the mold to between 120 °C and 140 °C (248 °F and 284 °F).

Under these conditions, the injected parts exhibit excellent dimensional stability, an exceptional surface appearance, and very good mechanical properties, even at high temperatures.

By contrast, if the temperature of the mold is less than 120 °C (248 °F), 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® PARA injected in a mold at 120 °C (248 °F) above the T_g (Figure 3) with that of the same part but using a mold at 60 °C (140 °F) below the T_g (Figure 4).

The peak near 90 °C in the case of the part manufactured in a 60 °C (140 °F) mold 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® PARA part made in a 120 °C (248 °F) mold.

Figure 3: DSC analysis of a part injected in a mold at 120 °C (248 °F)

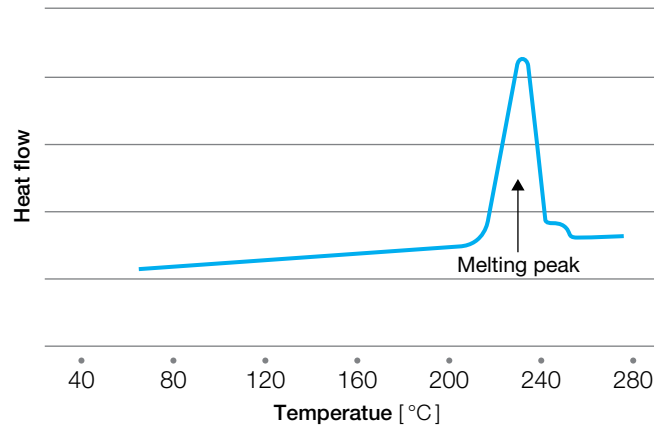
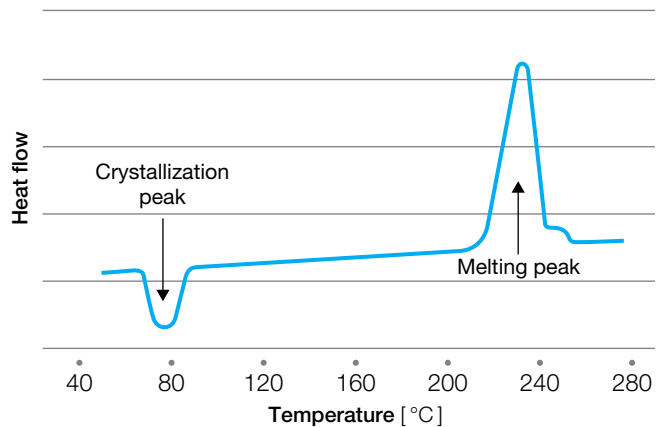


Figure 4: DSC analysis of a part injected in a mold at 60 °C (140 °F)



Nomenclature of Ixef® PARA Compounds

The range of Ixef® PARA compounds is comprised of different products families, essentially for injection molding:

Table 1: Nomenclature of the Ixef® PARA product range

| Grades | Characteristics |
|--------------------------|---|
| Ixef® 1000 series | Compounds reinforced with glass fibers |
| Ixef® 1002 | 30 % glass fibers |
| Ixef® 1022 | 50 % glass fibers |
| Ixef® 1023 | 50 % glass fibers; UV stabilized for internal applications |
| Ixef® 1025 | 50 % glass fibers; UV stabilized for external applications |
| Ixef® 1027 | 50 % glass fibers; heat stabilized grade |
| Ixef® 1028 | 50 % glass fibers; laser printable |
| Ixef® 1032 | 60 % glass fibers |
| Ixef® 1500 series | Flame-retardant compounds reinforced with glass fibers (UL-94 V-O) |
| Ixef® 1501 | 30 % glass fibers |
| Ixef® 1521 | 50 % glass fibers |
| Ixef® 1600 series | Impact modified reinforced compounds |
| Ixef® 1622 | 50 % glass fibers and an elastomer |
| Ixef® 2000 series | Compounds containing mineral reinforcements either alone or in combination with glass fibers |
| Ixef® 2004 | 65 % mineral fibers and an elastomer |
| Ixef® 2011 | Mineral reinforced |
| Ixef® 2030 | 55 % mineral reinforcements and glass fibers |
| Ixef® 2057 | Mineral reinforced |
| Ixef® 2500 series | Flame-retardant compounds with mineral reinforcements and/or glass fibers (UL-95 V-O) |
| Ixef® 2530 | Flame-retardant version of the Ixef® 2030 grade |
| Ixef® 3000 series | Compounds reinforced with carbon fibers |
| Ixef® 3006 | 30 % carbon fibers |
| Ixef® 5000 series | Compounds reinforced with glass fibers, self lubricating |
| Ixef® 5002 | 20 % glass fibers with PTFE |

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

Processing Ixef® PARA Compounds

Injection Molding

Table 2 summarizes the processing parameters recommended for Ixef® PARA compounds. The following sections contain a more extensive discussion of these conditions.

More details are available on our website:
www.solvayspecialtypolymers.com

Table 2: Injection molding parameters for Ixef® PARA compounds

| Properties | Unit | Value |
|--|---------|--------------------|
| Cylinder temperature | | |
| Feed zone | °C (°F) | 250–280 (482–536) |
| Compression zone | °C (°F) | 250–280 (482–536) |
| Homogenization zone | °C (°F) | 250–280 (482–536) |
| Nozzle zone | °C (°F) | 260–290 (500–554) |
| Temperature of the material (measured on purged material) | | |
| Standard grades (e.g. Ixef® 1022, 2030) | °C (°F) | 280 (536) |
| Flame-retardant grades (e.g. Ixef® 1521, 2530) | °C (°F) | <270 (<518) |
| Impact modified grades (Ixef® 1622) | °C (°F) | <270 (<518) |
| Mold temperature | | > 120 (>248) |
| 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 |
| Cooling time* | s | 2.5 w ² |

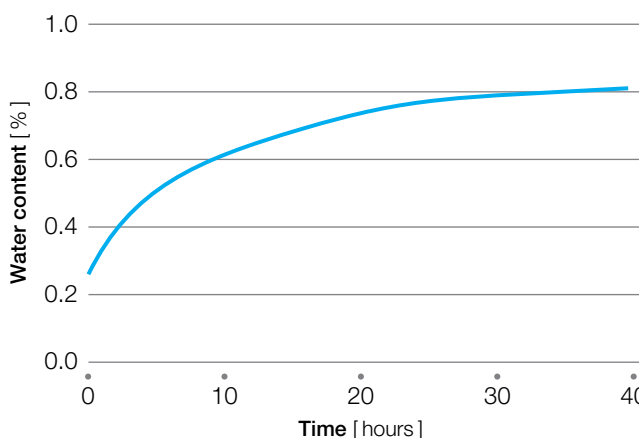
* indicative

w = wall thickness in mm

Water Content and Drying

Ixef® PARA compounds are delivered in granular form (bulk density around 0.7 g/cm³) usually in 25 kg bags or 1 ton octabins. Both package types are sealed and watertight, 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 that depends on the environmental conditions. For example, if a layer of granules 2 cm (0.79 inches) thick left at 20 °C (68 °F) in an atmosphere with a 65% relative humidity, it will absorb water at a rate illustrated in Figure 5 (Ixef® 1022).

Figure 5: Water pickup of Ixef® 1022 granules



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 (176 °F) 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 (194 °F) should not be used.

Drying under vacuum is intrinsically more effective and makes it possible to work at higher temperatures. We recommend using a temperature of 120 °C (248 °F). Under these conditions, for a layer of granules 3 cm (1.181 inch) thick and a reduced pressure of $P = 2-3$ mm Hg, the drying rate described in Figure 6 is observed.

Equipment Temperature

As discussed earlier, the resin matrix of Ixef® PARA compounds is polyarylamide which 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 that 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 mold cavity.

The glass transition temperature of the resin used in Ixef® PARA compounds is 85 °C (185 °F). It is thus necessary to use a mold temperature that is well above 85 °C (185 °F). Tests conducted on a 3-mm (1.181-inch) 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 mold temperature (Figure 7). These results show that a mold temperature of the order of 120 °C (248 °F) 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 mold temperature: DSC analysis (Differential Scanning Calorimetry).

A small piece of the injected part is slowly heated (20 °C (68 °F) per minute) and the amount of heat liberated is registered (Figures 3 and 4).

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

This crystallization process liberates heat and a negative peak (exothermic around 80 °C to 120 °C (176 °F to 248 °F)) appears on the DSC graph.

Figure 6: Moisture loss during vacuum drying of Ixef® 1022 at 120 °C (248 °F)

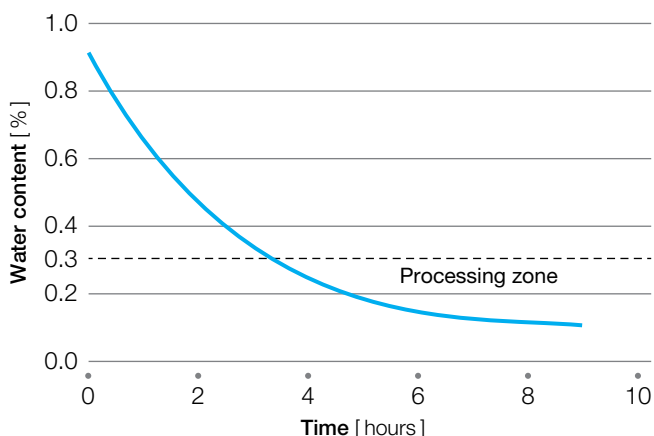
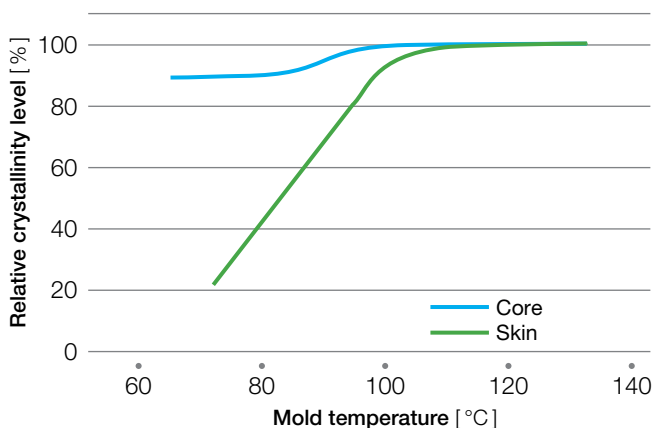


Figure 7: Crystallinity as a function of the mold temperature



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

- The water pickup of parts molded in a cavity whose temperature was below 120 °C (248 °F) will be higher than that of parts molded at 120 °C (248 °F) (Figure 8). This is due to a larger amorphous region.
- Parts molded at a mold temperature lower than 120 °C (248 °F) risk undergoing post-crystallization and thus distortion after molding. This is caused by a drop of the glass transition point due to water pickup.
- The creep of **cold** molded parts is higher than that of parts molded at the correct tool temperature (Figure 9).
- A low mold temperature will produce an irregular surface with both smooth and rough zones or with fibers on the surface. A mold temperature above 120 °C (248 °F) is necessary to obtain an excellent surface finish.
- Injection into a mold cavity below 80 °C (176 °F) will result in very low shrinkage, which can cause problems during part ejection.

Figure 8: Water absorption of Ixef® 1002 injected at mold temperatures of 75 °C and 130 °C (167 °F and 266 °F)

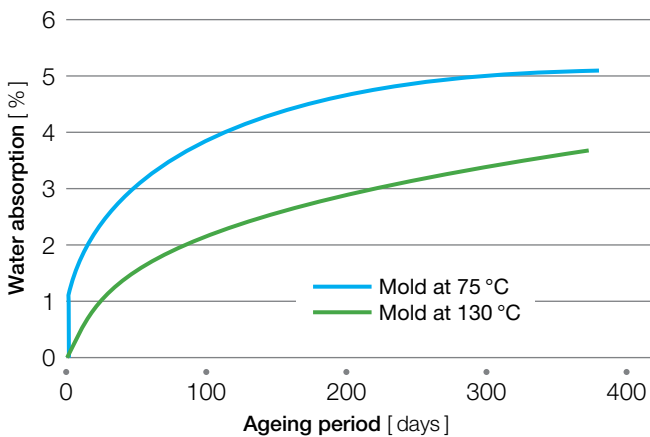
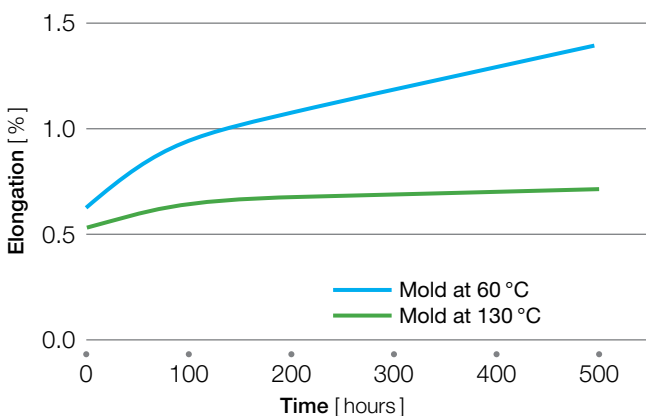


Figure 9: Tensile creep (23 °C (73 °F), 120 MPa) of Ixef® 1032 at two different mold temperatures



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 (536 °F) is required; 270 °C (518 °F) is the maximum for flame-retardant or impact modified grades. The temperature profile should increase steadily from the hopper to the nozzle, with 250 °C (482 °F) at the feed zone.

Because Ixef® PARA compounds begin to oxidize at 300 °C (572 °F) causing discoloration of the material, one must verify the actual material temperature by purging some of the material outside the mold. The shearing done by the screw and the high-speed flow produce an increase of temperature (normally estimated at 20 °C (68 °F)) which can sometimes be excessive. Nevertheless, standard Ixef® PARA grades do not display any degradation likely to create a danger for the user below 310 °C (590 °F).

Ixef® PARA compounds crystallize near 200 °C (392 °F); therefore, it is necessary to limit heat losses from the barrel nozzle to the tool to prevent material freeze off.

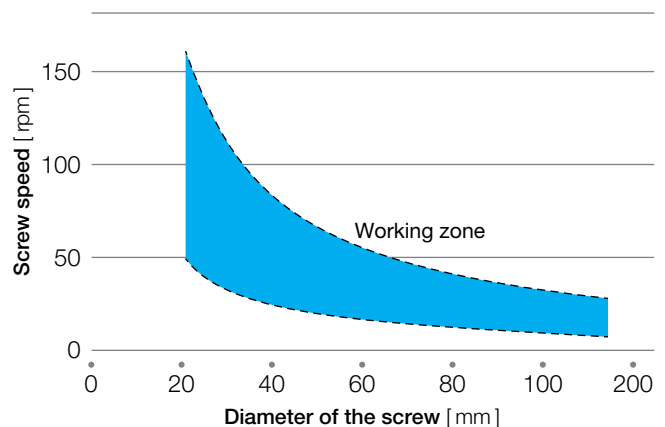
Screw speed

The screw speed must be such that the peripheral speed is 3 m/min to 10 m/min (10 ft/min to 33 ft/min).

Figure 10 gives the range of screw speeds as a function of the diameter of the screw.

For a peripheral speed above 10 m/min (33 ft/min), the mixing becomes too intense and can cause damage to the glass fibers.

Figure 10: Screw speed as a function of diameter



Back pressure

The back pressure on the screw must be low and can even be zero (hydraulic pressure from 0 to 10 bar (0–145 psi)). A slight back pressure is sufficient to obtain good homogeneity of the molten material.

Injection Phase

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

The hydraulic unit in an injection molding press allows pressure to be applied to the molten material and permits transfer of the material from the barrel to the mold cavity. The mold 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 a 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 mold, the speed of injection, and the temperature of the material. Increasing this pressure increases the lengths of flow as shown by the spiral mold injectability tests in Figures 11 and 12.

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 changeover point is situated between these two phases.

Figure 11: Spiral length as a function of injection pressure for a 1-mm thickness of various Ixef® PARA grades

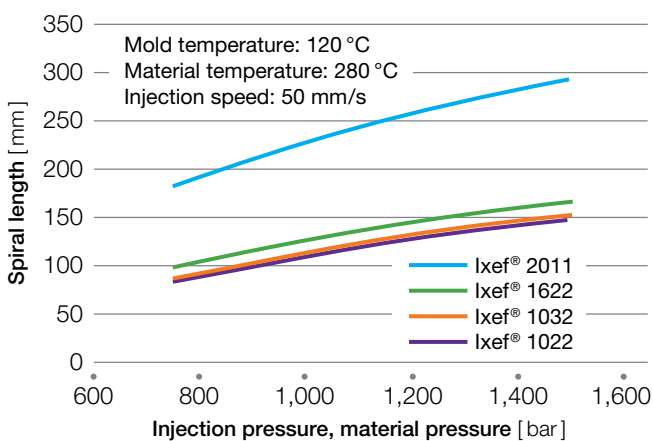
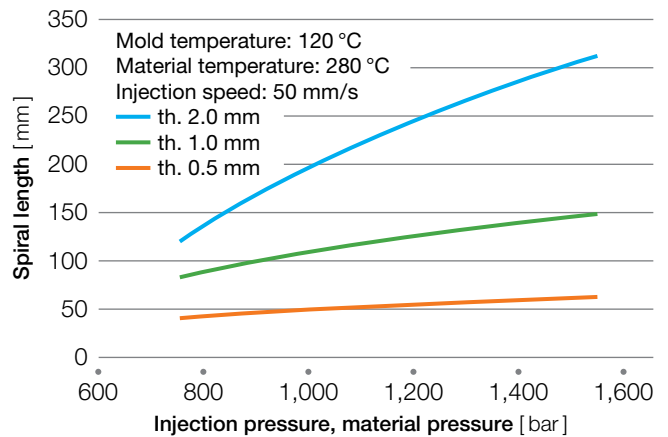


Figure 12: Spiral length as a function of injection pressure for various thicknesses of Ixef® 1022



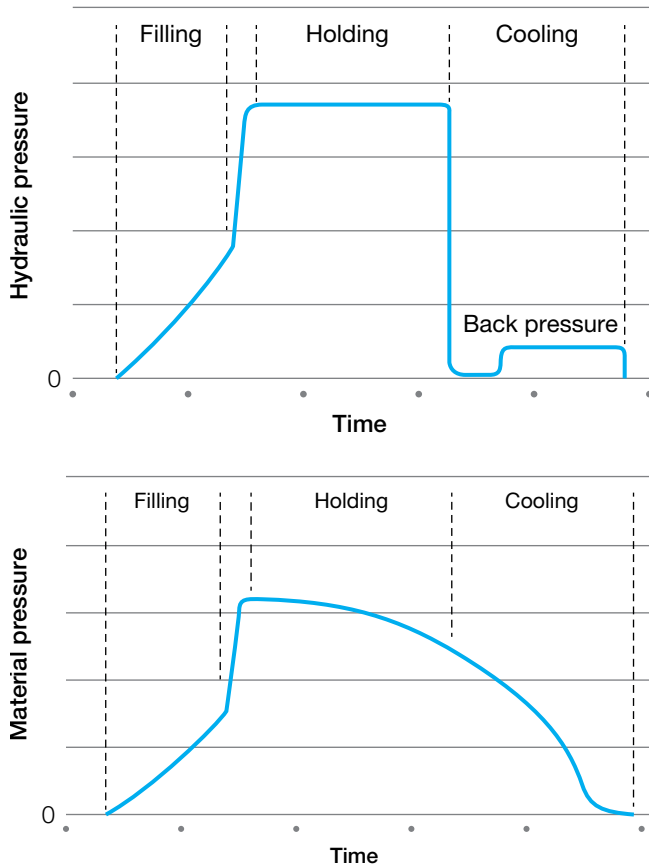
Holding Phase

The holding phase, which follows injection (Figure 13), completes the filling of the part and compensates for the decrease of the specific volume (caused by a reduction of the temperature and crystallization) 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 bar and 1,500 bar (4.5 kpsi and 21.8 kpsi). A holding pressure which is too high can lead to overfilling and difficulty during ejection.

