Gluing Guide

Gluing of Engineering Plastics
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1. Introduction

Gluing for assembly of plastic parts is an effective method of making permanent connections. This method produces esthetic clean looking joints with low weight and sufficiently strong connections. This is a very effective joining method for heat sensitive plastics that would normally deform if welded.

In order to achieve a strong bond, it is important that the selection of the glue, the application technique and the shape of the connection are all integral parts of the design process.

There are three different gluing processes: solvent bonding, adhesion bonding and bonding with double sided tape. These will be discussed in more detail in the chapters 2, 3 and 4. Surface wetting and cleaning, which are important for all gluing processes, are discussed in the chapters 5 and 6.

2. Solvent Bonding

2.1. Principle

Solvent bonding or solvent welding is a process in which the surfaces of the parts to be joined are treated with a solvent. This swells and softens the surface and by applying pressure to the joint and with the evaporation of the solvent, the two surfaces bond. Adhesives are not used. The process is commonly used with amorphous thermoplastics such as Xantar.

Specific advantages of solvent bonding are:
- homogeneous distribution of mechanical loads
- good esthetics / no special requirements to hide the bond
- economic assembly
- low weight, no heavy screws, bolts and nuts
- able to join heat sensitive constructions or materials which welding would distort or destroy
- good sealing and insulating properties.

Potential limitations are:
- entrapment of solvent in the joint
- stress cracking or crazing
- dissimilar materials can only be joined if both are soluble in a common solvent or in a mixture of solvents
- differences in thermal expansion of components are not compensated in a thick adhesive layer if dissimilar materials are bonded
- reproducibility / process control
- curing time
- no disassembly possible
- assembly hazards such as fire or toxicity.
2.2. Solvents

Suitable solvents for bonding selected DSM products are given in the table below. Arnite and Arnitel are generally bonded by other techniques such as adhesive bonding.

Table 1. Suitable solvents for some DSM products.

<table>
<thead>
<tr>
<th>DSM Products</th>
<th>Polymer description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akulon</td>
<td>PA6 &amp; PA66</td>
</tr>
<tr>
<td></td>
<td>Formic acid</td>
</tr>
<tr>
<td></td>
<td>Alcoholic calcium chloride</td>
</tr>
<tr>
<td></td>
<td>Concentrated aqueous chloral hydrate</td>
</tr>
<tr>
<td></td>
<td>Concentrated alcoholic phenol/recorcinol</td>
</tr>
<tr>
<td>Stanyl</td>
<td>PA46</td>
</tr>
<tr>
<td></td>
<td>Formic acid</td>
</tr>
<tr>
<td></td>
<td>Aqueous phenol solution (88%)</td>
</tr>
<tr>
<td></td>
<td>Resorcin/ethanol (1:1)</td>
</tr>
<tr>
<td>Xantar</td>
<td>PC</td>
</tr>
<tr>
<td></td>
<td>Methylene chloride</td>
</tr>
<tr>
<td></td>
<td>Ethylene dichloride</td>
</tr>
<tr>
<td>Xantar C</td>
<td>PC + ABS</td>
</tr>
<tr>
<td></td>
<td>Methylene chloride</td>
</tr>
<tr>
<td></td>
<td>Ethylene dichloride</td>
</tr>
</tbody>
</table>

Different solvents can be mixed to produce a mixture with optimal properties. For instance, if two dissimilar materials are to be joined, a mixture of two miscible solvents specific to the different polymers can be used. A mixture of methylene chloride and ethylene dichloride is sometimes used for Xantar polycarbonate and polycarbonate blends. Methylene chloride evaporates faster than ethylene dichloride. A longer assembly time is therefore required if ethylene dichloride has been added.

A slurry made of solvent and up to 25% of the base resin can be used to produce a smooth filled joint when the mating parts do not fit perfectly. Adding base resin makes the solvent easier to use.

It is important to consult the Material Safety Data Sheet of the solvent used, for health and safety information and for proper handling and protection equipment.
2.3 Procedure

Good wetting of the surface with the solvent is a requisite to achieve good solvent bonding. Chapter 5 describes the key parameters that are involved in surface wetting.

The mating surfaces must be clean and free of grease before bonding. Cleaning with a suitable solvent may be necessary, see par. 6.

Parts that have a single joining surface are simply pressed against a sponge or felt pad that has been impregnated with solvent. The quantity of solvent used should be kept to a minimum to avoid drips and crazing. More complex multiplane joining surfaces require contoured solvent applicators made from wood or a metal. It may be necessary to allow a few seconds to ensure sufficient swelling. The parts are then clamped together with a moderate pressure. The parts are removed from the clamping equipment and must not be used for a period of 24 to 48 hours to ensure that full strength has been attained. Heat can be used to accelerate the overall rate of evaporation and reduce the cycle time.

2.4 Design for solvent bonding

The load on the assembly can be applied in several ways as indicated in figure 1.

Figure 1. The load can be applied in several ways.

General design guidelines are:
- design for lap-shear loads
- maximize the bonding surface; for instance, use a scarfed or a dovetail joint
- avoid stress concentrations at thick-thin sections
- ensure that there is sufficient venting.

Scarf or dovetail joints should be relatively shallow, so that solvent entrapment is avoided. Entrapped solvent can cause crazing over time and lead to part failure. The parts should therefore be molded with a minimum of internal stress.

Gates should be located away from the areas to be bonded. Caution should also be exercised when working with “closed” parts, to avoid getting solvent trapped inside the part.