The application time can be estimated at 3 seconds per mm of thickness ($w \geq 2$ mm (0.079 inches)). Nevertheless, one must verify during the first moldings 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 13: Hydraulic pressure and material pressure during a molding cycle



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):

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

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

The cooling time needs to be refined to optimize the cycle time.

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 (356 °F), a temperature at which its modulus is 5 GPa (725 kpsi).

Additives

Lubricants

Problems of part distortion during ejection or parts hanging up in the mold are often caused by the mold design or the injection molding conditions. If the modification of these parameters is not possible or does not solve the problem, Ixef® PARA compounds containing increased levels of lubrication can be used.

There are two Ixef® 1022 compounds that contain increased levels of mold 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 mold.

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

Colored master batches

Although Solvay sells several grades of Ixef® PARA molded in color, it is possible to use colored master batches to produce tinted parts.

For Ixef® PARA grades, we recommend (among others) colored master batches based on polyamide (PA 6.6).

Colored master batches containing TiO₂ 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 °C to 270 °C (464 °F to 518 °F) (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 °C to 250 °C (464 °F to 482 °F)
- 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 optimized in accordance with the initial molding results.

Recycling

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

As an indication, Figures 14 and 15 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 color.

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 3.

Table 3: Marking of Ixef® PARA 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 14: Evolution of tensile strength of Ixef® 1022 during successive recyclings at 30%

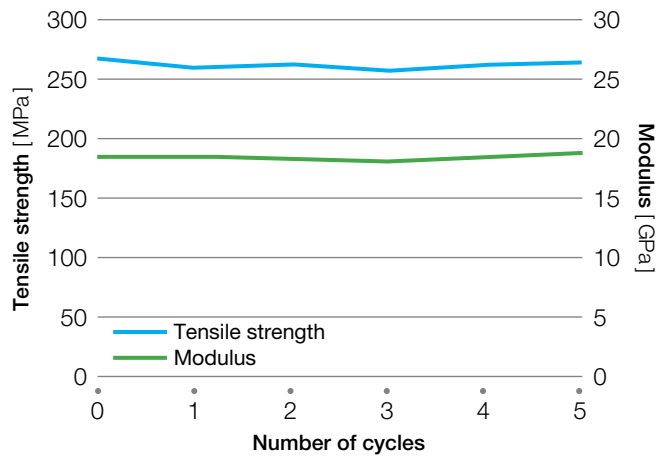


Figure 15: Evolution of elongation at break of Ixef® 1022 during successive recyclings at 30%

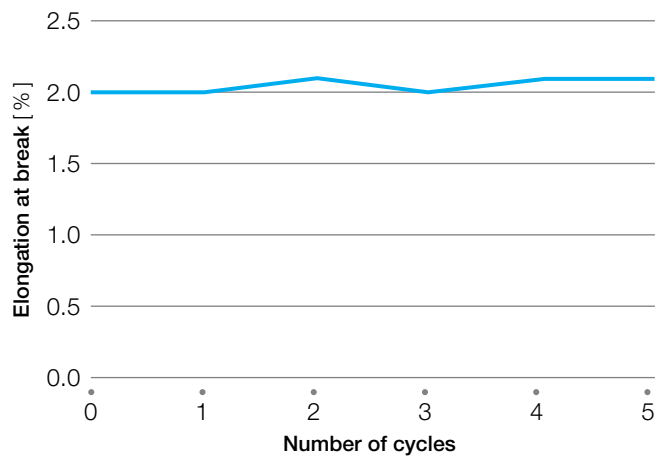


Table 4: Solutions for common processing problems

| Problems | Possible Remedies |
|--|---|
| Greasy spots on the parts and mold (signs of degradation) | Reduce material temperature (screw and/or hot runners) |
| White spots (same phenomenon but with cold mold) | Increase mold temperature Reduce material temperature (screw and/or hot runners) Release agents, lubricants |
| Bad surface appearance | Increase mold temperature Increase injection speed Verify holding time and pressure |
| Glass fibers visible on surface | Increase mold 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 mold 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 mold | Reduce holding time Reduce holding pressure level Increase the draft angle of the mold cavity |
| Sink marks | Increase the holding time and pressure Change the position and dimension of the injection point |

Injection Molding Equipment

Injection Unit

Ixef® PARA grades do not require special injection molding 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 1,000 bar at the head of the screw that means 0.8 to 1 t per cm² of projected surface area (for example a press of 120 t for a surface area of 120 cm²).

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

Because Ixef® PARA compounds are based on semi-crystalline polymers, they 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).

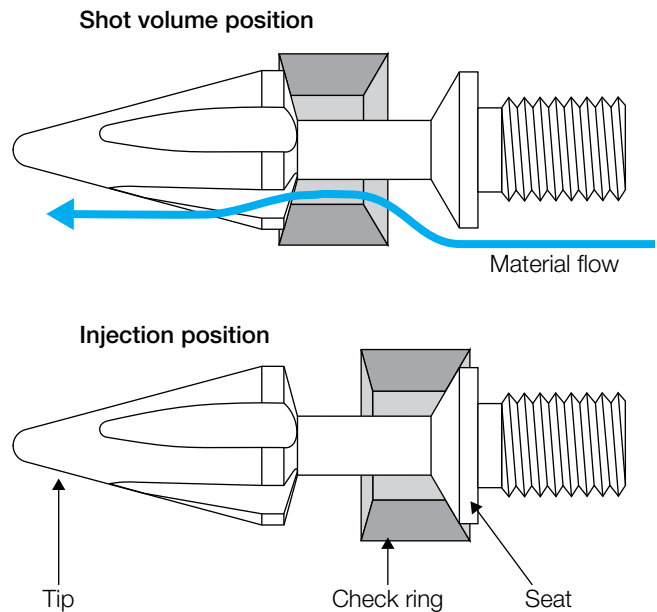
Preferably, new or renovated screws will be covered by a Stellite® alloy (on the sides and the thread crests), or a core-hardened alloyed steel with a high chrome content (high hardness and constant thickness).

Nitride-hardened screws are not recommended for the injection molding 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 16).

Figure 16: Check valve



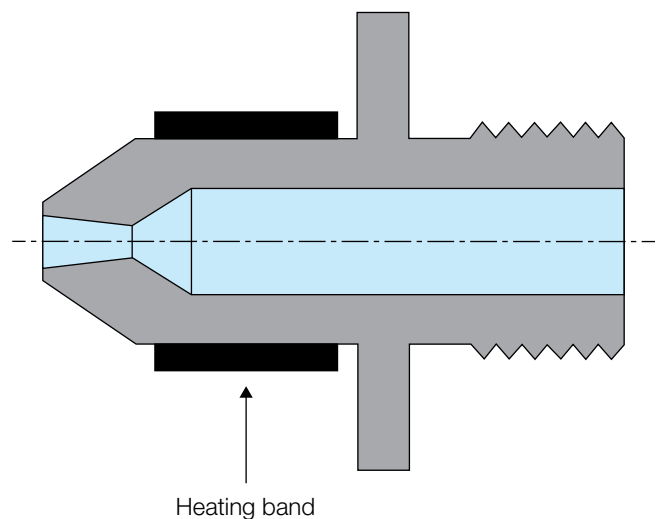
The valve is subject to heavy wear caused by the high shear rates of the material; a solution to wear is offered by protectively treating the surface with a gas-phase chemical deposit.

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 mold. It must be heated to compensate for the heat lost to the mold, which is cooler (Figure 17).

Figure 17: Open nozzle



A shut-off nozzle is not indispensable, but it does offer the advantage of eliminating any drooling. All types of shut-off nozzles 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® PARA compounds when melted, it is important to firmly screw the nozzle into the barrel to prevent any material infiltration and the resultant material degradation.

Mold

Construction materials

The steels used for constructing molds 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 favors 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 Ixef® PARA we recommend the use of through-hardened steels to obtain a hardness of between 54–60 HRC after heat treatment.

Examples:

- AFNOR Z160CDV12 – DIN X155CrVmo12-1 – 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 Z40CDV5 – DIN X40CrMoV5-1 – 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® PARA grades (Ixef® 1501, 1521 or 2530), in addition to the hardness criteria (54–60 HRC), it is recommended to choose corrosion resistant steels.

Examples:

- AFNOR Z40C14 – DIN X42Cr13 – 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® PARA compounds require a mold temperature of at least 120°C (248°F).

The surface temperature of the cavity wall must be as uniform as possible, with a deviation of no more than 5°C (41°F) 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® PARA compound).

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

- Around 100 kg: 3 to 6 kW
- Around 1,000 kg: 6 to 9 kW
- Around 2,000 kg: 9 to 12 kW

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

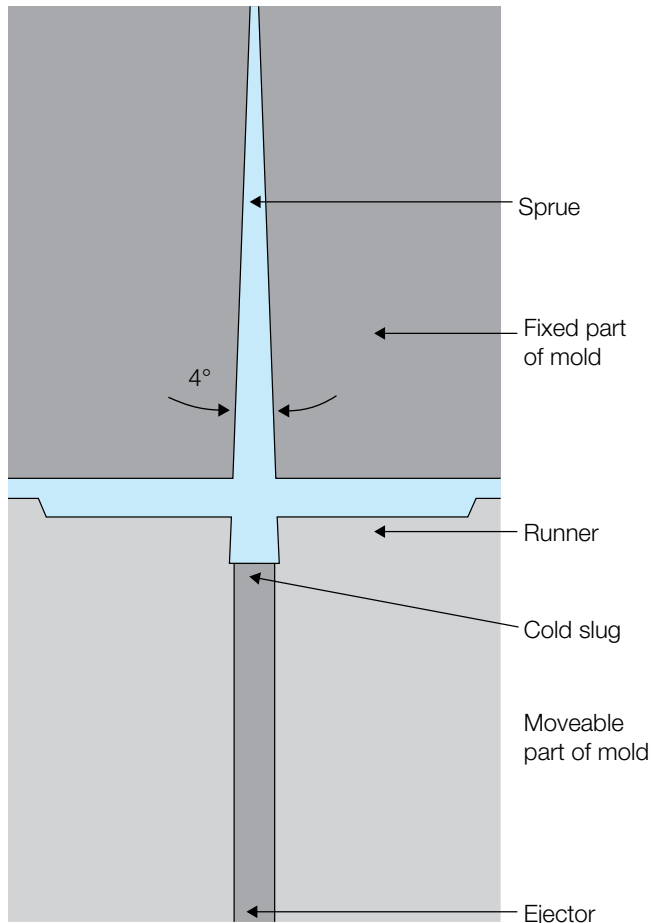
It is also necessary to thermally insulate the mold to limit heat transfer to the mold platens. The manufacturers of mold accessories (such as HASCO, DME, etc.) can be consulted on this subject.

Runners

The sprue, which leads the molten material from the nozzle of the injection unit to the mold parting line, must have a sufficient draft angle and a polished surface to prevent the sprue from sticking to the tool. The total draft angle must be between 3° and 4° (Figure 18).

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 (0.158 inch) for a volume below 50 cm³ and 8 mm (0.135 inch) for a volume above 150 cm³.

Figure 18: Cold slug



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 mold, a balanced feed system must be provided which fills all cavities at the same speed and pressure.

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

Injection gates

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

- Orientation of the fibers, 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 mold 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:

- $d^3 w$ for a direct feed
- $d^3 0.7 w$ for a lateral feed
- $d^3 2 w$ for a thin part

The injection gate must be positioned as a function of the mechanical and aesthetic requirements of the part. Solvay's technical marketing 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 19)
- At the end of long parts so that the orientation of the glass fibers is as uniform as possible (see Figure 19)
- 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 19: Placement of the injection point

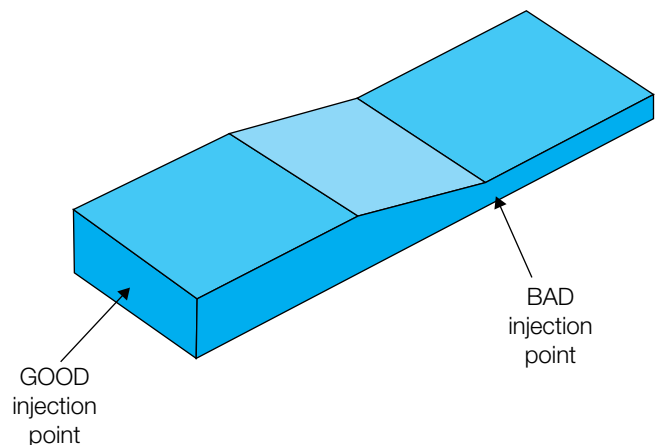
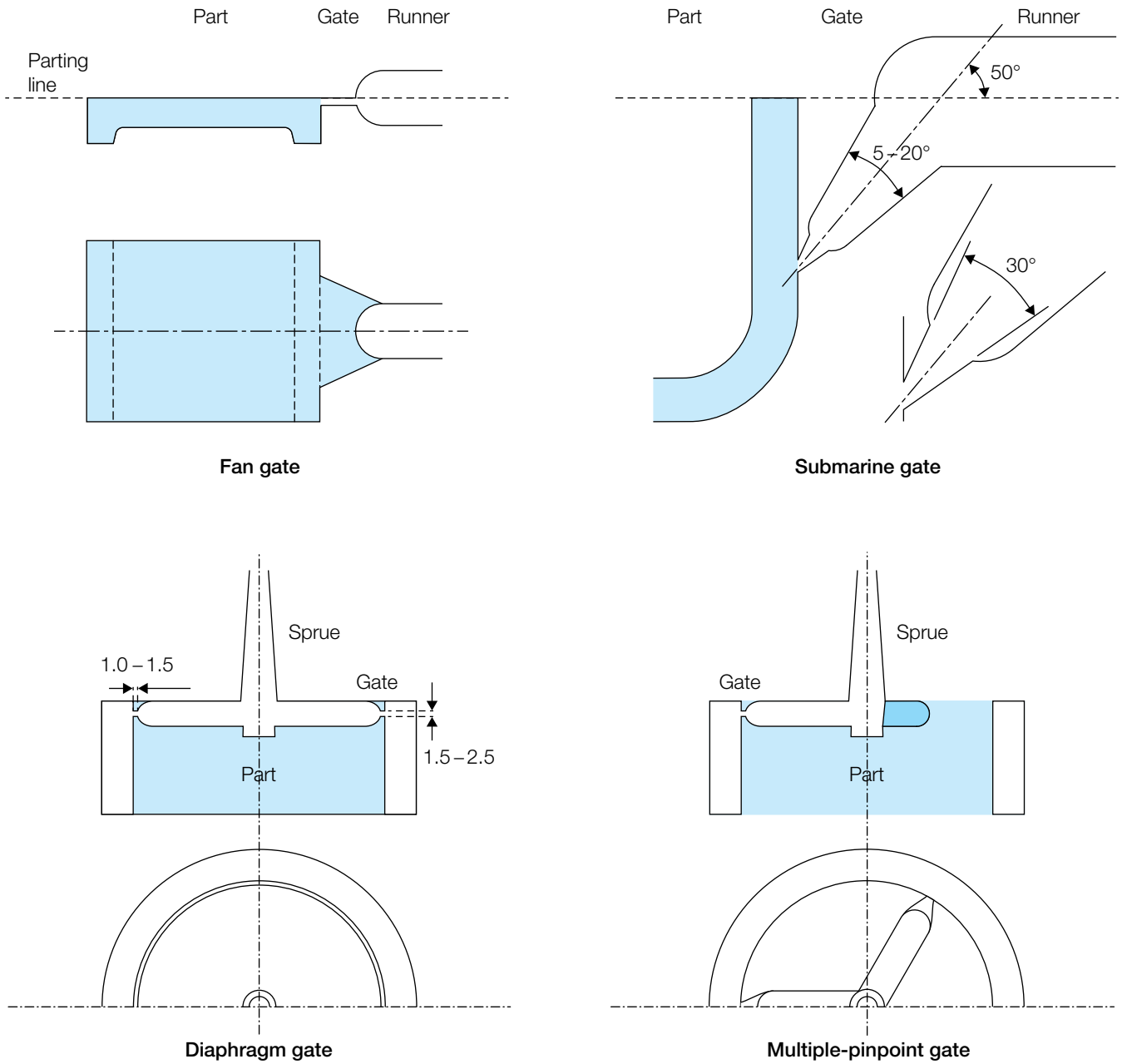


Figure 20: Examples of different injection gates



Safety Measures

Vents

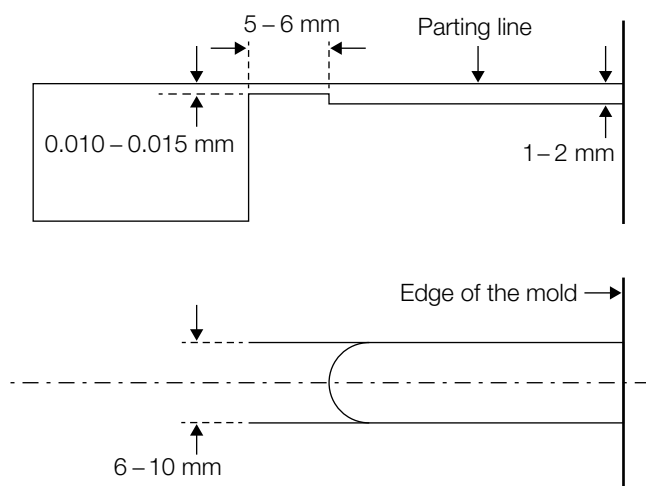
Molding parts with Ixef® PARA compounds requires the presence of vents in the mold. They must be designed to allow the evacuation of air in the mold when filling the cavity (see Figure 21).