The designer should take account of the fact that the material strength in the bond between two parts made of glass fibre reinforced materials will never exceed the material strength of the matrix material, because the glass fibres do not bridge the gap between the two parts.
3. Adhesive Bonding

3.1. Principle

The main criteria for achieving good adhesive bonding are surface wetting and curing of the adhesive. Important variables for the application of an adhesive and distribution on a substrate are surface wetting, adhesive viscosity and chemical resistance of the substrate to the adhesive. The principles of surface wetting are described in more detail in paragraph 5.

In general, adhesion is based on various mechanisms as shown (see figure 2).

- Mechanical interlocking can contribute to the strength of the bond if the substrate surface is rough, thus enabling the glue to flow into the micro holes.
- The same physical forces of the wetting process also play an important role for the adhesion of the cured glue to the substrate. A good adhesion between the molecules of the substrate and the glue contributes to the bonding strength. When polar groups (e.g. \(-\text{COOH} \), \(-\text{C} = \text{O} \), \(-\text{NH} \), \(-\text{NH}_2 \)) are present at the surface of a substrate a strong interaction is possible between the glue and the substrate.
- In some cases there is a chemical reaction between the reactive groups of the glue and the substrate. Very high bonding strength can be achieved with a relatively small amount of these chemical bonds.
- Molecular interdiffusion can also occur on a molecular level. An “interpenetrating network”. This could happen when the surface of a plastic dissolves in the glue. A kind of third phase is formed between the substrate and the glue where the polymer chains are mixed on a molecular level (interdiffusion).

Figure 2 Different adhesion mechanisms.
Molecular interdiffusion is limited by crystallites, therefore it is more difficult to achieve good adhesion on semi-crystalline thermoplastics compared to amorphous ones. Adhesion on non-polar thermoplastics, e.g. polyolefins, will improve considerably when the surface is pretreated using corona, UV, plasma or flame treatments.

Poor bonding occurs when the adhesive layer does not stick properly to the substrate. Pretreatment may be helpful, e.g. cleaning, degreasing and sanding, see paragraphs 3.4 and 3.5.

Specific advantages of adhesive bonding are:

- application on various substrates like thermoplastics, thermosets, elastomers and metals
- homogeneous distribution of mechanical loads
- differences in thermal expansion of components can be compensated by using a thick adhesive layer
- good esthetics / no special requirements to hide the bond
- economic assembly
- low weight, no heavy screws, bolts and nuts
- able to join heat sensitive constructions or materials, which welding would distort or destroy
- no thermal stresses introduced
- good sealing and insulating properties
- in many cases cheaper (no high investment costs, no additional costs of metal parts).

Potential limitations are:

- long term behavior may not be very good
- stress cracking or crazing of the plastic may occur
- dissimilar materials can only be joined if both are compatible with the adhesive
- reproducibility / process control
- curing time can be long, depending on the adhesive
- no disassembly possible
- assembly hazards such as fire or toxicity
- sometimes requires a complex process (pretreatment, special equipment, curing)
3.2 Adhesive types

A wide variety of adhesives are commercially available.

**Epoxy**

Various epoxy adhesives are available, with different characteristics and properties. The various curing mechanisms are:

- 2 component hot or cold curing
- 1 component hot curing
- UV-curing.

Standard epoxy adhesives are very strong but brittle and show low peel strength. To improve toughness, modified epoxy adhesives have been developed. The use temperature varies between -40°C and 80°C (-40°F - 180°F) for cold curing systems. Hot curing epoxies can normally be used up to 150°C (300°F). Epoxies have a good moisture resistance.

In general, large deviations are found in lap-shear bonding strength, depending on the particular combination of adhesive and material.

With some plastics, pretreatment can give a considerable improvement. Oils and grease negatively affect the adhesion of epoxies.

**Polyurethane**

Polyurethane adhesives are relatively inexpensive and show good adhesion. Varieties exist from elastomeric to rigid. Several types of curing mechanisms are available:

- 1 component thermosetting
- 2 component catalyzed
- reactive hot melts.

Polyurethane adhesives are tough and show a high peel strength. They can be used at temperatures between -80°C and 100°C (-110°F - 210°F).

Adhesion on engineering plastics is good. Degreasing is often sufficient to obtain the required bonding strength.
**Acrylic**

Acrylics are flexible and tough. Fast curing takes place at room temperature. Care should be taken when joining amorphous thermoplastics such as Xantar, as environmental stress cracking may occur.

Several systems are available:
- 1 component UV-curing used for transparent plastics
- 2 component premix
- 2 component no-mix

Use temperature is between -55°C and 120°C (-70°F - 250°F). Acrylics show excellent peel strength and are tough.

Good adhesion is obtained on amorphous thermoplastics. Pretreatment may improve the lap shear bonding strength considerably.

**Cyanoacrylate**

Cyano-acrylics are fast curing systems (under the catalytic effect of moisture from the air on the surface, an anionic reaction) but rather brittle, which results in low peel strength and impact properties in the joint. Rubber modified cyanoacrylics have been developed to improve toughness. Cyanoacrylate adhesives are specially developed for small surfaces and are not suited for outdoor applications.

A very high lap shear bonding strength can be obtained with most engineering thermoplastics. Unfilled polyesters (Arnite PET and PBT) show moderate results. Effective primers are available to improve the bonding strength on polyolefins.

**Silicone**

Silicone adhesives react under the catalytic effect of water. Humidity in the air or some moisture on the surface of the parts is sufficient. The reaction times are relatively long, compared to cyano-acrylics. Silicone adhesives offer a high elasticity. Silicone adhesives show very good weathering and temperature resistance.
**MS (Modified silane polymer)**
Modified silane adhesives achieve good adhesion to various substrates and have good UV resistance.

**UV Cure**
UV curable adhesives use ultraviolet light to initiate polymerization and contain no solvents. Curing time is short, typically 3 to 10 seconds. UV curable adhesives have a high bond strength and can easily be applied to transparent materials like Xantar polycarbonate. (However, this does not apply when UV-blockers have been added).

**Contact glue**
These are solvent based adhesives that are formulated with different raw material groups, including natural and synthetic rubbers and suitable resin combinations (Naphtas, ketones, esters or aromatics). Adhesive films will be formed upon evaporation of solvents. Assemblies may be made by contact bonding (adhesive application to both surfaces) or wet bonding (applied to one of the bond surfaces). Most of the contact adhesives are based on polychloroprene rubber. They display good initial strengths and achieve high strengths on numerous substrates. The typical contact pressure during assembly is 0.5 MPa.

**Hot melt**
Hot melt adhesives are thermoplastics, available as pellets, or in block, tape or foil shape. The adhesive is heated above its melting temperature and applied to the surfaces to be bonded with special equipment like rollers, nozzles or calandars. The bond is formed after the melt cools to a solid. The operating equipment has to operate fast for effective bonding. These adhesives are fairly viscous, solvent free and have good gap filling abilities.
3.3 Compatible adhesives and substrates

Figure 3 gives an impression of good solutions for adhesion bonding of plastics. The matrix with substrates and adhesives gives an indication of compatible combinations. Combinations that deliver a bond with a high strength have been indicated by a black rectangle. Good bonds are indicated by a black and white rectangle, and moderate bonds are indicated by a white rectangle.

Figure 3 Compatibility of substrates and glue types (Courtesy Henkel)
### DSM Engineering Plastics

#### Thermoset

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<th>PVC-U</th>
<th>SAN*</th>
<th>EP</th>
<th>MF</th>
<th>PF</th>
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<td>✔</td>
</tr>
</tbody>
</table>

#### Reinforced Plastics

- PVC-U
- SAN*
- EP
- MF
- PF
- PUR
- UP
- CRP
- GRP
- CR
- EPDM
- R
- NBR
- NR
- PU
- SBR
- SI
- TPE

#### Elastomers

- 401, 406, 480
- CA + Primer 770
- 4354
- 9509
- 3421, 3422, 3425, 5461, 5465, 5492
- 3288 + Activator 7386
- 3282
- 3030
- 3311, 3321, 3341
- Teromix 6700
- Terokal 2444
- Terostat 9220
- 5910, 5970
- 5088
- Terostat 90

#### Glass

- 7063
- 7070

#### Metal

- Physical Treatment
- Mechanical Treatment

#### Loctite® and Teroson products examples

- 401, 406, 480
- CA + Primer 770
- 4354
- 9509
- 3421, 3422, 3425, 5461, 5465, 5492
- 3288 + Activator 7386
- 3282
- 3030
- 3311, 3321, 3341
- Teromix 6700
- Terokal 2444
- Terostat 9220
- 5910, 5970
- 5088
- Terostat 90
3.4 Adhesive properties

Each adhesive type is characterized by a set of typical properties, as demonstrated by figure 4.

- The adhesion time required to reach the desired bonding strength highly depends on the type of adhesive, and may vary between a few seconds to up to 24 hours, see figure 4a. The minimum bonding strength of 1 N/mm² should be reached by then.
- The time required for complete curing up to the maximum strength may take considerably longer, see figure 4b.
- The design working temperature of the construction should not exceed the maximum allowable use temperature of the adhesive given in figure 4c.
- Figure 4d gives an impression of the shear strength of the different adhesive types.
- The gap filling capacity in millimetres for the different adhesives is shown in figure 4e.
- The flexibility of the adhesive is important for constructions that are subjected to large strains, see figure 4f.
- Figure 4g gives an impression of the resistance against environmental influence.

Figure 4 Adhesive properties
(Courtesy Henkel)
**Flexibility**

- **Static**
  - Indoor: 300
  - High humidity: 200
  - UV: 150
  - Outdoor: 120
  - Contact with chemicals: 100

- **Dynamic**
  - Indoor: 300
  - High humidity: 200
  - UV: 150
  - Outdoor: 120
  - Contact with chemicals: 100

**Environmental Resistance**

- **Temperature Range**
  - Room temperature: -40°C to 30°C

- **Strength**
  - Bond strength: 30 MPa to 2 MPa

Bond strength depends on substrate and load type. Adhesion see selection table.
3.5 Pre-treatments

The surfaces to be adhesion bonded must be clean and free of oils, grease, mold-release agents and other foreign materials for good adhesion of the adhesive, so it may be necessary to clean the parts (see par. 6).

Gluing should be done in a dust free environment.

Apart from cleaning, several other pretreatments exist to enhance adhesion of the adhesive to the substrate:

- Flaming is a simple and widely used process, in which a gas flame is moved a few centimetres above the surface of the part. The speed with which the flame is moved is in the order of 0.1 m/sec. Propane, butane and natural gas can be used to fuel the flame.

- Corona treatment is an electrical discharge process. A high voltage, high frequency electrode is moved over the surface of the part at a distance of 1 to 2 mm, activating the surface through oxidation. As a side effect, ozone is formed. This process is normally used for parts with flat surfaces and is especially suitable for sheet material.

- Low pressure plasma treatment is specifically suited for complex parts, with surfaces that can not easily be reached in flame or corona treatments. In this batchwise process, the parts are exposed to gas discharge at low pressure.