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

The principal vent is constituted by the mold 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 mold inserts.

Wide but thin vents are recommended; in general, the width is from 6 mm to 10 mm (0.236 inch to 0.394 inch) and the thickness should not exceed 0.010 mm to 0.015 mm, to avoid flashing. At a distance of 5 mm to 6 mm (0.197 inch to 0.236 inch) from the cavity, it is useful to increase the thickness of the vents to 1 mm to 2 mm (0.039 inch to 0.079 inch).

Figure 21: Vents



Ejectors

The low shrinkage during molding and the rigidity at high temperatures of Ixef® PARA 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 mold, we recommend to check the alignment of the split line (blue marking) under a force corresponding to 15 % of the clamping force used in production.

The use of Ixef® PARA 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 molding 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 (356 °F). The cylinder can be reheated to 250 °C to 280 °C (482 °F to 536 °F) just before resuming molding.

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

During a definitive shutdown, it is recommended to completely empty the barrel and purge the cylinder several times with a polyethylene HLMI 10 (e.g. Rigidex® HM5411 from BP Solvay).

Assembly Techniques

It is sometimes necessary to assemble plastic materials in order to obtain a finished product that satisfies a specific function.

This assembly can be carried out directly with other plastic materials, regardless of whether they are of the same nature, but also with more traditional materials (steel, metal alloys, etc.)

There are numerous possibilities; however, this booklet aims to summarize the techniques suitable for Ixef® PARA compounds, specifying the results obtained where appropriate.

The material assembly techniques can be classified into one of the following three major categories:

- Welded assemblies, generally reserved for plastic materials of a similar nature
- Glued assemblies, particularly suitable for plastic materials of a different nature
- Mechanical assemblies, enabling different materials to be associated and potentially dismantled

These various techniques will be reviewed in turn in the following part of this document.

Assembly by Welding

Various welding methods are currently available on the market, each offering advantages and disadvantages that have to be assessed before making a choice.

The general principle of all of these procedures is that they create a fusion on the surface of the parts that are in contact, either:

- By a thermal process (hot air, heating plates or heating mirror)
- By friction (rotation, vibration or ultrasound)
- By electromagnetic process (EMAWELD™ process)

Thermal Welding

This process is particularly recommended for assembling asymmetrical parts that have fragile internal elements that are unsuited to welding by vibration or ultrasound.

The isolated fusion is achieved by bringing the parts to be welded into contact with an electrically heated plate covered with PTFE (heating plate method) or by radiation (hot air or heating mirror).

After heating, the elements to be assembled are pressed together. This technique only enables identical materials to be welded. Also, the contact surfaces preferably have to be flat. Ixef® PARA compounds are not really suitable for this type of welding.

Nylon type resins oxidize when exposed to the melting operation when welding. In the oxidized state, they become difficult to weld because the temperatures reached are very high.

Furthermore, the cycle times are very long compared with other welding techniques and problems related to the polymer sticking to the heating plate are very frequent.

Friction Welding

Welding by rotation

This technique is used for materials that are not sufficiently rigid to be welded by ultrasound. They are suitable for assembling circular parts with an axis of symmetry.

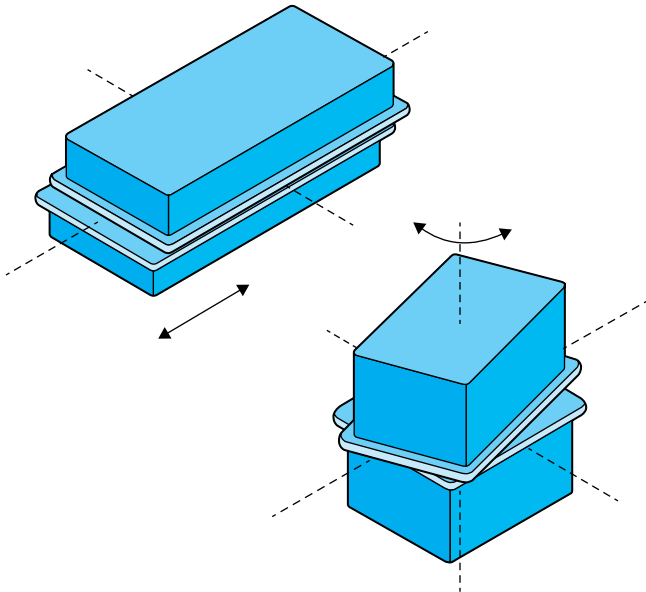
One of the elements to be welded turns around the axis of rotation and is in contact with the other element, which is immobile. The heat given off heats the material, and pressure is applied until it solidifies.

Welding by vibration

Derived from welding by rotation, linear and angular friction welding uses the heat given off from the two parts to assemble being rubbed together, which are then pressed together and agitated in an alternating movement following a translation or arc of a circle (relative vibratory displacement).

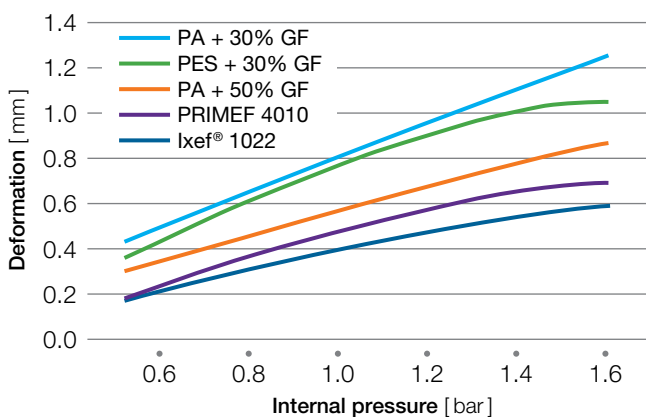
This technique was successfully used to assemble the box shown in Figure 22.

Figure 22: Linear welding and angular welding



After being pressurised (up to 1.7 bar max. representing the real working pressure), the deformation of the box in the transversal direction was measured. The values compared for different materials are shown in Figure 23.

Figure 23: Welding by vibration⁽¹⁾



⁽¹⁾ Cold shrinking deformation under internal pressure (maximum pressure in the box = 1.7 bar)

Note: For it to be possible to weld using one of the aforementioned techniques, the parts have to be of a shape that enables the two parts of the assembly to be vibrated.

The potential to weld the materials is proportionate to the friction coefficient and inversely proportionate to the charge rate, density, specific heat and fusion temperature.

Welding by ultrasound

Principle

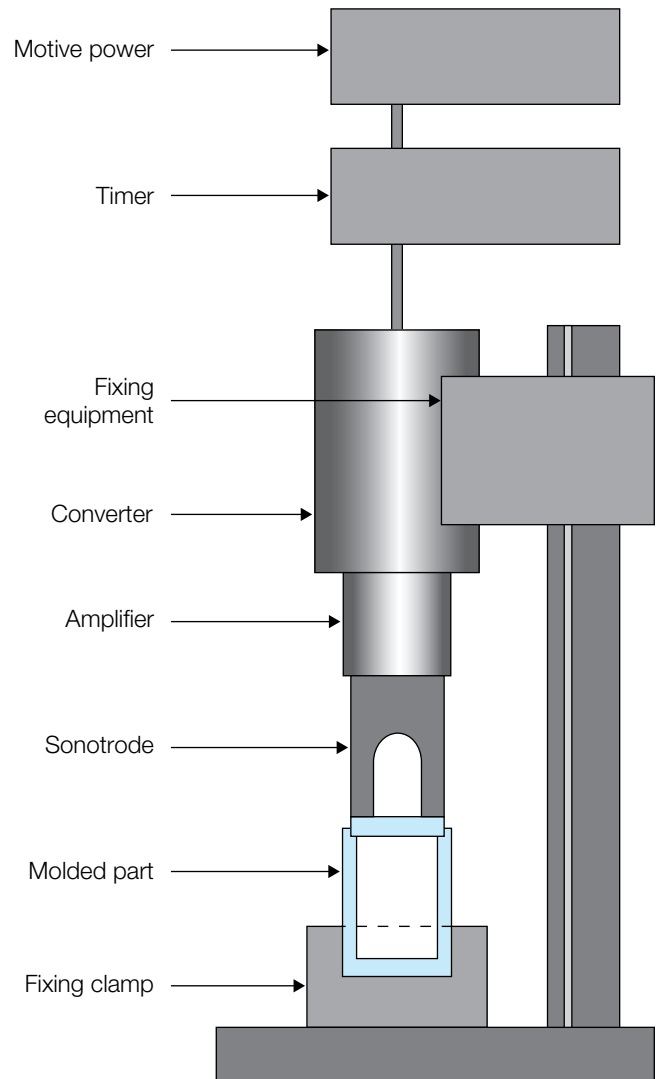
An ultrasound welder is equipped with an ultrasonic converter (ceramic material).

The mechanical vibrations resulting from this piezoelectric (or sometimes magnetostrictive) transformation are transmitted through the two parts to be welded by a sonotrode.

These ultrasonic vibrations, through the friction (and fatigue) of the material, result in the heating up of the joint of the parts to be assembled.

The weld is said to be “close” when the vibrating sonotrode is applied very closely to the assembly joint (plastic material with a weak rigidity module and thus poor ultrasonic wave conductors). This technique’s limitation is in the need for the ultrasound to match as closely as possible the shape of the joint to be welded.

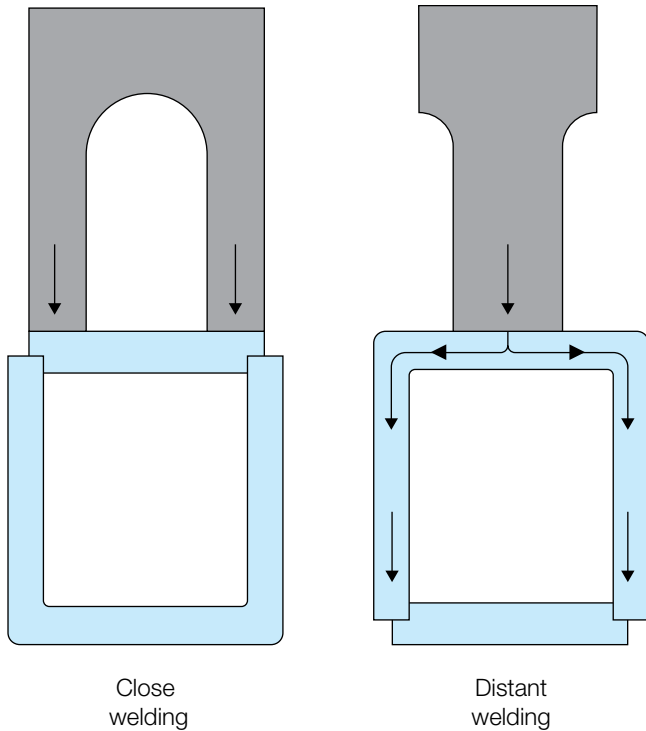
Figure 24: Basic equipment for ultrasound welding⁽¹⁾



⁽¹⁾ Mecasonic S.A. (Ville-la-Grand, France) “Applications des ultrasons aux thermoplastiques” p.3

The weld is said to be “distant” when the sonotrode can be distanced from the welding point (plastic materials propagating vibrations without cushioning, i.e. with a high rigidity modulus). See Figure 25.

Figure 25: Close welding and distant welding⁽¹⁾

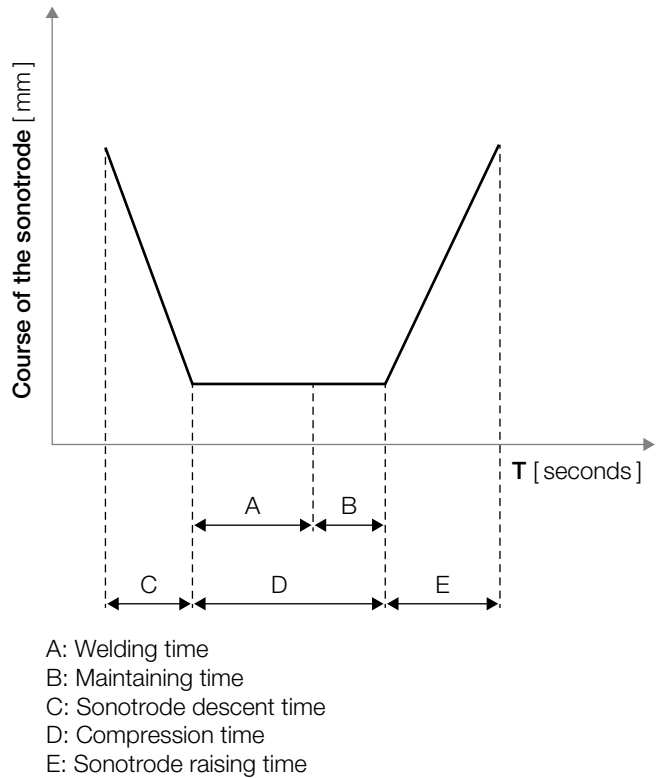


⁽¹⁾ Mecasonic S.A. (Ville-la-Grand, France) “Applications des ultrasons aux thermoplastiques” p.3

This method makes it possible to weld complex shaped parts with a simple form of sonotrode, and also to assemble large parts using several carefully positioned sonotrodes, taking into account the “critical distances” beyond which the weld is no longer even.

A cycle of ultrasound welding operations is shown in Figure 26.

Figure 26: Cycle of ultrasound welding operations



Basic criteria to be considered

The choice of the shape determines the success or failure of the assembly, even for materials that are suitable for welding.

- The initial surface should be reduced in order to obtain a high energy concentration, required for rapid welding
- The clearance should be sufficient in the socket for the parts to be assembled to be able to vibrate slowly in relation to one another and create the friction required for welding
- An area for the return of the melted material should be envisaged so as to avoid external blistering and the cracking of joints

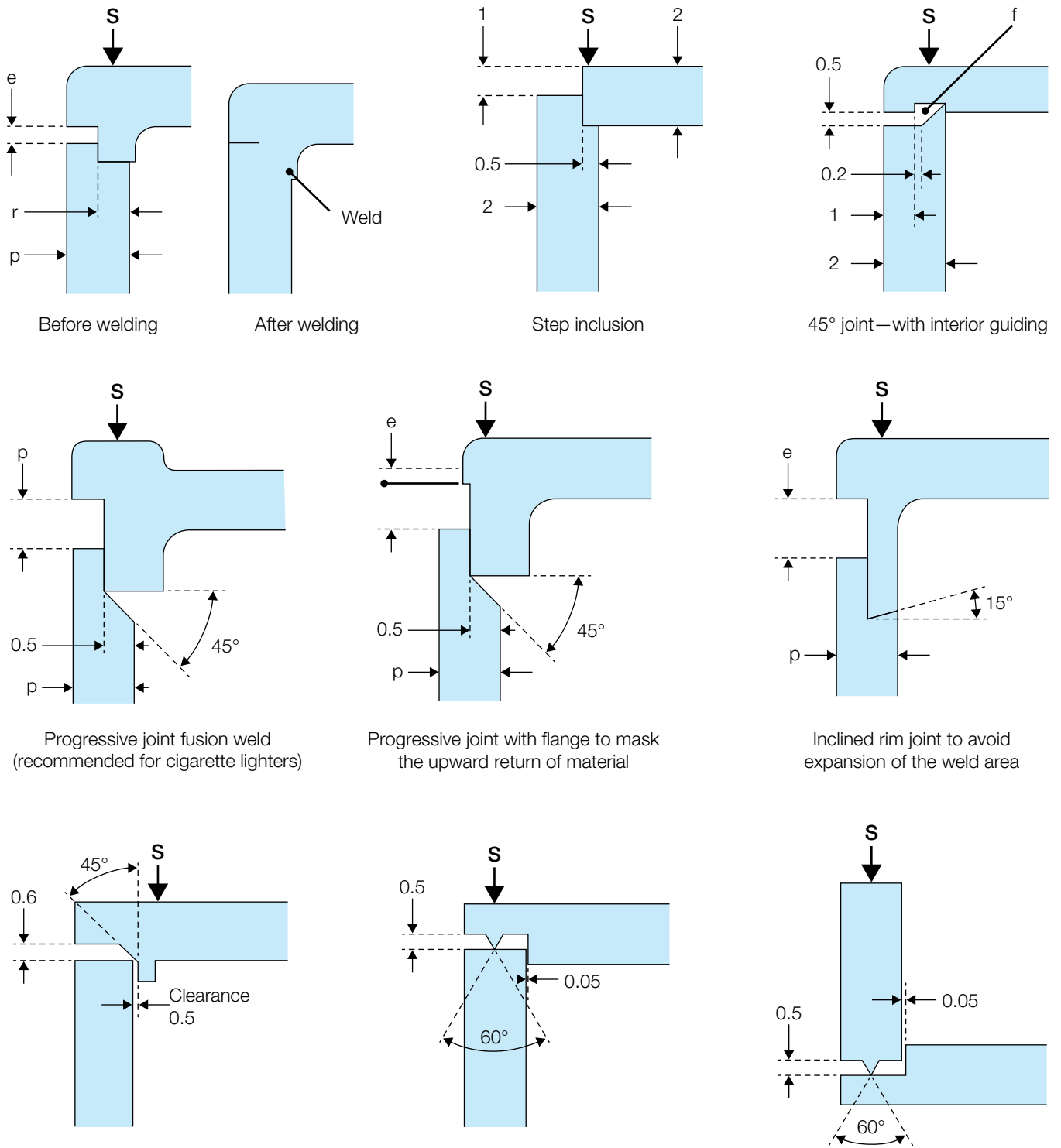
A few examples of joint and inclusion designs recommended for ultrasound welding are shown in Figure 27. Errors to be avoided are shown in Figure 28.