- In-line plasma treatment by Openair® atmospheric-pressure plasma technology was developed by Plasmatreat GmbH, Steinhagen. This plasma process, patented as early as 1995, is characterized, amongst others, by the fact that the plasma beam, which in this case emerges from jets (see figure 5), is electrically neutral. Its intensity is so high that treatment speeds of several 100 m/min can be achieved. In doing so, the plastic surfaces heat up by less than 20°C. The jets can be used for the most diverse parts (3-dimensional workpieces with grooves or undercuts etc.). They are also compatible with robots and can be integrated into existing product lines. The Openair® system brings about multiple effects: it activates the surface by selective oxidation processes and increases its free surface energy by a significant factor. In this way, values of more than 72 mN/m are possible on many plastics. At the same time the surface is statically discharged and cleaned very thoroughly. Moreover, by adding a precursor, selective nanocoatings may also be applied in order to influence product properties in particular ways. This makes it possible to produce plastics with surfaces particularly receptive to adhesive bonding.
Plasma treatment may result in better adhesion, but (atmospheric) plasma equipment is generally 2 to 3 times more expensive than corona equipment.

The surface is dried by the atmospheric plasma, so that complete curing may require some more time in case cyanoacrylate adhesive is used. Five minute intervals between the plasma treatment and the gluing operation are generally sufficient to admit moisture from the air for the polymerization reaction.

- Priming.
- Sanding.
3.6 Recommendations for DSM products

In this chapter recommendations are given for DSM products and their compatibility with some adhesive types is shown on the basis of shear tests that were done on small strips.

Shear tests
The shear tests were conducted according to ISO4587, on strips with a thickness of 1 to 3 mm, a width of 25 mm and an overlap of 12.5 mm. 19 different DSM engineering plastics grades - representing material clusters - were tested, in combination with four different adhesives grades from Henkel:

- cyanoacrylate (Loctite 406)
- 2 component epoxy (Loctite Hysol 9466)
- 2 component polyurethane (Terokal 4310 - 700)
- modified silane polymer (Terostat MS-937)

The Akulon and Stanyl strips were brought in the moist state in advance of the test by accelerated conditioning at 70°C and 62% relative humidity.

Three different pretreatment procedures were followed:

- cleaning by wiping with IPA (isopropyl alcohol)
- cleaning by wiping with IPA, followed by a corona treatment for 30 seconds
- cleaning by wiping with IPA, roughening with a Scotch Brite general purpose hand pad, type 3M 7447 (very fine), followed by wiping with IPA

The thickness of the adhesive layer was adjusted using thin metal wire as a spacer, as follows:

<table>
<thead>
<tr>
<th>Adhesive Type</th>
<th>Gap size</th>
</tr>
</thead>
<tbody>
<tr>
<td>cyanoacrylate (Loctite 406)</td>
<td>0.05 mm</td>
</tr>
<tr>
<td>2 component epoxy (Loctite Hysol 9466)</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>2 component polyurethane (Terokal 4310 - 700)</td>
<td>0.1 mm</td>
</tr>
<tr>
<td>modified silane polymer (Terostat MS-937)</td>
<td>2 mm</td>
</tr>
</tbody>
</table>

The curing time before testing was seven days. All materials were tested with a tensile speed of 10 mm/min, except the low modulus Arnitel TPE, which was tested at 50 mm/min.
**Mechanical considerations about shear tests**

The interpretation of shear test results is not a simple matter. The flexible strips are bent during the test, which results in additional bending stresses. Local tensile stresses can easily be twice as high as the nominal stress. Figure 6 gives an impression of the high local tensile stresses at the edges of the overlap. These high stresses may cause breakage of the strips before the adhesive fails. Several strips did indeed break during the shear tests, before cohesive or adhesive failure of the glue layer could take place. These broken strips have been indicated by an asterisk in the figures 8 to 13.

Moreover, the shear stress is not uniform over the total length of the overlap, as demonstrated by the stress calculation in figure 6. Stress concentrations are present at the edges, indicated by the blue line in figure 7. A normal stress is also present, with peaks at the edges of the overlap, indicated by the red line in figure 7.

Figures 6 and 7 clearly show that shear tests only provide a rough ranking for adhesive performance, and should not be used for precise calculations.
**Akulon (PA6 and PA66)**

Cyanoacrylate, epoxy, polyurethane, silicone and hot melt adhesives are suitable for bonding Akulon PA6 and PA66.

Shear tests were performed on four different Akulon grades, see figure 8. A high shear strength was found for cyanoacrylate adhesive, indicated by the blue bars in figure 8. Roughening of the surface gave no significant improvement for cyanoacrylate adhesive.

The results for 2-component epoxy (the yellow bars in figure 8) and the 2-component polyurethane (the grey bars in figure 5) were also good, especially after roughening or corona treatment. The corona treatment generally gave somewhat better results than the roughening treatment.

As expected, the strength of modified silane adhesive is relatively low, as indicated by the green bars in figure 8. This elastic adhesive has excellent gap-filling capacities (a gap size of 2 mm was chosen in the test for this adhesive) and must be regarded as an elastic sealant/adhesive.

The shear strength of the unfilled Akulon F223-D was considerably lower than the strength of the three glass-filled materials, which is understandable, as the stiffness of this material is much lower, so that the strips will be bent more during the test and the adhesive layer will be loaded more easily in an unfavourable peel mode.

Figure 8

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* = Test strip broke before the glue failed
**Stanyl (PA46)**

Although many different glues can be applied to polyamides, only a few are recommended for use in Stanyl at high temperatures of 120°C – 150°C. A selection of possible adhesives for Stanyl is listed in Table 2.

Applicable pretreatments for Stanyl are:

- Abrading the surface with medium grit (80-150) emery paper or grit blasting (especially effective for polyurethanes and acrylates)
- Etching the surface (3 minutes at 20°C) with a mixture of sulphuric acid (90%), potassium dichromate (4%) and water (6%)
- Priming the surface by means of a mixture of resorcinol, ethanol and p-tolueensulfonacid, a nitrilphenol based solution or by means of a resin based on resorcinformaldehyde
- Plasma or UV/ozone pretreatment (especially effective in combination with glues based on epoxies)

The adhesive forms the weakest link in a glued Stanyl component, due to the lower temperature resistance of the adhesive. Consequently adhesive bonding is not a preferred joining technique for Stanyl. More stable systems are achieved using welding techniques or mechanical fasteners.

The strength of glued Stanyl parts depends on:

- The moisture content of the polyamide parts: dry as molded parts give higher strengths than conditioned parts.
- Environmental conditions (chemical attack), size and kind of loading, size of the gap between the mating parts.
- The application of a pretreatment.

<table>
<thead>
<tr>
<th>Trademark</th>
<th>Type</th>
<th>$T_{\text{max}}$ (°C)</th>
<th>Cured at</th>
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<tbody>
<tr>
<td>Bostik M690</td>
<td>Acrylate, mod.</td>
<td>125</td>
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<td>EC 2214 HT</td>
<td>Cyan-acrylate</td>
<td>130</td>
<td>Room temperature</td>
</tr>
<tr>
<td>E 1000</td>
<td>PA</td>
<td>150</td>
<td>Hot melt</td>
</tr>
<tr>
<td>Henkel:</td>
<td>Acrylate</td>
<td>140</td>
<td>High temperature</td>
</tr>
<tr>
<td>Macromelt</td>
<td>Silicone</td>
<td>150</td>
<td>Room temperature</td>
</tr>
<tr>
<td>Loctite:</td>
<td>Acrylate</td>
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<td></td>
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<tr>
<td>Loctite 152-50</td>
<td>Silicone</td>
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</tr>
<tr>
<td>Loctite 5910</td>
<td>Silicone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marston:</td>
<td>Ethyl</td>
<td>150</td>
<td>Room temperature</td>
</tr>
</tbody>
</table>

Table 2 High temperature resistance adhesives for Stanyl.
Shear tests were conducted on three different Stanyl grades, see figure 9. The cyanoacrylate adhesive showed a high shear strength, indicated by the blue bars in figure 9. Roughening of the surface did not improve the results for cyanoacrylate adhesive, on the contrary, the strength was even lower.

The 2-component epoxy (the yellow bars in figure 9) provided moderate results if a cleaning operation was only performed. Roughening already gave some improvement, but the best results are found for corona treatment.

The 2-component polyurethane (the grey bars in figure 9) produced moderate to good results. Roughening or corona treatment do not result in a big improvement.

The strength of modified silane adhesive is relatively low, as expected (see the green bars in figure 9). This adhesive has excellent gap-filling capacities (a gap size of 2 mm was chosen in the test for this adhesive) and must be regarded as an elastic sealant/adhesive.

On average the unfilled Stanyl TW 341 has a lower shear strength than the two glass filled Stanyl types, just as was found for unfilled Akulon, but the result is less significant.

Figure 9

* = Test strip broke before the glue failed
**Arnite (PBT and PET)**

Ethylcyanoacrylate, methacrylatelastomer, ethyl, methyl, polyurethane, epoxy and silicone type adhesives are suitable for Arnite PBT and PET. Hot melt adhesives can also be applied. The area to be joined should be lightly roughened and free of grease. A corona treatment is even more effective than roughening. The adhesion strength obtained, however, will be below the specified product strength.

Shear tests conducted on four different Arnite grades showed a high shear strength for cyanoacrylate adhesive, see the blue bars in figure 10. The strength can even be improved considerably by roughening of the surface. The strength of 2-component epoxy (the yellow bars in figure 10) provided low to moderate results if only a cleaning operation was performed. Roughening already gave a significant improvement, but the best results were attained with the corona treatment.

The 2-component polyurethane (the grey bars in figure 10) produced moderate to good results. Roughening and especially corona treatment brings a big improvement. The strength of modified silane adhesive is relatively low, as expected (see the green bars in figure 10). MS-adhesive has excellent gap-filling capacities (a gap size of 2 mm was chosen in the test for this adhesive) and can be regarded as an elastic sealant/adhesive.

---

**Figure 10**

![Image of shear strength test results for Arnite](image-url)

**Results of shear tests on Arnite**

* = Test strip broke before the glue failed
Gluing Guide

Arnitel (TPE)
Good bonding results can be achieved on Arnitel components with polyurethane adhesives. Normally two-component systems are used, with isocyanate or di-isocyanate hardeners. Arnitel can be laminated (e.g. to fabric) with a TPU (thermoplastic Polyurethane) hot melt adhesive. The high temperature during melting of the adhesive activates the hardener in the hot melt.

Shear tests have been done on four different Arnitel grades, as shown in figure 11. The grades UM 551-V and VT 3108 are harder and stiffer than the grades EM 400 and PL 380, and had a higher shear strength. The deflection of these stiffer test strips under the load will be lower, so that the adhesive layer will not be loaded in an unfavorable peel mode.