A few models of inclusions envisaged for ultrasound welding

On examination of all of the illustrations in Figure 27, it should be remembered that after assembly the setting guide is superfluous and the part has the same sides that it would have had if there were no joint.

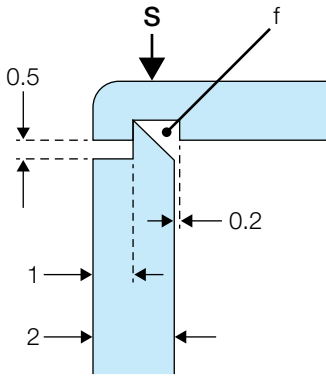
In any case, the inclusions should be unrestricted.

Figure 27: A few models of inclusions envisaged for ultrasound welding

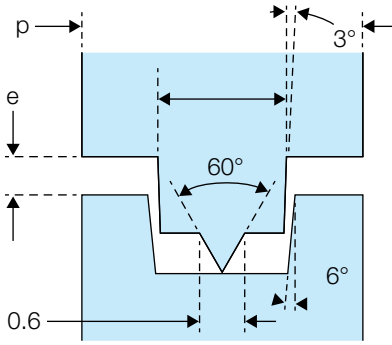


Key: r = material expulsion area, e = setting guide, f = melted material flow area, s = sonotrode contact with the part
 Mecasonic S.A. (Ville-la-Grand, France) "Applications des ultrasons aux thermoplastiques" pages 2 to 5.

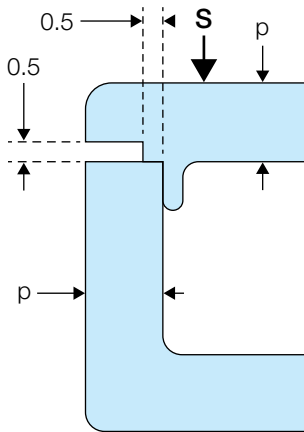
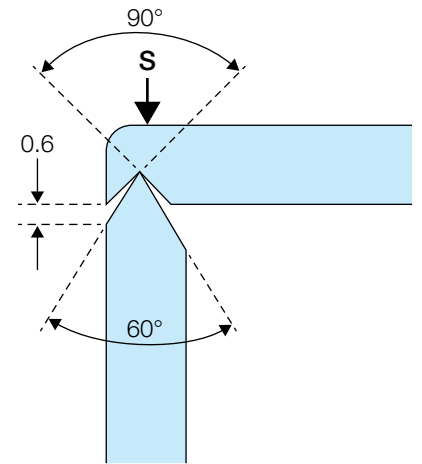
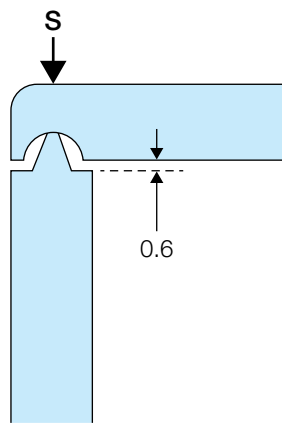
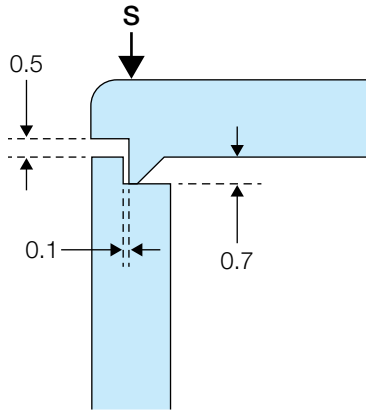
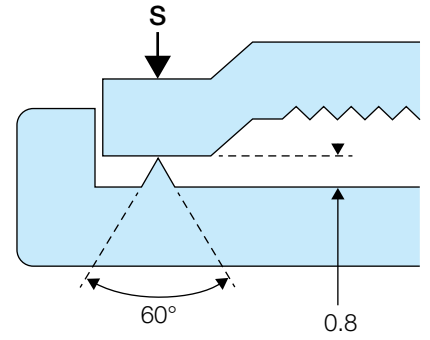
Figure 27 continued: A few models of inclusions envisaged for ultrasound welding



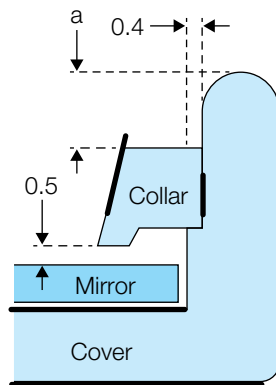
45° joint - with exterior guiding



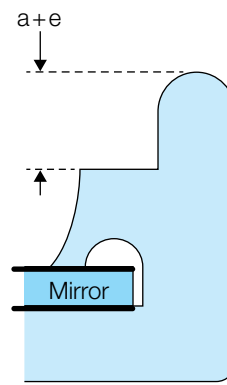
Joint for welding reflectors



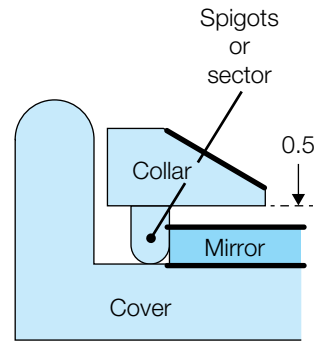
Inclusion without clearance



Before welding the collar does not touch the mirror

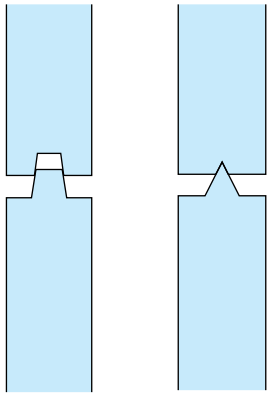


After welding the collar is reinforced on the mirror

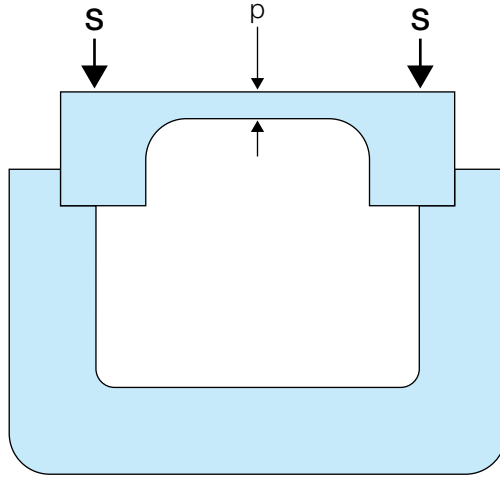


Fitting of a mirror in the cover

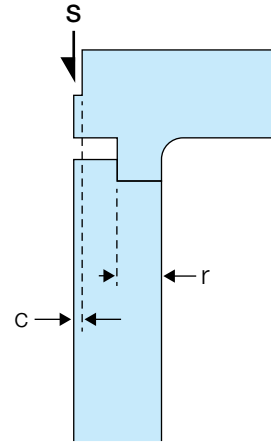
Figure 28: Errors to be avoided



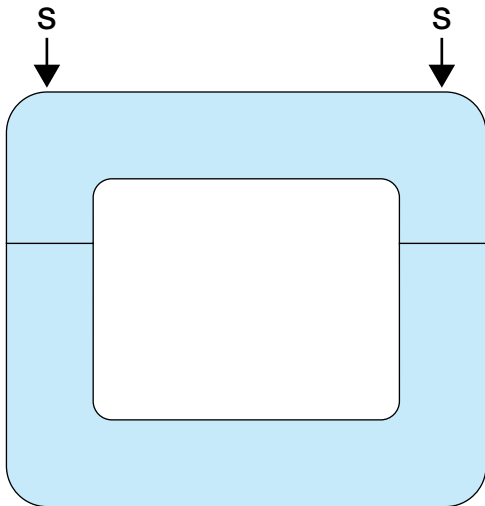
Inclusions that are too tight, preventing any relative vibration.



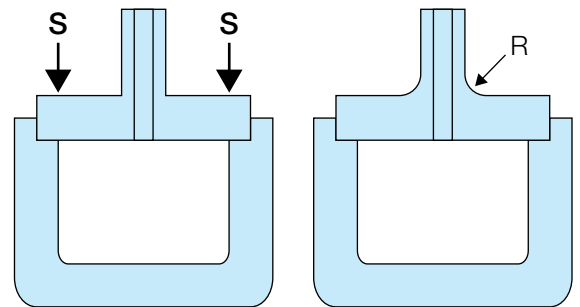
Insufficient thickness, the part is going to collapse in the middle, owing to the effect of the ultrasound. This phenomenon is commonly known as "central flash".



Contact area C of the sonotrode is too weak compared with r. The part is going to be deformed by the sonotrode. In general, $c > 2\text{mm}$.



Facing surfaces too large. The weld will be uneven.



Wrong

Right

Sharp angles next to a rod. A connection is required, otherwise the rod will break at the base.

Mecasonic S.A.

Application to Ixef® PARA Compounds

Welding trials with a simple joint were conducted for our polymers.

To weld 2 simple joints, it is necessary to use the welding process by energy director.

The energy directors are the machining allowance as shown in Figure 29. They should be the right size to enable the material forming this excrescence to spread across the entire welding area.

The test samples used are shown in Figure 30.

The features of the equipment used are as follows:

Megasonique Omega 8000 Welder

- Ultrasound frequency: 20,000 Hz
- Power generated: 800 W max.
- Welding time: 0 to 3 seconds
- Maintain time: 0 to 5 seconds
- Hydraulic pressure applied on the sonotrode: 0 to 6 bar

The welding conditions are given in Table 5.

The quality of the welding was assessed by a pure shearing test of the joint. The test results are shown in Table 6 for information purposes.

We note that the shearing stresses of the polyarylamide Ixef® 1022 welded joints are similar to those for PA 6 and PA 6.6 30% FV and for PC 30% FV.

Our experience demonstrates that the quality of the welding, carried out on molded parts with Ixef® PARA compounds are excellent.

Table 5: Welding conditions

| Welding Conditions | Ixef® 1022 Unit |
|--------------------|-----------------|
| Welding pressure | 5 bar |
| Duration | 20 seconds |
| Holding pressure | 5 bar |
| Duration | 10 seconds |

Figure 29: Shape of the joints and energy directors

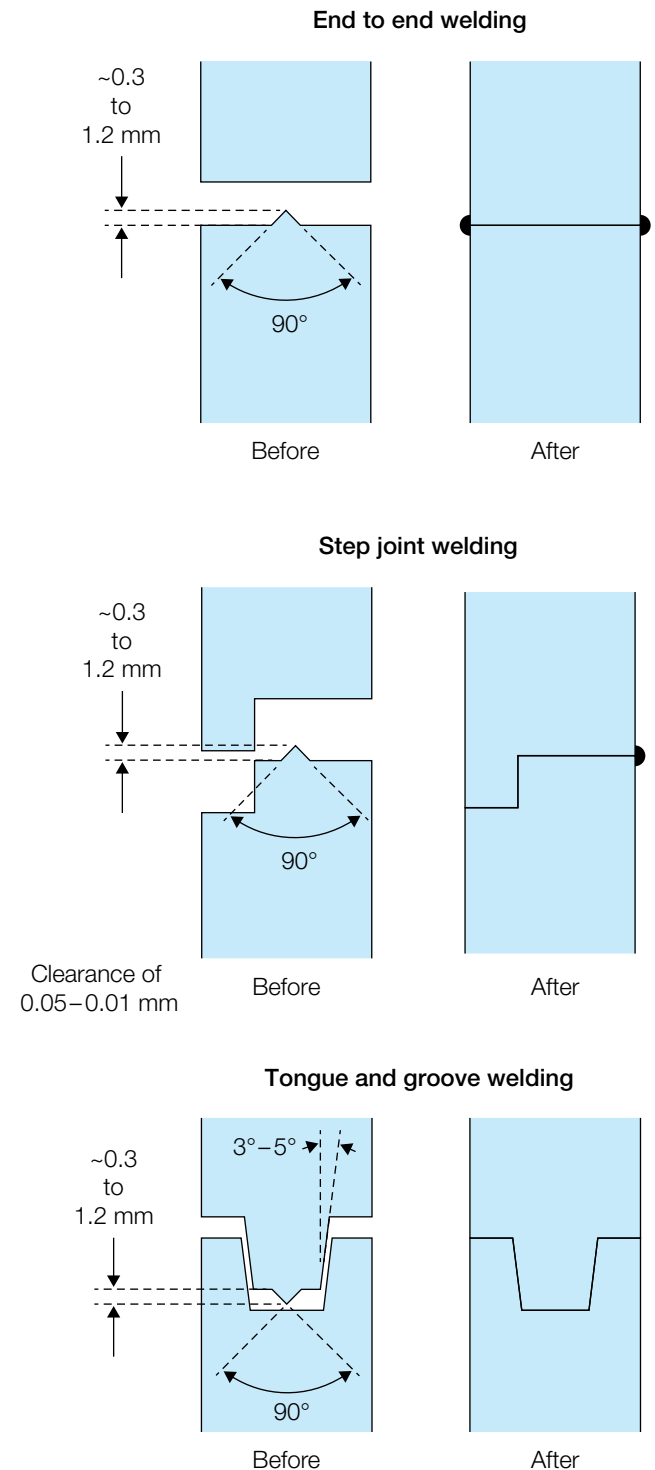
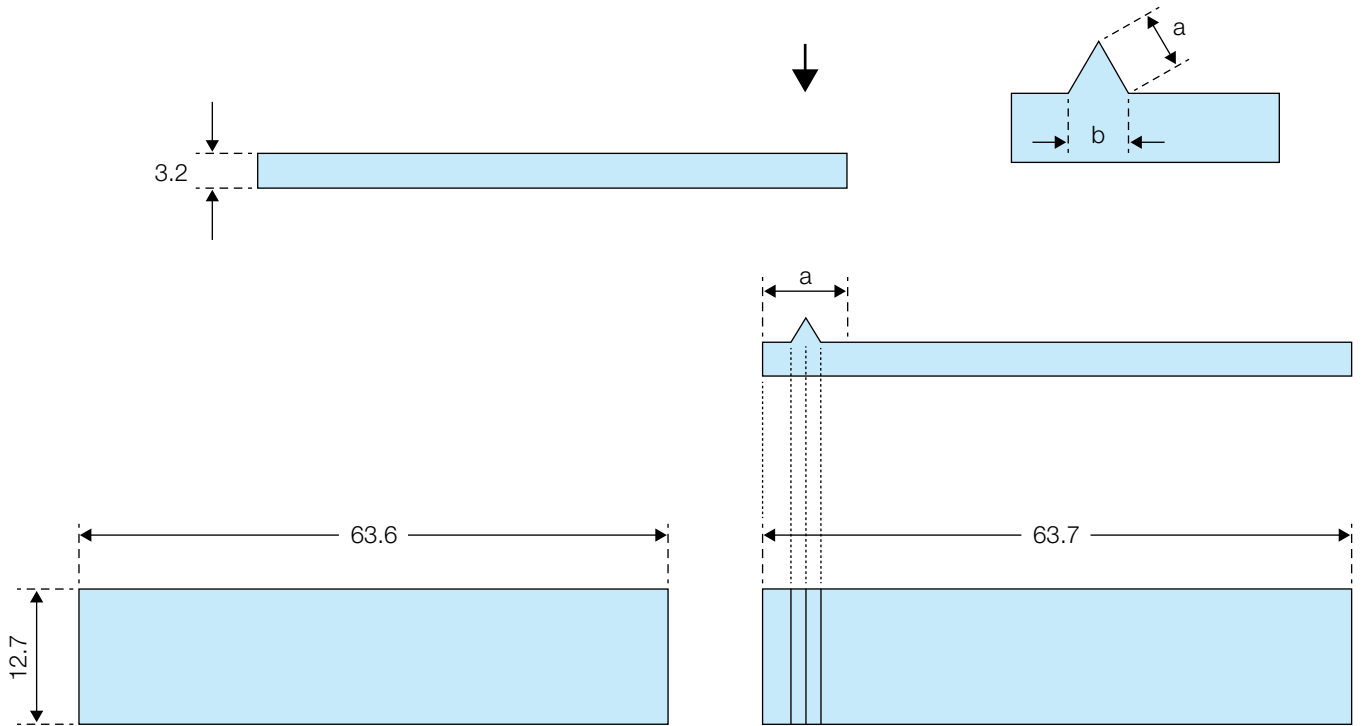


Figure 30: Test samples for welding by energy director



Key: a = weld area, b = size of the energy director

Table 6: Shearing test of a welded joint

| Compounds | Force Applied on the Sonotrode [N] | Welding Time [seconds] | Breadth b of the Energy Director [mm] | Shearing Rupture Stresses [MPa] |
|-----------------|------------------------------------|------------------------|---------------------------------------|---------------------------------|
| Ixef® 1002 | 580 | 0.8 | 0.55 | 26 |
| Ixef® 1022 | 580 | 0.8 | 0.55 | 19 |
| Ixef® 1313 | 580 | 0.8 | 0.55 | 20 |
| Ixef® 1501 | 580 | 0.8 | 0.55 | 19 |
| Ixef® 2620 | 580 | 0.8 | 0.55 | 18 |
| Ixef® 6301 | 580 | 0.8 | 0.55 | 20 |
| PA 6, 30 % GF | 580 | 0.8 | 0.55 | 21 |
| PA 6.6, 30 % GF | 580 | 0.8 | 0.55 | 22 |
| PBT, 30 % GF | 580 | 0.8 | 0.55 | 13 |
| PC 30 % GF | 580 | 0.8 | 0.55 | 23 |

Electromagnetic Welding

Limitations of use

The quality of the welding process depends on the capacity of the material to transmit ultrasound vibrations.

Generally speaking, materials that have a high elasticity module and low mechanical loss factors are highly suited to this type of welding.

The presence of certain additives and charges forming various compounds can greatly reduce the quality of the welds, for example:

- Water (production of vapor bubbles within the welded joint)
- External demolding agents (reduction of the friction phenomenon)
- Internal lubricants (reduction of intermolecular friction)
- Mineral charges and glass fibers (there is a direct correlation between the increase in the charge rates and the reduction of the mechanical resistance of the welded joints)
- Elastomer materials (reduction of rigidity and increase in the capacity to absorb ultrasounds)
- Titanium oxide (white colored materials)

Ultrasound welding of materials of a different nature is generally not possible. This is essentially due to the fusion temperature differences and the macromolecular structure that prevents any significant inter-penetration.

Correct results can nevertheless be obtained in certain cases of joining materials. The resistance of the welded joints is greatly reduced in this case:

- PC/Ixef® PARA: between 5 % and 15 % of the values obtained for Ixef® PARA/Ixef® PARA
- PMMA/Ixef® PARA: around 20 %
- PA amorphous/Ixef® PARA: around 60 %

Principle

Electromagnetic welding, commonly known as EMAWELD, achieves structural, hermetic or high pressure joints through operations that can be automatic, semi-automatic or manual.

The weld is obtained by heating a thread of thermoplastic electromagnetic material by induction between the parts to be joined at the fusion temperature of these parts.

The layer of electromagnetic material is composed of a dispersion of metallic powders (iron, stainless steel, graphite, ferrite, etc.) in a matrix of the same thermoplastic as the parts to be assembled.

An alternating current generates a variable magnetic field, responsible for the induction of the current in the metallic powder. This powder is heated by Joule effect.

The heat generated in this welding material liquifies the thermoplastic matrix, which in turn liquifies the surfaces of the parts to be welded, bringing about the assembly with no internal current. In practice, the time taken to reach the melting temperature varies from a few seconds for small parts to 15 to 60 seconds for large parts (welding joints of 50 cm to 400 cm (20 inch to 157 inch).

Material

Four basic components make up the system:

- Induction generator
- Induction coils (copper tubes or plates)
- Fixing support (non-conducting)
- EMAWELD materials (specific to each application)

The material matrix is either identical to that of the plastic to be assembled, or formed of a special mixture of the two polymers to be welded.

It should be noted that the design of the joint is an essential stage in the success of the weld.

Advantages of the EMAWELD process

Traditional welding of charged materials is limited. Indeed, the fibers or charges replace part of the thermoplastic matrix, which leads to low resin areas that are thus delicate to weld.

In the EMAWELD process, the thermoplastic matrix of the special material carries out a dual function: transporting the fusion heat and also providing additional resin required at the polymer on polymer junction.

In addition, it is even possible to reactivate the weld joint and separate the assembled surfaces if required.

Conducted trials

Initial directional trials were conducted with the Ixef® 1022.

The features of the equipment used are as follows:

- Generator type: EIA-20
- Coil type: STD HAIRPIN
- Load: 105 %
- Grid: 140 mA
- Variac: 100 %
- Frequency: 0.25 MHz
- Pressure (Gauge): 5 bar
- Cylinder size: 2.5 inch
- Coil leads: STD
- Nylon as EMAWELD material
- Test samples: 60 × 60 mm (thickness: 2 mm) (2 × 2 inch (thickness: 0.08 inch))
- Assembly: coverage of test samples over 15 mm to 20 mm (0.59 inch to 0.79 inch (average welding area: 950 mm²))

The welded test samples were subjected to a shearing test, the results of which are given in Table 7 (minimal values obtained).

The first results obtained are thus encouraging, even though they are lower than those obtained by the ultrasound process.

The test conditions should be optimized in order to be able to draw definitive conclusions.

Table 7: Shearing

| Compound | Shearing Stresses [MPa] |
|------------|-------------------------|
| Ixef® 1022 | 6 |

However, it is possible to consider that this process will be reserved for parts of a simple shape with large areas to be welded. The mechanical resistance of such assemblies will be limited.

Further information on the EMAWELD process can be obtained by directly contacting the EMABOND company, whose address is given in the appendix.

Assembly by Gluing

Principle

Gluing is a very widespread assembly method (the binding agent is “the glue”).

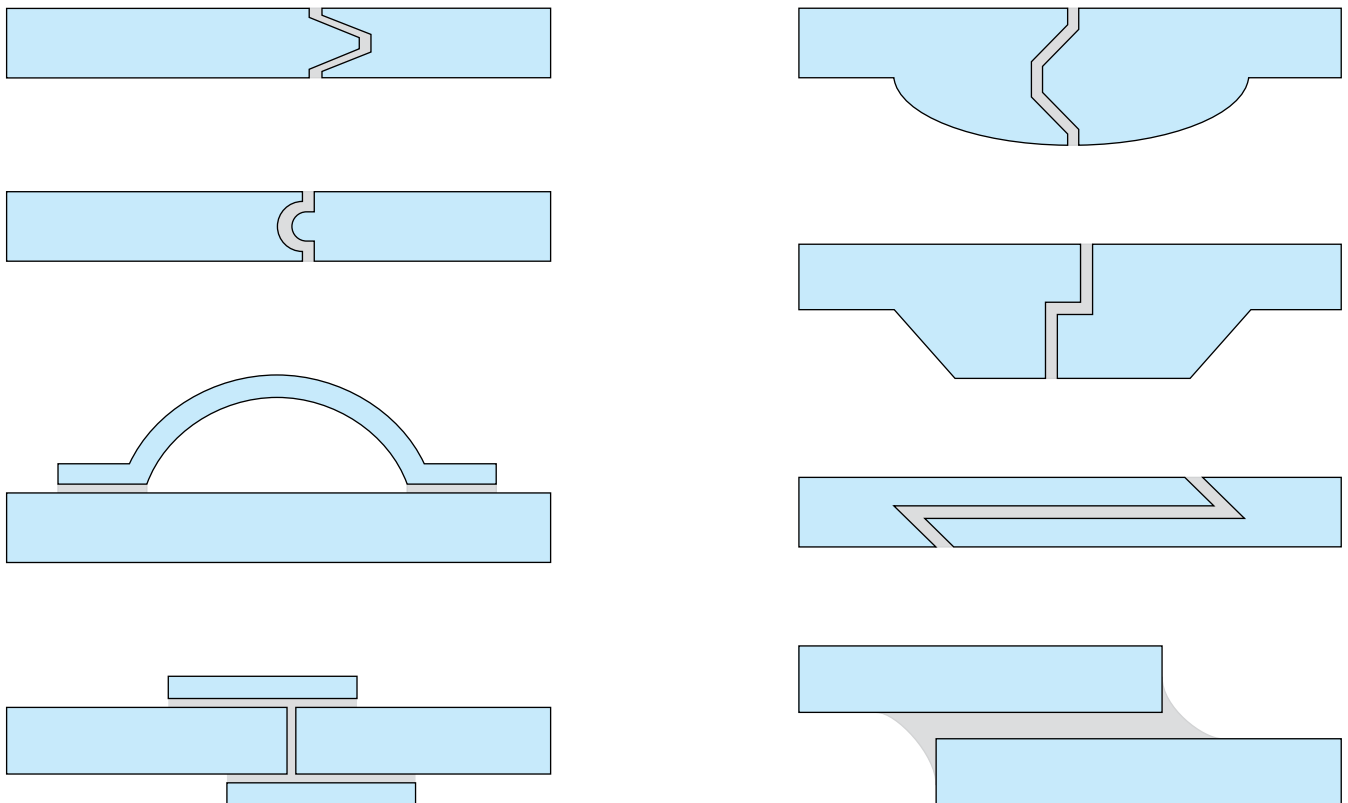
This process can be used to assemble plastic materials of a similar or different nature, and sometimes to assemble plastics with other materials (in particular soft steel).

The gluing mechanism is related to different theories that we shall not go into here: mechanical, electrical, diffusion, polarity and absorption, etc.

The glue contact with the elements to be assembled should be as great as possible, which generally requires prior preparation of the surfaces to be glued in order to remove foreign particles (dust, grease, oils, oxides, water, etc.).

The application of the glue, which is initially fluid, is achieved with the help of a certain degree of pressure (removal of trapped air), leading to good adherence and suitable resistance when the glue solidifies (see Figure 31).

Figure 31: Types of joints recommended for assembly by gluing



Types of Glues

Glues made from natural materials are increasingly being replaced by synthetic glues.

Classification

By nature

- Thermosetting resins: phenolics, epoxides, polyesters, polyimides, etc.
- Thermoplastic resins: acrylics, cellulose, vinyls polyimides, etc.
- Elastomer: nitriles, polyurethanes, silicones

By hardening method

- Chemical reaction
- Evaporation of a solvent
- Cooling after fusion

By presentation

- Liquid with or without solvent
- Paste of one component with or without solvent
- Paste of several components with or without solvent
- Solid (band, film, stick)

Application for Ixef® PARA Compounds

Gluing trials were conducted with Ixef® 1022. Figure 32 shows the shape and sizes of the test samples.

The glued test samples underwent shearing trials (traction speed = 5 mm/min (0.2 inch/min)).

Different glues were tested (references and manufacturers given in the appendix) for Ixef® PARA/Ixef® PARA, and Ixef® PARA/steel assemblies. The results are given in Table 8.

Test samples were injection molded using Ixef® 1022. Surfaces to be glued were degreased with isopropanol. Samples were tested for shearing at 5 mm/minute. Joints were not aged.

Figure 32: Shape and size of the glued test samples

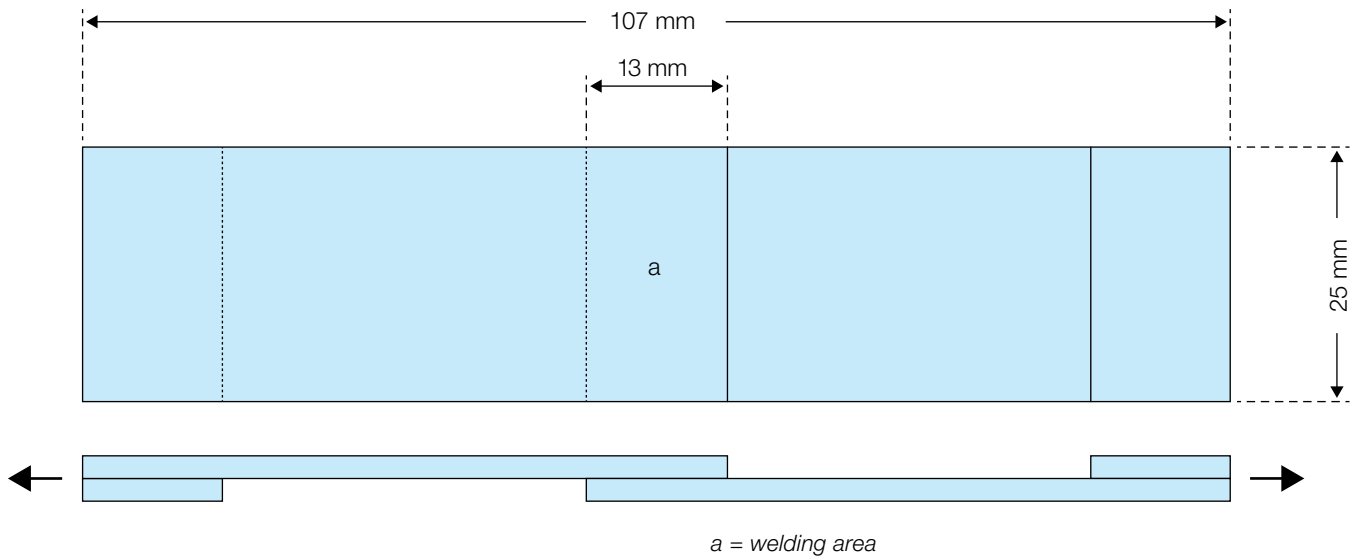


Table 8: Rupture stress in shearing, N/cm²

| Materials | Cyanoacrylate Glue | Acrylic Glue | Epoxy Glue | Polyurethane Glue |
|-----------------------|--------------------|--------------|------------|-------------------|
| Ixef® 1022/Ixef® 1022 | 86 | 114 | 20 | 13 |
| Ixef® 1022/steel | 33 | 147 | 70 | 11 |

Advantages and Disadvantages of Glues Tested

Cyanoacrylate glues (Cyanolit® 811)

- Very fast assembly speed
- High shearing resistance
- Maximal usage temperature: 80 °C (176 °F)
- Low resistance to impact
- Poor water-resistance of bond

Acrylic glues

(Permabond® F246 for Ixef® PARA/Ixef® PARA and F241 for Ixef® PARA/Steel)

- Fast assembly speed (1 to 3 minutes)
- Good resistance to shearing and impact
- Good water resistance
- Use of an activator primer
- Maximal usage temperature: 100 °C (212 °F)

Epoxy glues

(Araldite® AY 105/Hardener HY 991)

- Slow assembly speed
- Good resistance to impact
- Good water resistance
- Requires the glued parts to be baked
- Maximum usage temperature: 200 °C (392 °F)

Polyurethane glues

(“Bison” Polyurethane Glue)

- Slow assembly speed
- Good shock resistance
- Good water resistance
- Retain their properties at low temperatures
- Creep above 30 °C (86 °F)

Based on these results, we recommend more specifically the use of acrylic glues for the Ixef® PARA compounds.

Mechanical Assembly

The linear dilation coefficient of Ixef® PARA compounds is close to that of metals and thus enables mechanical assemblies to remain specific for a wide temperature range.

Fitting of Metal Inserts

The fitting of inserts is a traditional technique enabling forces located in very specific areas to be withstood by a greater surface area of plastic material.

Inserts can be placed in the mold before molding (two-shot injection) or placed on the parts after molding (either by vibration, cold shrinking pressure, by pressure after heating by conduction, or even by ultrasound).

The use of Ixef® PARA in the field of structural parts leads us to encounter frequent problems in the fitting of inserts.

Two-shot injection

It is possible to two-shot inject Ixef® PARA onto metallic inserts (and also onto parts that have already been molded).

It is advisable to calculate the temperature at which the insert should be placed, in order to avoid an unacceptable disturbance of the flux during injection.

For very fine thicknesses of walls, the insert should always be heated to the temperature of the mold.

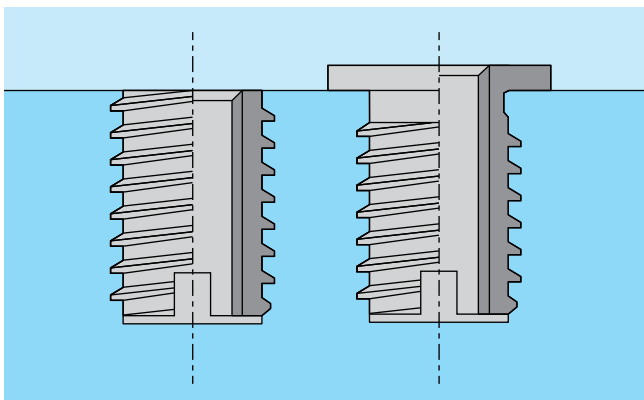
For inserts that can be deformed (e.g. with aluminium walls), the thresholds and feed channels should be widened in order to enable the precise pressure regulation for effective maintenance.

Insertion

Ixef® PARA can pose specific problems in terms of inserts owing to their very poor elongation at rupture, and the difficulties of placing the inserts into the mold at high temperatures.

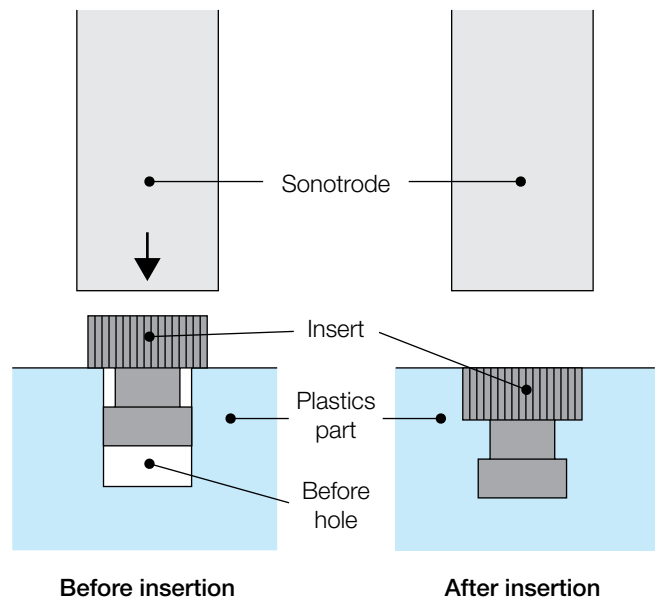
Fitting of inserts after molding thus offers a solution as long as the fitting is carried out correctly.

Figure 33: Insert principle (Quick-Sert®)



Source: Böllhoff GmbH & Co. KG, Verbindungs- und Montagetechnik (Bielefeld, Germany) "Gewindeeinsätze für Kunststoffteile", p.16

Figure 34: Fitting of an insert



Source: Mecasonic S.A. (Ville-la-Grand, France).
"Applications des ultrasons aux thermoplastiques" p.13

Insert fitting techniques

Insert producers develop specific shapes of dowels for each of the fitting techniques and advocate the dimensions of the spaces associated with them.