A good shear strength was found for cyanoacrylate (the blue bars in figure 11) after a cleaning operation only. The strength could not be improved significantly by roughening of the surface.

The shear strength of the 2-component epoxy (the yellow bars in figure 11) is quite low after cleaning, but can be improved considerably by a roughening operation. A corona treatment gives even better results.

The 2-component polyurethane (the grey bars in figure 11) provided results that are comparable with those of cyano-acrylate. Roughening or corona treatment gave no significant improvement.

The strength of modified silane adhesive is relatively low, as expected, shown by the green bars in figure 11. This kind of adhesive has excellent gap-filling capacities (a gap size of 2 mm was chosen in the test for this adhesive) and should be regarded as an elastic sealant/adhesive.

Figure 11

Results of shear tests on Arnitel

* = Test strip broke before the glue failed
**Xantar (PC), Xantar C (PC + ABS) and Stapron E (PC + PET)**

A variety of adhesive types can be used for bonding Xantar PC and PC-blends: epoxy, urethane, cyanoacrylate, acrylic, methacrylic, silicone and hot melt. UV-transparent grades can also be bonded with UV-cure types. Being amorphous materials, Xantar PC and PC-blends are relatively sensitive to stress cracking induced by solvents, or to degradation due to specific chemical substances like amines. The best results are generally achieved with solventless materials.

Reactive adhesives make it possible to bond Xantar to many other materials. The application of reactive adhesives is simple and fast compared to adhesive solvents and there is less need to accurately align the joint areas. Reactive adhesives with elastic properties after curing are used in the automotive industry (e.g. for gluing lenses of transparent PC to metallized surfaces or to opaque PC). Reactive adhesives for Xantar based on epoxy resin must be free of low molecular weight amines. Polymeric amino amides can be used as hardeners. The possible reaction of residual amino groups with Xantar must be avoided by ensuring that the amino groups react completely with the epoxy groups.

Two-component and one-component polyurethane adhesives have also proven successful in joining PC, but they must be free of solvents and amines.

Silicone adhesives are particularly suitable as jointgap-filler systems (e.g. for glazing of industrial and greenhouse windows).

Cyanoacrylate adhesives, should be used only to bond stress-free parts that will not be subjected to hydrolytic loads during use. If glass filled PC surfaces that undergone some machining operation, like sawing or milling, are joined with cyanoacrylate adhesive, the solvent in the adhesive may penetrate the small gaps between the glass fibres and the matrix, causing environmental stress cracking problems.
Shear tests have been performed on three Xantar grades: unfilled Xantar 19R PC, unfilled Xantar C CM 406 PC-ABS and glass filled Xantar G4F 23R PC, see figure 12. On average a better shear strength was found for the glass filled Xantar G4F 23R, just as for a glass filled Akulon and Stanyl. The higher stiffness of the material prevents bending of the test strip and loading of the adhesive in the unfavorable peel mode.

Cleaning the surface is sufficient in most cases. The shear strength was not improved by roughening the surface or corona treatment in most cases. This is in sharp contrast with semi-crystalline materials.

2-component polyurethane (the grey bars in figure 12) and 2-component epoxy (the yellow bars in figure 12) gave good results. Cyanoacrylate adhesive in combination with unfilled Xantar 19R produced somewhat lower shear strength values, as indicated by the blue bars in figure 12.

As expected, the strength of modified silane adhesive is relatively low, as shown by the green bars in figure 12. MS-adhesive has excellent gap-filling capacities (a gap size of 2 mm was chosen in the test for this adhesive) and can be regarded as an elastic sealant/adhesive.

Figure 12

Results of shear tests on Xantar

<table>
<thead>
<tr>
<th>Shear strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corona</td>
</tr>
<tr>
<td>Xantar 19R</td>
</tr>
</tbody>
</table>

* = Test strip broke before the glue failed
The results of shear tests on Stapron E EM 605 PC-PET are shown in figure 13.

Roughening of the surface did not bring an improvement and even deteriorated the adhesion in some cases. A positive effect of corona treatment was found for 2-component epoxy (see the yellow bars)

A good shear strength was found for cyanoacrylate, 2-component epoxy and 2-component polyurethane.

The strength of modified silane adhesive is relatively low, as expected, see the green bars in figure 13. This kind of adhesive has excellent gap-filling capacities (a gap size of 2 mm was chosen in the test for this adhesive) and should be regarded as an elastic sealant/adhesive.

Figure 13

Results of shear tests on Stapron

<table>
<thead>
<tr>
<th>Material</th>
<th>Shear strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyanoacrylate (Locitile 406)</td>
<td>12</td>
</tr>
<tr>
<td>2-comp. epoxy (Locitile 9465)</td>
<td>10</td>
</tr>
<tr>
<td>2-comp. PU (Terokel 4310 - 700)</td>
<td>8</td>
</tr>
<tr>
<td>Modified silane (Terostat MS337)</td>
<td>6</td>
</tr>
</tbody>
</table>

Shear strength (N/mm²)
3.7 Design for adhesive bonding

The load on the assembly can be applied in a similar way to solvent bonding, see figure 1.

Thin layers are advisable in case of lap-shear. Peel and split loads are best taken up by a thick layer of adhesive.

General design guidelines are:
- design for lap-shear loads
- maximize the bonding surface; for instance, use a scarfed or a dovetail joint
- avoid stress concentrations at thick-thin sections
- ensure sufficient venting on substrate.

Recommended joint designs are given in figure 14. Hermetic seals required for containers and bottles may be achieved with the designs shown in figure A and B. Joint C is more universal.

To ensure successful joining with adhesives it is important to know the functional requirements of the assembly and the possibilities and limitations of the adhesive in combination with the substrate.

The following checklist may prove useful:

- product: design joints specifically for adhesives
- mechanical load: lap-shear, peel, split or tensile
- life of joint: use temperature, environment, relative humidity
- thermoplastic substrate: mechanical properties, wetting, moisture absorption
- adhesive: temperature and chemical resistance
- pretreatment: cleaning, etching, sanding, oxidation, primer
- safety: MSDS (Material Safety Data Sheet) chart.
- process: numbers, curing conditions, application techniques

The moisture content of polyamides does not strongly influence the bond strength. However, it is advisable to conduct some bonding tests with conditioned parts prior to production.
3.8 Quick adhesive test

The compatibility of a substrate and an adhesive can quickly be tested as follows.

1. Dispense a drop of the adhesive onto the sample and cure accordingly. When testing multiple adhesives, apply each adhesive to the substrate and cure them all at once. Label each adhesive.

2. Allow the part to cool for approximately 1-2 minutes (the adhesive may produce different results when warm).

3. Conduct the adhesion test: Pick the adhesive off with the tip of a dental pick or a safety razor. Rate products for their adhesion on the specific substrate. Evaluating adhesion is somewhat subjective and may vary from person to person. Having more than one person perform the test and using a composite rating minimizes this error.

4. Record results. More rigorous pick tests may include exposure of cured adhesive to hot or cold temperatures or to water or other solvents if adhesion under those conditions is important.

3.9 How to select the best adhesive?

Step 1. Adhesion
The first and most basic property that all adhesives must have is good adhesion to all of the substrates that need to be bonded. The substrate selector guide in figure 3 may be a good place to start the selection process. When a single substrate material is to be bonded (for example PA6 to PA6) the process of selecting possible adhesives is straightforward. When two different substrates are to be bonded, i.e., PA6 to PBT a range of possibilities should be evaluated. After a few pick tests (see paragraph 3.8) it will be obvious which substrate is more difficult to bond and choices can be optimized for that substrate.

Step 2. Viscosity
In determining viscosity, consideration should be given to how the adhesive must flow (or not flow) on the part after the adhesive is applied. Part geometry, process geometry and assembly speeds and methods should all be considered when selecting a viscosity.

Step 3. Physical properties
If an application requires an adhesive with a special set of physical properties, this step should be considered before viscosity. Product data sheets of the adhesives include a more extensive list of product properties i.e., hardness, tensile properties, shrinkage and water absorption.
Figure 4d shows that glues can be divided into two groups. Epoxy, acrylic, cyanoacrylate, polyurethane and contact glues are bonders with high strengths (figure 4d) and relatively short curing times (figures 4a and 4b). Flexible PU, MS-polymer and silicone glues have a high gap filling capacity (figure 4e) and are very flexible (figure 4f), but they have a relatively low strength.

The figures 4c and 4g given an impression of the use temperature range and the environmental resistance. Modified silane adhesives can be used in a wide range, but epoxy and acrylic adhesives also have excellent temperature resistance. The environmental resistance of epoxies and silicones is very good.

Step 5. Curing equipment
Light curing adhesives are formulated to react optimally with specific types of light. Best cure results are obtained when the output of the curing lamp is matched with the absorption spectrum of the adhesive.

Step 6. Price
The price per kilo of glues varies considerably, as demonstrated by figure 15. The cheapest glue type that fulfills all the technical requirements should be selected.

Step 7. Use testing
Final adhesive selection should include a sound evaluation of suitable adhesives by application and cure of adhesive to actual parts subjected to real-life stress conditions. Use testing should also include process validation tests, which include the production of parts using planned adhesive application and curing methods. Adhesive use testing should include stresses somewhat higher than those expected for assembled parts. The severity of this testing is best determined by part designers.

DSM's Technical Service Department for engineering plastics may be consulted for all gluing advices.

Figure 15 Rough price index per kilo of different adhesive types.
The adhesives at the bottom of the pyramid are the high-volume types.
4. Double-Sided Tape

Double-sided coated tapes are adhesive-coated on both sides of paper, film or tissue. This increases the adhesive’s dimensional stability for easy handling and application. Double-sided pressure sensitive tapes are available with a variety of carriers, adhesives and load bearing capabilities.

Specific advantages of double-sided tapes are:

- homogeneous distribution of mechanical loads
- dampen vibrations and noise
- absorb impact
- join dissimilar materials
- resist plasticizer migration, avoiding stress cracking problems
- good esthetics / no special requirements to hide the bond
- economic assembly / minimal application training / no investment in major equipment
- low weight, no heavy bolts and nuts
- differences in thermal expansion of components can be compensated by a thick adhesive layer
- ability to join heat sensitive constructions or materials, which welding would distort or destroy

Potential limitations are:

- stress cracking or crazing caused by the adhesive
- reproducibility / process control
- disassembly.

Adhesive transfer tape consists of a pressure-sensitive adhesive pre-applied to a special release liner. The tape is simply applied to a surface and the liner is peeled off. This leaves a clean, dry strip of acrylic adhesive for joining of lightweight materials.

Pressure-sensitive tapes require a clean surface for optimal strength. Cleaning of the part may be necessary to remove oil, grease, mold release agent and other foreign materials, see par 6.
5. Surface wetting

The wetting of the surface is characterized by the contact angle of the liquid with the surface, as shown in figure 16. If the contact angle is 90° or larger, wetting will be incomplete.