The most common fitting techniques are the following:

- Fitting by expansion
- Hot fitting by conduction
- Fitting by self-tapping dowel
- Fitting by ultrasound

It appears that the latter technique will no longer be used in the future, as the ultrasounds can lead to health problems for personnel.

Fitting by ultrasound is actually banned in Italy and in the process of being banned in France.

In any case, the system by ultrasound is very similar to the thermal process insofar as the insert's vibrations against the recess result in the generation of heat that makes the material melt around the insert.

This system does not offer any advantage over that of fitting by thermal conduction (the performances obtained are less satisfactory even) and lead to far more inconvenience, if only in terms of the noise level generated by the appliance.

Application for Ixef® PARA compounds

The Böllhoff/Otalu company has conducted tests for the fitting of inserts on Ixef® 1022; 10 mm (0.394 inch) thick plates were injected.

The problems to resolve related to the shape of the insert for a given position (diameter, coning, cylindrical or attachment insert) and also concerning which fitting technique to recommend.

Fitting by expansion (Dodge® Inserts)

The Dodge® dowel is a threaded, cylindrical dowel, knurled externally on one section of its length.

Tests conducted with Dodge® M4 type dowel involving a total implantation length of 8 mm (0.315 inch) highlighted the absence of fissuring in the material around the insert.

It should nevertheless be ensured that the manufacturer's instructions are followed, particularly as to the diameter of the recess that should comply with recommendations (for M4, the diameter d equals 5.5 mm (0.217 inch)).

The sides around the insert should respect the prescribed dimensions, thickness of side $a = 0.6 d$ and thickness of base $b = 0.5 d$.

Mechanical features

A diagram of the principle of the tests undertaken is provided in Appendix 1.

Three tests were conducted:

- Pull by traction
- Pull by traction using a screw and measuring the corresponding torque
- Rotation of the insert in its mounting and measuring the corresponding torque

For the latter test, the metal-polymer de-cohesion torque is greater than the thread resistance, such that the latter is removed during the test (torque > 7 Nm). This comment is also relevant to the types of inserts presented further.

Table 9: Mechanical features

| Feature | Ixef® 1022 | Unit |
|-------------|------------|------|
| Pull torque | 6 | Nm |
| Pull force | 6,450 | N |

Fitting by thermal process (Hit-Sert® 2 Dowel)

Being of a particular shape, this insert offers very good resistance to torsion and pull forces.

The fitting system by thermal process is based on the thermal exchange principle. The insert is heated very quickly by a specially adapted heating element and transmits this heat to the plastic material, which softens.

Simultaneous pressure is applied to the insert, causing it to embed in the plastic material.

Fitting trials were conducted for this process using threaded dowels with M4 thread, of 7.5 mm (0.295 inch) in length; the designation of the article is thus Hit-Sert® 2 M4*7.5.

The results are included in Table 10.

Table 10: Fitting features

| Feature | Ixef® 1022 | Unit |
|-----------------------|-----------------------|---------|
| Recess | Specified in appendix | |
| Electrode temperature | 330 | °C |
| Cylinder pressure | 5 | bar |
| Fitting time | 8 | seconds |

These are the optimal conditions for thermal fitting.

Resistance tests provided the results shown in Table 11.

Table 11: Mechanical features

| Feature | Ixef® 1022 | Unit |
|-------------|------------|------|
| Pull torque | 4 | Nm |
| Pull force | 5,240 | N |

Cold shrink fitting of the self-threading dowel (Quick-Sert® Dowel)

The Quick-Sert® dowel is a threaded dowel with a standardized thread and an exterior thread with a special profile which attaches itself in the material.

Assembly is achieved with the help of an adapted rotary broach on a drill or pneumatic screwdriver.

Fitting trials were conducted in this way with Quick-Sert® M4*8 dowels.

The results are shown in Table 12.

Table 12: Fitting features

| Feature | Ixef® 1022 | Unit |
|-----------------|------------|------|
| Recess diameter | 6.3 | mm |
| Fitting torque | 4.5 | Nm |

The recess is a cylindrical shape. The diameter recommended for the insert M4 is 6 mm (0.236 inch) and the values indicated above have been improved by successive trials for each of the products tested.

Mechanical tests were undertaken identical to those described above.

Table 13: Mechanical features

| Feature | Ixef® 1022 | Unit |
|-------------|------------|------|
| Pull torque | 6 | Nm |
| Pull force | 6,450 | N |

Conclusions

The tests conducted show that it is possible to use three types of inserts with the Ixef® PARA grade tested.

It should be ensured, however, that the housing dimensions are respected as prescribed by the manufacturers so as to avoid fissures when they are positioned.

The most appropriate technique for Ixef® PARA compounds is the Quick-Sert® process with the threaded valve.

This process, in fact, offers superior mechanical features to those of other techniques. Fitting is fast and easy and the investment is reduced, owing to the simplicity of the tools. The inserts, however, are more expensive than those used in other techniques.

The performance of inserts positioned by expansion and by means of heat are very similar. We would give the former technique a slight advantage, as it is faster and thus requires a lesser investment.

Comments

This research contributes to the clarification of the situation in terms of solutions to be used in terms of inserts. It is not exhaustive, however, as only one diameter of insert has been tested.

However, the curves in Appendix 2 show the progress of the pull effort according to the product's rupture stress for the various types of inserts.

The difference between the curves remains relatively constant whatever the material's rupture stress. It is initially possible therefore to extrapolate the pull efforts for various diameters using the values obtained for M4.

For a specific insert fitting order, it is advisable to seek advice directly from the Böllhoff/Otalu company which, through its development department, can find appropriate solutions for customers' particular applications. (The company's details are given in Appendix 4; the product range is presented briefly in Appendix 3)

Assembly by Bonding

The Ixef® PARA compounds can be assembled by bonding without any difficulty.

Four main types of adhesives have been evaluated for bonding Ixef® PARA on Ixef® PARA and Ixef® PARA 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°C to 110°C (176°F to 230°F) (depending on grade)
- Two part acrylics
 - Tough, and semi-flexible
 - Good adhesion to many substrates
 - Optimum gap fill 1 mm (0.039 inch)
 - Maximum temperature 100°C to 120°C (212°F to 248°F) (depending on grade)
- Modified silane adhesive/sealants
 - Very flexible
 - Slow cure
 - Excellent gap fill 3 mm to 4 mm (0.118 inch to 0.158 inch)
 - Good water resistance

Table 14: 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 6.6 30% GF | 22 |
| PBT 30% GF | 13 |
| PC 30% GF | 23 |

- Epoxies
 - Good shear and impact resistance
 - Optimum gap fill 2 mm (0.079 inch)
 - Maximum temperature 100°C (212°F)

These tests allow to set the following main important recommendations:

Joint Design

- Keep bond line gaps small
- Maximize bond area where possible and optimize the joint overlap (see Figure 35)

Surface Finish/Preparation

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

Table 15 presents the shear strength results (Ixef® 1022/Ixef® 1022 and Ixef® 1022/steel) for various bonding tests and adhesives.

Figure 35: Influence of the overlapping length and the bond width on the bond strength

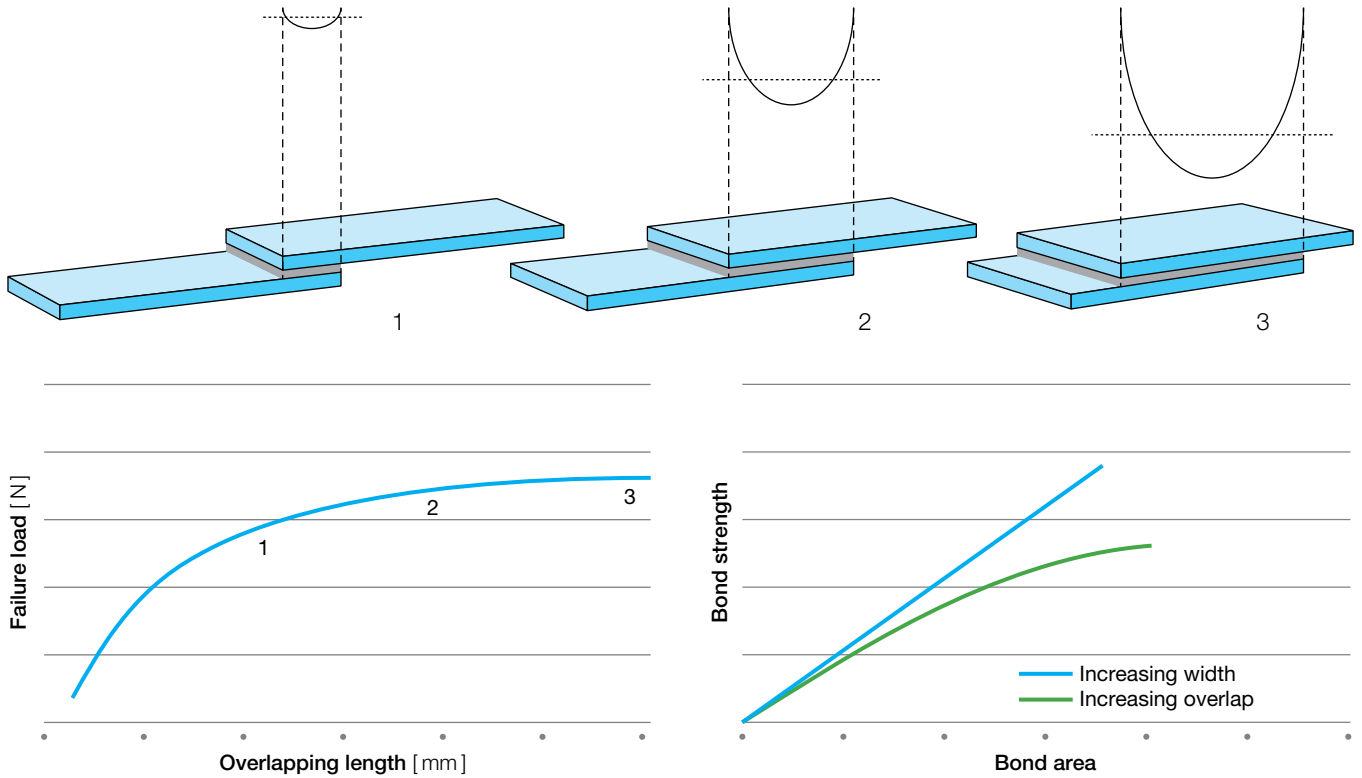


Table 15: Results of bonding tests (Ixef® PARA/Ixef® PARA and Ixef® PARA/steel)

| Adhesive | Cure Speed | Typical Tensile Shear Strength [N/mm ²] | | | | |
|----------------------------------|---------------|---|-------------------------------|----------------------------|-------------------------------|---------------------|
| | | Ixef® 1022/Ixef® 1022 | | Ixef® 1022/Steel | | |
| | | As Received ⁽¹⁾ | Abraded 4–5 Ra ⁽²⁾ | As Received ⁽¹⁾ | Abraded 4–5 Ra ⁽²⁾ | |
| 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⁾ | 3–6 | 7–10 ⁽³⁾ |
| Two part Acrylic | Loctite® 3295 | 10–30 min | 3–5 | 3–6 | 3–5 | 4–7 |
| Two part Acrylic | Loctite® 406 | 8–20 min | 2–4 | 2–5 | 2–4 | 3–5 |
| Epoxy | Dexter® H3101 | 1.5 hour | 3–6 | 4–7 | 3–6 | 4–6 |
| Modified Silane Adhesive/Sealant | Loctite® 5069 | 3.5 mm/24 hour (skin over 30 min) | 2–4 | 2–4 | 2–4 | 2–4 |

⁽¹⁾ Surface finish 1–2 Ra

⁽²⁾ Abraded with 60 grit paper (4–5 Ra)

⁽³⁾ Substrate failure of Ixef® PARA

Snap-Fit Assembly

Clicking or clipping makes it possible to fit an element (cams, fasteners, hooks) into a corresponding back taper.

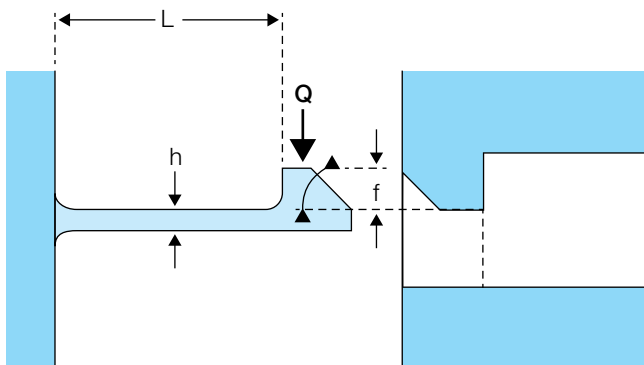
As shown in Figure 36, the male part has a spigot (created by molding or potentially by machining), which is inserted after deformation in the female part.

In order to assist assembly, the entry angle should be greater than 45°.

It is possible to dismantle it, but is more or less convenient according to the fixing angle (note that the admissible load for a unit made by clipping is significantly reduced after having been dismantled by force).

The stress withstood by a clipping system depends on the rigidity (thickness of the walls) of the fixing elements, the fixing angle and the back taper.

Figure 36: Clip design



The equations giving the stress and the deflection (f) are (whilst e is low compared with l, otherwise the deformation by shearing also has to be taken into account):

$$f = \frac{QL^3}{3EI}$$

Where:
 L and h are defined in Figure 36
 Q = Applied force
 E = Flexion mode
 I = Inertia
 $\sigma = \frac{QLh}{2I}$
 σ = Superficial flexion stress

Note: By elimination in these 2 relations of the applied force and considering the limit values of the various products, the maximum value of f can be taken as follows:

$$f = kL^2/h$$

Where:

k = 0.0005 for the composition Ixef® 1022

k = 0.0004 for the composition Primef 7002

k = 0.0006 for the composition Primef 4010

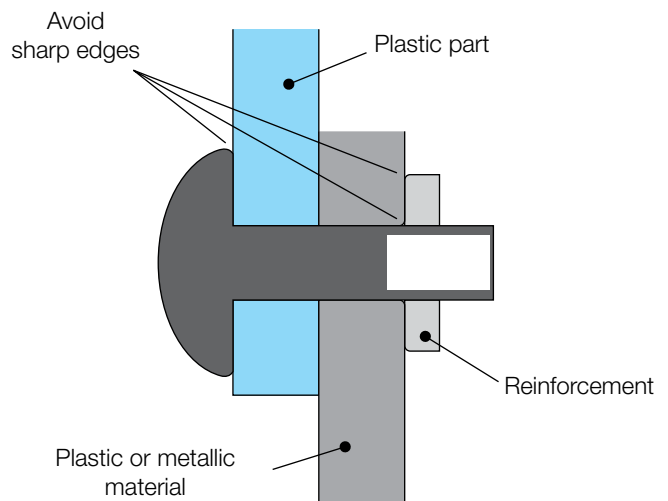
Riveting

Principle

Riveting is a method intended for the permanent assembly of parts (similar or different plastics and metal).

The rivet is made up of a spigot produced by molding on one of the elements to be assembled. The other part is molded with a hole and a recess for the head of the rivet as shown in Figure 37.

Figure 37: Recommended riveting technique



Note: The Ixef® PARA and Primef compositions offer high rigidity and low elongation at rupture. It would thus always be necessary to conduct an in-depth study of the shape of the clip before it is created.

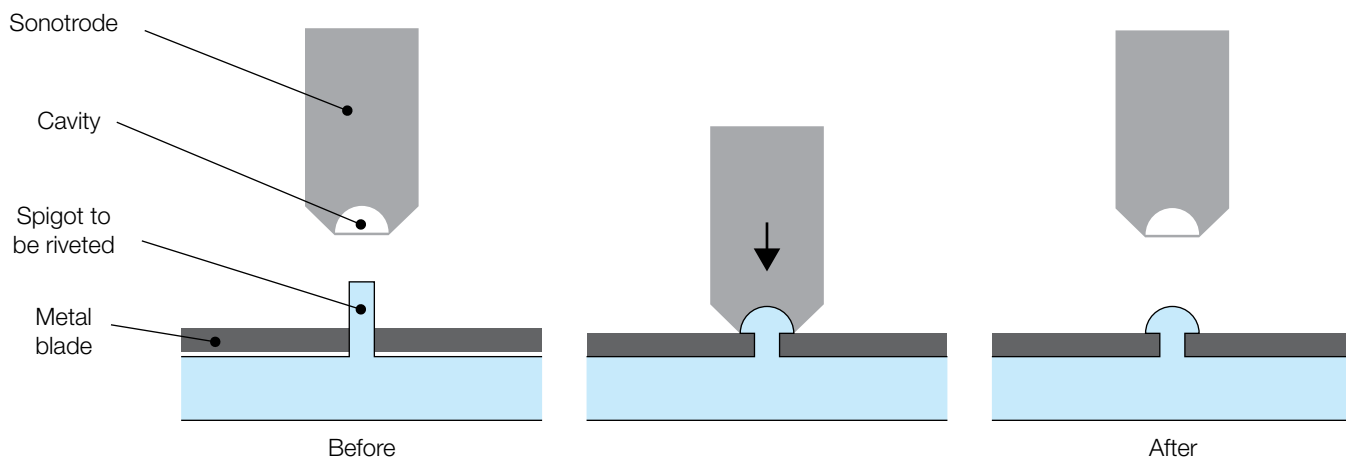
The permanent deformation of the head of the rivet is achieved by applying pressure (rather than by impact) using a shaping tool.

However, this process does not allow for high rates as the heating and cooling times are too long.

Also, riveting by ultrasound offers advantages over traditional riveting procedures. It involves shaping the head of a rivet at the top of a spigot with the aid of a shaped sonotrode in less than 2 seconds. See Figure 38.

The strong vibration energy of the ultrasound tool enables immediate fusion through mechanical loss at the point of contact and easy formation of a rivet head. The machined cavity at the end of the sonotrode determines the shape of the rivet head.

Figure 38: Riveting by ultrasound



Source: Mecasonic S.A. (Ville-la-Grand, France). "Applications des ultrasons aux thermoplastiques" p.16.

Applications for the Ixef® PARA Compounds

The use of this process for various Ixef® PARA grades does not pose any particular problem.

Our experience thus enables us to recommend riveting by ultrasound to achieve the permanent assembly of our products with another thermoplastic, thermoset or metal element.

Screw Assembly

Assembly of parts in plastic materials with other plastic or metallic parts is possible using internal or external threading, with the help of nuts or screws.

Assemblies that are liable to be dismantled frequently can also be achieved with bolts (metal dowels may or may not be incorporated in the plastic elements using one of the insertion techniques shown above).

As thermoplastics tend to creep (especially at high temperatures), the unscrewing of bolts can be avoided though the use of sufficiently large washers to reduce surface pressure.

The maximum tightening torque that an Ixef® PARA polyarylamide plate can withstand and the extraction force which a screw can resist (Figure 39) are outlined in Table 16 for the Ixef® 1022 grade.

Figure 39: Measurement of the maximum torque and the extraction force

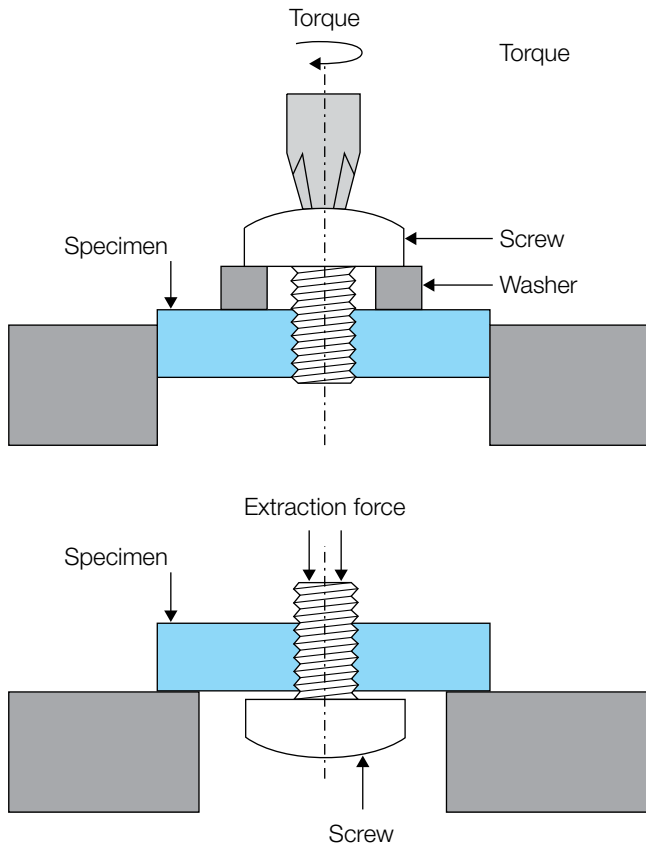


Table 16: Screw assembly in an Ixef® PARA polyarylamide part

| Screw Type | Diameter of the Hole [mm] | Maximum Torque [N.m] | Extraction Force [kN] |
|--------------|---------------------------|----------------------|-----------------------|
| M 2.6 × 0.45 | 2.2 | >1.0 | >1.7 |
| M 3.0 × 0.5 | 2.5 | >1.5 | >3.6 |
| M 4.0 × 0.7 | 3.4 | >4.5 | 4.6 |
| M 5.0 × 0.8 | 4.3 | 7.5 | 6.1 |
| M 6.0 × 1.0 | 5.1 | >6.5 | 7.7 |

Without Thermal Cycle

The pull force that a screw can resist has been determined by a compression test according to the diagram presented in Figure 40.

The results obtained for the various diameters of the holes are shown in Table 16.

Tests further conducted with M20 bolts on a 10-mm (0.394-inch) thick Ixef® 1022 plate resulted in a required pull force of 6,000 kg (13,230 lb).

Figure 40: Measurement of the pull force

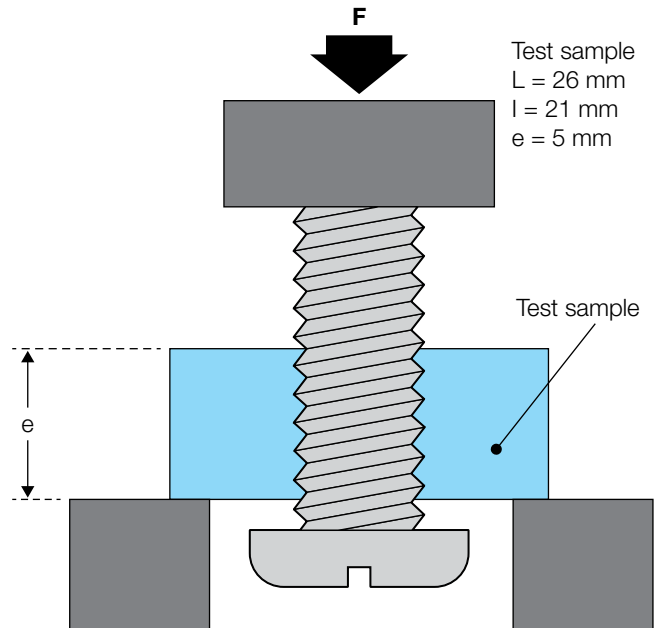


Table 17: Pull force for various types of screws and various diameters of holes

| Types of Screw | Diameter of the Hole [mm] | Pull Force [kN] of Ixef® 1022 |
|----------------|---------------------------|-------------------------------|
| M 3.0 × 0.5 | 2.5 | - |
| M 4.0 × 0.7 | 3.2 | 4.1 |
| | 3.4 | 3.5 |
| | 3.6 | 3.9 |
| M 5.0 × 0.8 | 4.1 | 4.9 |
| | 4.3 | 4.6 |
| | 4.5 | 4.1 |
| M 6.0 × 1.0 | 4.8 | 5.2 |
| | 5.1 | 5.6 |
| | 5.4 | 4.9 |

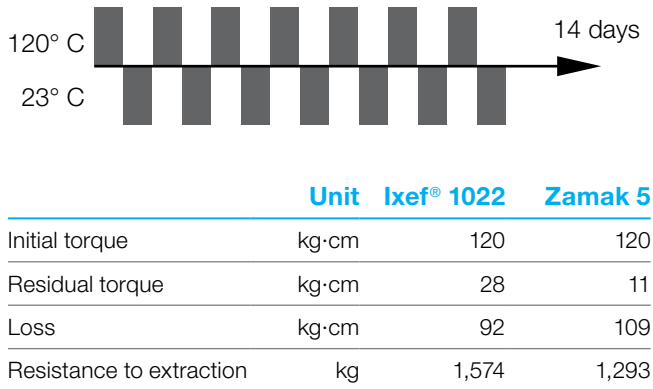
With Thermal Cycle

M5 type steel bolts were tightened onto Ixef® 1022 and ZAMAK® 5 polyarylamide plates.

They were subjected to a consistent 14-day thermal cycle alternating the temperature every 24 hours between 120 °C and 23 °C (248 °F and 73 °F) as shown in Figure 41.

Considering the results obtained, it is possible to successfully make threaded holes in Ixef® PARA and even use self-tapping screws that offer very high resistance to pull.

Figure 41: Tightening torque: Comparisons



Note: Test carried out on M5 type bolts

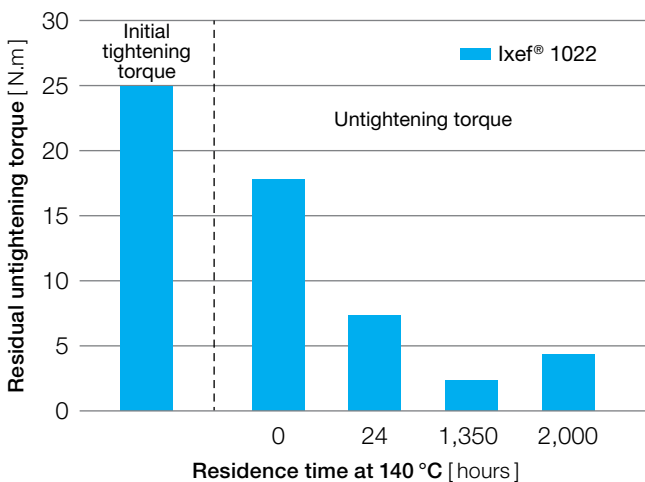
Relaxation of the Torque at High Temperature

Type M8 bolts were tightened to threaded plates in Ixef® 1022.

The bolted plates were then heated to 140 °C (284 °F) and untightening torque measurements were taken. The initial stress of Ixef® 1022 relaxed rapidly at this temperature. See Figure 42.

Figure 42: Relaxation at 140 °C (284 °F)

Ixef® 1022, M8 bolts, residual untightening torque, N.m



At the test temperature (e.g. under the bonnet of an engine), the fixing of a part without the use of metallic inserts is not recommended for Ixef® 1022.

Adding Handles to the Press

Ixef® PARA compounds generally perform very well for creep. As this property essentially conditions the resistance of press shrinking, we can recommend this type of plastic/plastic or plastic/metal assembly.

Tightening

The theory of cylindrical elements with thick sides makes it possible to define the tightening of assemblies made by press shrinking:

$$\delta = p \cdot \varnothing_m \left[\frac{D_e + u_e}{E_e} + \frac{D_i - u_i}{E_i} \right]$$

$$= \frac{\sigma_e - \varnothing_m}{D_e} \left[\frac{D_e + u_e}{E_e} + \frac{D_i - u_i}{E_i} \right]$$

$$D_e = \frac{\varnothing_e^2 + \varnothing_m^2}{\varnothing_e^2 - \varnothing_m^2} \quad D_i = \frac{\varnothing_m^2 + \varnothing_i^2}{\varnothing_m^2 - \varnothing_i^2}$$

Where:

- d = diametric interference (mm)
- D_e = geometric factor (exterior)
- ∅_m = external diameter of the shaft (mm)
- ∅_i = internal diameter of the shaft (mm)
- u_e = Poisson coefficient of the sleeve material
- u_i = Poisson coefficient of the shaft material
- E_e = traction module of the sleeve material (Mpa)
- E_i = traction module of the shaft material (Mpa)
- p = pressure at the interface (joint)
- D_i = geometric factor (interior)
- ∅_e = external diameter of the sleeve (mm)
- s_e = admissible stress in traction (Mpa)

Comments

If ∅_i = 0 (solid shaft), D_i = 1 and the tightening is expressed by the following equation:

$$\delta = \frac{\sigma_e \cdot \varnothing_m}{D_e} \left[\frac{D_e + u_e}{E_e} + \frac{1 - u_i}{E_i} \right]$$

If ∅_e = infinity (e.g. very large piece in which an insert is placed), D_e = 1 and the simplified expression becomes:

$$\delta = \frac{\sigma_e \cdot \varnothing_m}{E_e} (1 + u_e)$$

Example

Let us find out the diametric interference of a sleeve in Primef 7002 PPS ($\varnothing_e = 20$ mm) and a steel shaft ($\varnothing_m = 10$ mm).

Admissible stress $s_e = 60$ Mpa (taking into account a perpendicular stressing to the fibers and a security factor).

Module $E_e = 10,500$ Mpa (same comment)

$$u_e = 0.35$$

$$D_e = \frac{\varnothing_e^2 + \varnothing_m^2}{\varnothing_e^2 - \varnothing_m^2} = \frac{[20]^2 + [10]^2}{[20]^2 - [10]^2} = 1.6667$$

$$\delta = \frac{60 \times 10}{1.6667} \left[\frac{1.6667 + 0.35}{10.500} + \frac{1 - 0.29}{2 \times 10.000} \right] = 0.069 \text{ mm}$$

if $D_e = 1$, d_{\max} has a value of:

$$\delta_{\max} = \frac{60 \times 10}{10.500} [1 + 0.35] = 0.077 \text{ mm}$$

Maintenance Force

The value of the maintenance force can be estimated by the following formula:

$$F = p \cdot S \cdot \mu = \Pi \cdot \varnothing_m \cdot l \cdot \mu \cdot p = \Pi \cdot \varnothing_m \cdot l \cdot \mu \cdot \frac{\sigma_e}{D_e}$$

Where:

F = assembly maintenance force

p = pressure at the interface

S = joint surface

\varnothing_m = shaft diameter

l = fitting length

μ = friction coefficient of one material on another

s_e = admissible stress in traction

D_e = geometrical factor

Example

In the example described above, the maintenance force can be estimated at:

$$\mu = 0.45$$

fitting length $l = 6$ mm (0.236 inch)

$$F = \frac{60}{1.6667} \times \Pi \times 6 \times 0.45 = 3.053 \text{ N}$$

We notice that the maintenance force reduces after fitting following a stress relaxation effect. It would thus be necessary to take it into account to estimate the long-term durability of the assemblies (evolution of the model according to time).

In practice, the value of F measured on the 10.06 mm (0.396 inch) diameter sleeves was equal to 1,660 N (i.e. about twice as low as the calculated value, corresponding to the relaxation effect on the mechanical properties).

On the other hand, the influence of temperature on the resistance of the assembly features a variation in the contact surface owing to the thermal dilation and the reduction of the traction module value (the module vs. temperature curve gives the E values to be used in the tightening equation for a given temperature T).

For a plastic sleeve and a metal shaft, the influence of thermal dilation on the diameter is given by the following formula:

$$\varnothing - \varnothing_o = (\alpha_e - \alpha_i) \varnothing_o \cdot \Delta T$$

Where:

\varnothing_o = initial diameter

\varnothing = diameter at temperature T

α_e = thermal dilation coefficient

α_i = thermal dilation coefficient of the shaft material

ΔT = temperature variation $T - T_o$

Conclusions

Many assembly trials of injected parts made of Ixef® PARA have been successfully conducted.

The results obtained enable us to recommend the following techniques for the assembly of parts manufactured with our products:

- **Ultrasound welding (and using the EMAWELD process for simple shaped parts that are not subject to a great mechanical load)**
- **Gluing with acrylic glues**
- **Metal assembly either by fixing inserts (Quick-Sert® process): cold fitting of self-threading dowels, or by ultrasound riveting, or even with threaded screws or press shrinking**

Our technical services are available to users to resolve specific problems and to provide help in the designing of Ixef® PARA.

Furthermore, in **Appendix 4** we provide a list of manufacturers of the main assembly processes referred to in this document. They are able to effectively advise the designer in the choice and use of the most appropriate technique so as to achieve the best value for money solution.

Decoration Techniques

Painting

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

Ixef® PARA compounds also have high HDT values, thus allowing them to be baked at temperatures of 180 °C (356 °F) 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® PARA 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 (176 °F)
- Acrylic/isocyanate
bake time 30 minutes
bake temperature 80 °C (176 °F)
- Polyester/amino
bake time 20 minutes
bake temperature 140 °C (284 °F)

The painted specimens were submerged in water at 40 °C (104 °F) for 21 days and also subject to heat cycles between –40 °C and 100 °C (–40 °F and 212 °F).

The adhesion was tested by measuring the quantity of paint removed when an adhesive tape is ripped off (Tape Test – ASTM D3002).

No delamination was observed.

Metallization

Ixef® PARA parts can be metallized for aesthetic, functional and electronic shielding requirements, directly replacing applications in metals and alloys.

There are a variety of techniques for the metallization of Ixef® PARA 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® PARA parts. These plate procedures are successful with any Ixef® PARA grade (till 60 % glass fiber reinforcement).

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

Compounds Molded in Color

Several Ixef® PARA compounds are delivered molded in color, in accordance with the customer's specifications.

For large quantities, it is normally possible to prepare an Ixef® PARA compound molded in color according to the customer's colorimetric reference.

Machining Ixef® PARA Compounds

Machining Ixef® PARA 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 Table 18.

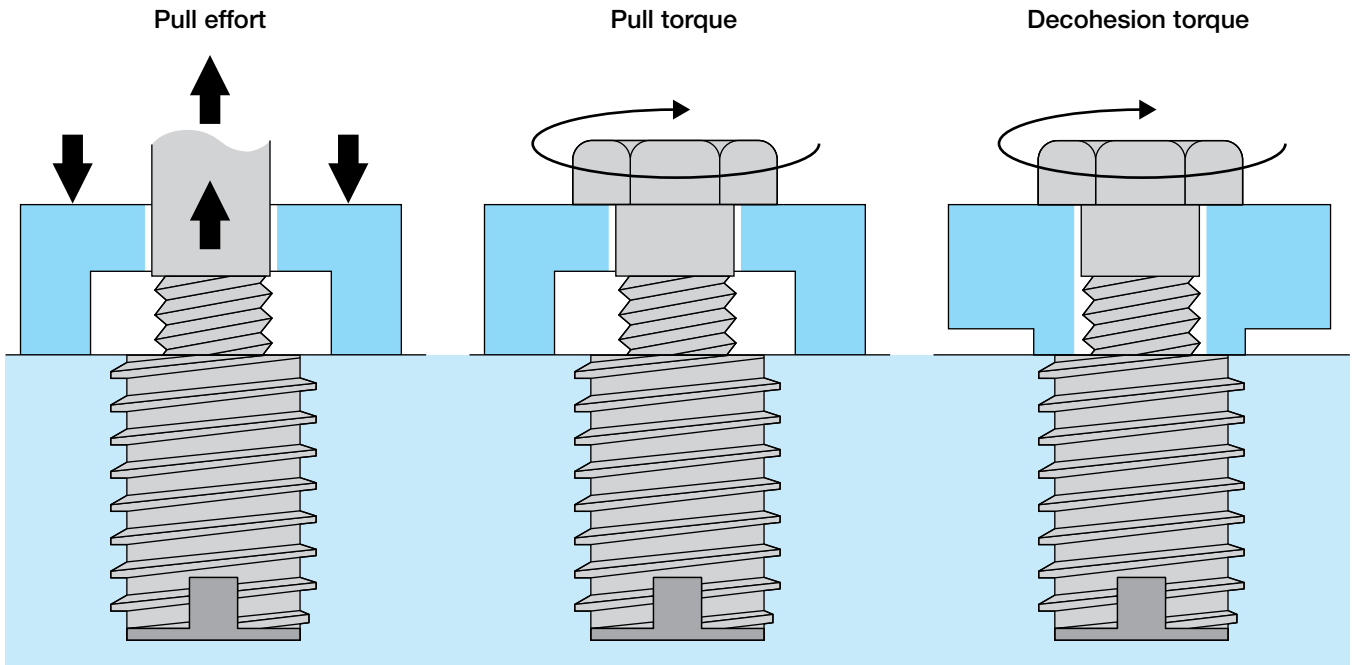
Table 18: Operating conditions for machining Ixef® PARA parts

| | | | | | |
|--|-------------------------|------------------------|---------------------|------------------------|--------|
| Operating Conditions | Turning or milling tool | Recommended type | A: High speed steel | | 5–6° |
| | | | C: Metal carbide | | |
| | | Characteristics angles | Dépouille | | |
| | Grinding angle | | High speed steel | 12–15° | |
| | | Cutting speeds (m/min) | Turning and Milling | Rapid steel | 90–150 |
| | Carbide | | | 90–200 | |
| | Sawing | | Fritted CW blad | 200 | |
| | Drilling | | High speed steel | | |
| | Tapping | | CW | | |
| | Lubrication | Turning and milling | | Oil and water emulsion | |
| | | Sawing | | | |
| | | Drilling | | | |
| | | Tapping | | | |
| Class N7-N8 without lubrication, N6 with lubrication | | | | | |

Appendices

Appendix 1

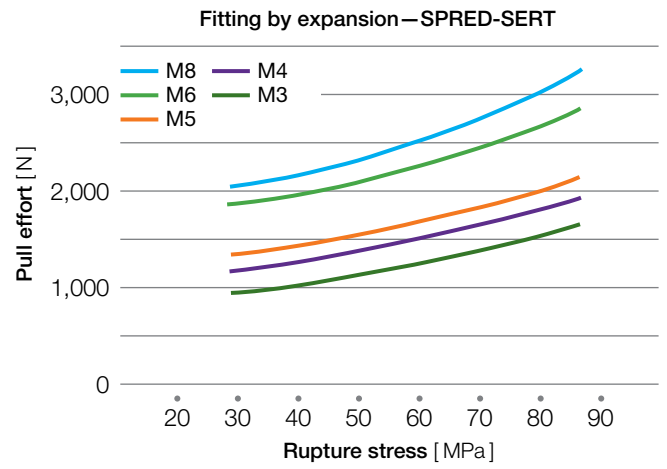
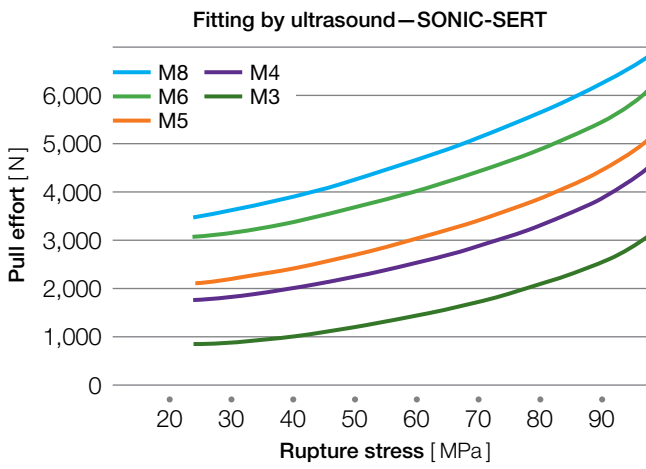
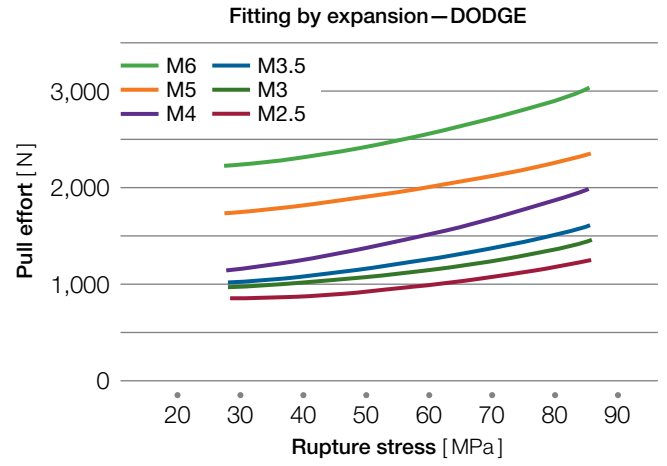
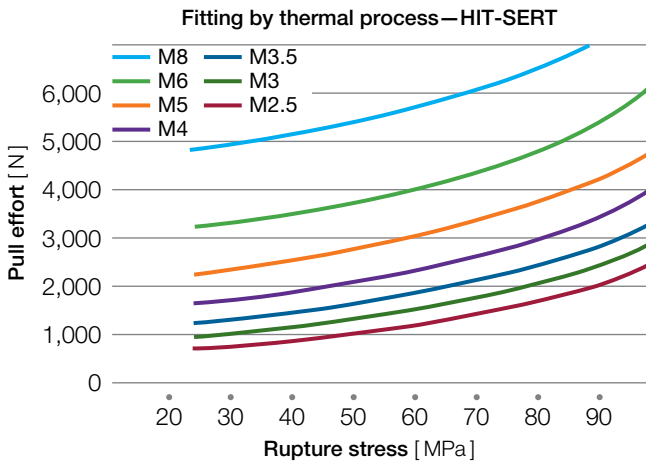
Pull test on inserts



Source Böllhoff Otalú S.A.

Appendix 2

Behavior curves for pull of various types of inserts

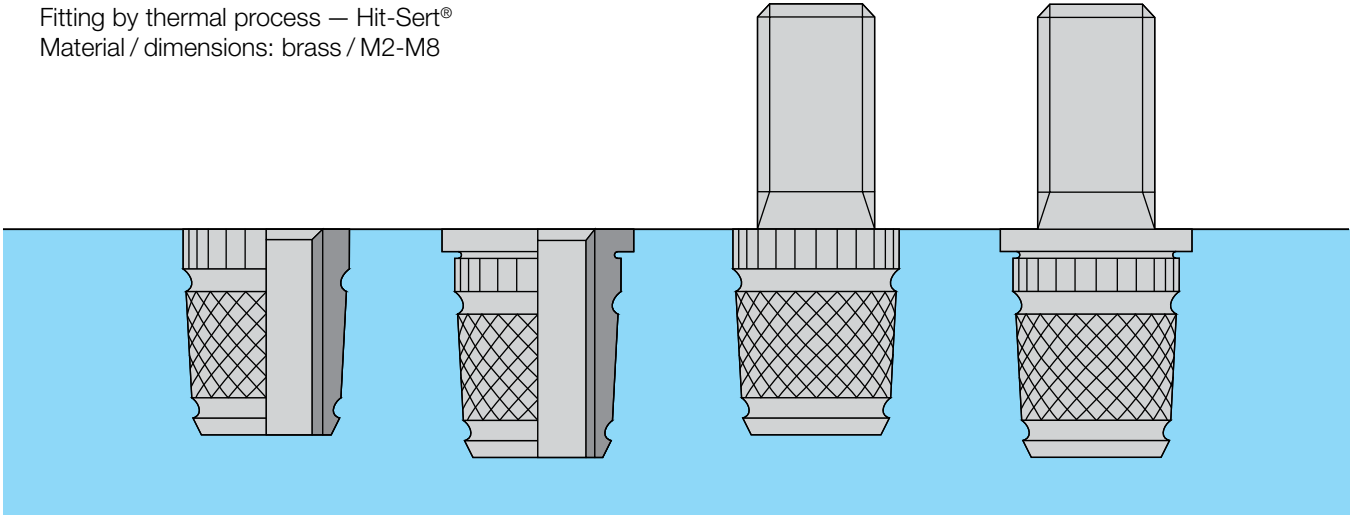


Source: BÖLLHOFF & CO, Verbindungs- und Montagetechnik (Bielefeld–Germany) "Gewindeeinsätze für Kunststoffteile", p.5.

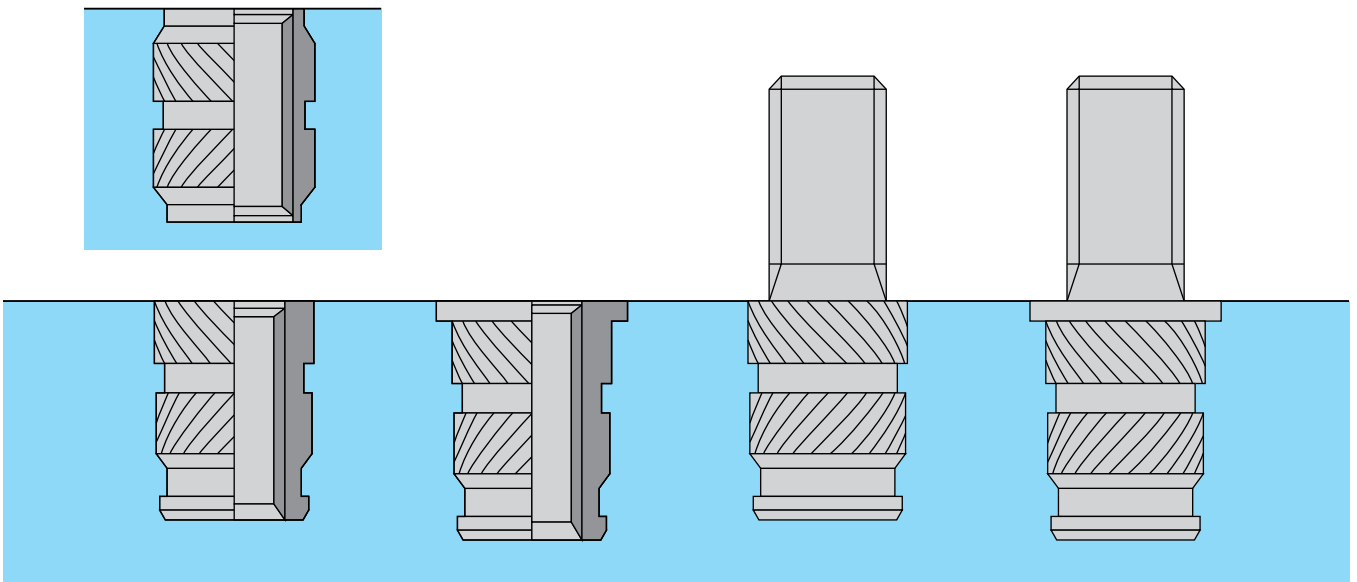
Appendix 3

Manufacturing programme – Böllhoff

Fitting by thermal process – Hit-Sert®
Material / dimensions: brass / M2-M8

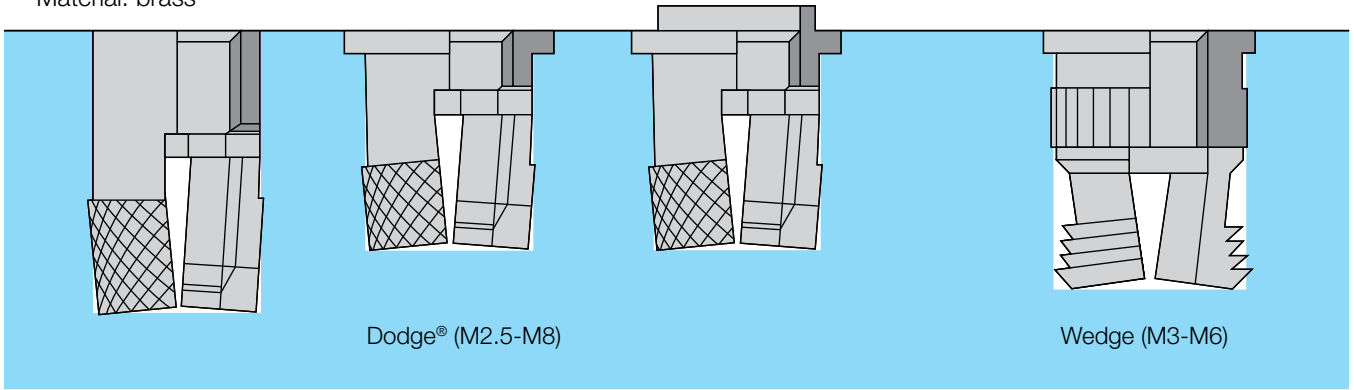


Fitting by ultrasound – Sonic-Sert®
Material / dimensions: brass / M2-M8

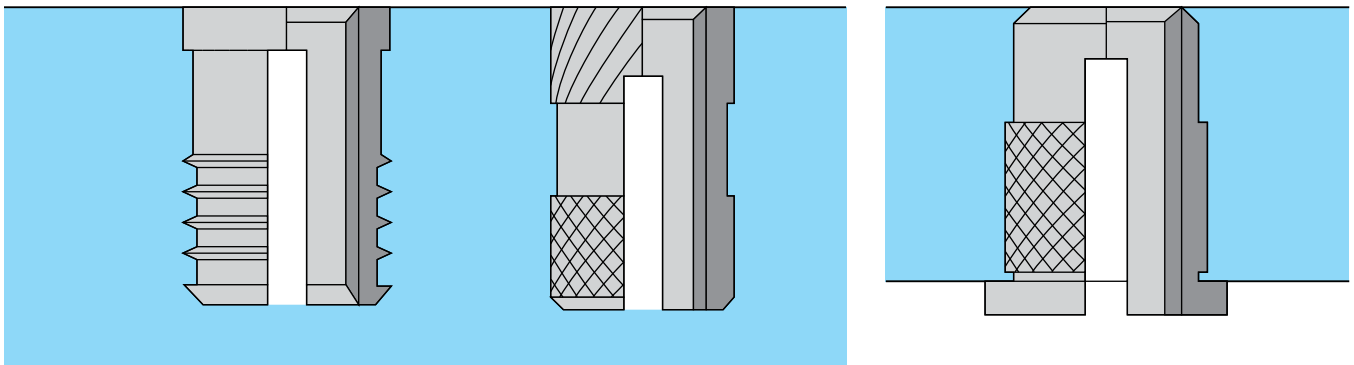


Source: Böllhoff GmbH & Co. KG, Verbindungs- und Montagetechnik (Bielefeld, Germany) "Gewindeeinsätze für Kunststoffteile", p.4.

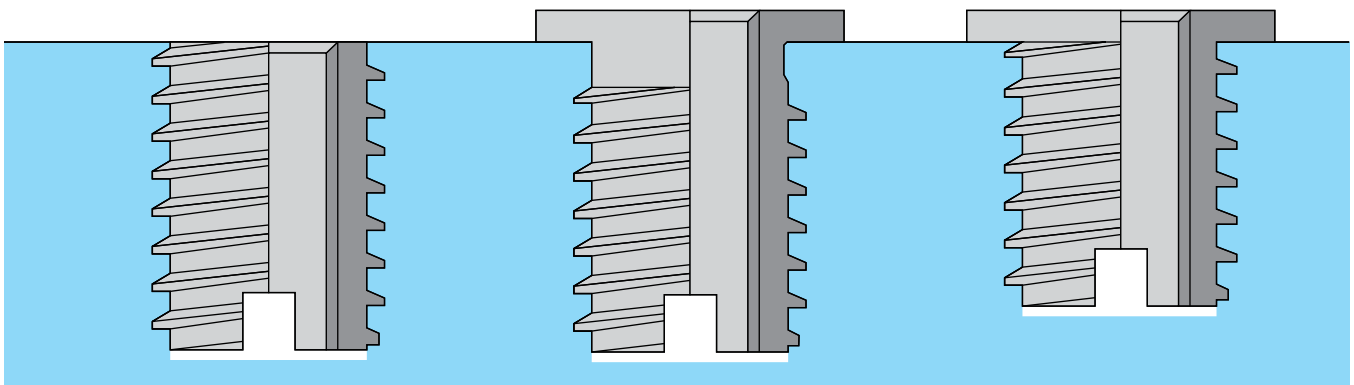
Fitting by expansion — Dodge®, Wedge
 Material: brass



Fitting by expansion — Spred-Sert®
 Material / dimensions: brass / M2-M8, M3-M6, M3-M8



Fitting by cold shrinking — Quick-Sert®
 Material / dimensions: brass / M4-M10 and steel M4-M10



Source: Böllhoff GmbH & Co. KG, Verbindungs- und Montagetechnik (Bielefeld, Germany) "Gewindeeinsätze für Kunststoffteile", p.4.

Appendix 4

The list of manufacturers of the main equipment and materials used in the assembly techniques.

Ultrasound welding and riveting

Mecasonic S.A.

Boîte postale 218
74104 Annemasse Cedex
France
Tel +33 50 37 47 00
Fax +33 50 37 31 47

KLN – Ultraschall GmbH

Postfach 120
6148 Heppenheim
Germany
Tel: +49 (0)62 521 40

EMAWELD process: Electromagnetic welding

Emabond Solutions™

49, Walnut Street
Norwood, New Jersey 07648
USA
Tel: +1 201 767 74 00
Fax: +1 201 767 36 08

Ashland Inc.

50 E. RiverCenter Blvd.
P.O. Box 391
Covington, KY 41012-0391
USA
Tel: +1 859 815 3333

Gluing

Cyanolit 811

REMY Industries N.V.
3018 Wijnmaal (Leuven)
Belgium

Permabond® F

Permabond Adhesive Ltd.
Woodside Road, Eastleigh
GB - Hants SO5 4EX
England

Araldite® AY

Ciba Geigy Ltd.
Basel
Switzerland

Bison

Perfecta Chemie B.V.
460 AD Goes
The Netherlands

Inserts

Bollhoff Otal S.A.

Head offices - Factory
Z.I. de l'Albanne - route d'Aprémont
73490 La Ravoire (Chambery)
France
Tel: +33 79 96 70 00
Fax: +33 79 96 70 11

Böllhoff Group

Postfach 14 02 40
Archimedesstraße 1-4
4800 Bielefeld 14
Germany
Tel: +49 521 44 82 01
Fax: +49 521 44 93 64

P.S.M. International P.L.C.

Longacres, Willenhall
West Midlands
WV13 2JS
England
Tel: +44 1902 366 081
Fax: +44 1902 635 583

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