The surface contact angle in its turn is determined by the surface tension of the liquid and the surface free energy of the plastic. Good wetting and distribution of the solvent or the adhesive on the substrate can be achieved only when the surface tension of the liquid is lower than the surface free energy of the substrate.

The surface free energy of the substrate can be measured in various different ways. One procedure is to measure the contact angle of a drop of de-ionized water that is applied to the substrate with a hand-held measuring device as shown in figure 17. The measuring results can be represented on a PC-screen, see figure 18.

Figure 16 The relation between the surface contact angle and wetting of the surface.

Figure 17 Hand-held measuring device, enabling measurement of the contact angle on the substrate without any sample preparation. The system looks from the side on the applied droplet and measures in this way the contact angle, the base, the height and the volume of the droplet, in both static and dynamic mode (= measurement as a function of time). (Images provided by courtesy of Rycobel - Belgium)

Figure 18 Screen presentation of the contact angle measurements.

The contact angle, the drop width and the drop height are presented as a function of time.
Figure 19 shows some typical surface energy values of DSM polymers that were measured in this way. The values were all high enough to ensure good wetting of the surface with an adhesive. If much lower surface energies are found, this could be an indication that the surface is not clean.
6. Cleaning

The surfaces of parts that must be joined together by a gluing process, must be clean and free of foreign materials, such as dirt particles, oil, grease or mold release agent in order to achieve a strong bond.

If the plastic pellets do not contain a mold release agent and if no mold release agent has been sprayed in the mold during the injection molding process and the parts were not touched with bare hands, cleaning in an air bath to remove dust particles may suffice.

The use of a mold release agent can be avoided by designing the parts with generous release angles.

If necessary, persistent contaminants can be removed by washing in a suitable solvent. Tables 3 to 7 give some examples of solvents that may be used for DSM's thermoplastics, assuming that the parts will not be exposed to these cleaning solvents for more than 10 minutes.

Atmospheric plasma enables both a cleaning and an activation effect on the polymer surface where there is a low level of contamination.

Table 3 Cleaning solvents for Akulon (PA6 & PA66).

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butanol</td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td></td>
</tr>
<tr>
<td>Isopropanol</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td></td>
</tr>
<tr>
<td>Propanol</td>
<td></td>
</tr>
<tr>
<td>Aliphatics</td>
<td>Heptane</td>
</tr>
<tr>
<td></td>
<td>Hexane</td>
</tr>
<tr>
<td>Aromatics</td>
<td>Benzene</td>
</tr>
<tr>
<td></td>
<td>Toluene</td>
</tr>
<tr>
<td>Ketones</td>
<td>Acetone</td>
</tr>
<tr>
<td></td>
<td>Methyl ethyl ketone</td>
</tr>
<tr>
<td>Chlorinated hydrocarbons</td>
<td>Methyl chloride</td>
</tr>
<tr>
<td></td>
<td>Tetra chloro methane</td>
</tr>
<tr>
<td>Others</td>
<td>Mild solution of soap (pH between 4.5 and 7.5)</td>
</tr>
</tbody>
</table>

Table 4 Cleaning solvents for Stanyl (PA46).

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butanol</td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td></td>
</tr>
<tr>
<td>Isopropanol</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td></td>
</tr>
<tr>
<td>Propanol</td>
<td></td>
</tr>
<tr>
<td>Aliphatics</td>
<td>Heptane</td>
</tr>
<tr>
<td></td>
<td>Hexane</td>
</tr>
<tr>
<td>Aromatics</td>
<td>Benzene</td>
</tr>
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<td></td>
<td>Toluene</td>
</tr>
<tr>
<td>Ketones</td>
<td>Acetone</td>
</tr>
<tr>
<td></td>
<td>Methyl ethyl ketone</td>
</tr>
<tr>
<td>Chlorinated hydrocarbons</td>
<td>Methyl chloride</td>
</tr>
<tr>
<td></td>
<td>Tetra chloro methane</td>
</tr>
<tr>
<td>Others</td>
<td>Mild solution of soap (pH between 4.5 and 7.5)</td>
</tr>
</tbody>
</table>

Table 5 Cleaning solvents for Arnite (PBT and PET).

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butanol</td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td></td>
</tr>
<tr>
<td>Isopropanol</td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td></td>
</tr>
<tr>
<td>Propanol</td>
<td></td>
</tr>
<tr>
<td>Aliphatics</td>
<td>Heptane</td>
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<td></td>
<td>Hexane</td>
</tr>
<tr>
<td>Aromatics</td>
<td>Benzene</td>
</tr>
<tr>
<td></td>
<td>Toluene</td>
</tr>
<tr>
<td>Ketones</td>
<td>Acetone</td>
</tr>
<tr>
<td></td>
<td>Methyl ethyl ketone</td>
</tr>
<tr>
<td>Ester</td>
<td>Ethyl acetate</td>
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<tr>
<td></td>
<td>Methyl acetate</td>
</tr>
<tr>
<td>Chlorinated hydrocarbons</td>
<td>Methylene chloride</td>
</tr>
<tr>
<td></td>
<td>1,1,1-Trichloro ethane</td>
</tr>
<tr>
<td>Chlorinated fluorocarbons</td>
<td>Trichloro trifluoro ethane</td>
</tr>
<tr>
<td></td>
<td>Trichloro trifluoro methane</td>
</tr>
<tr>
<td>Others</td>
<td>Mild solution of soap (pH between 4.5 and 7.5)</td>
</tr>
</tbody>
</table>
Some solvents may cause environmental stress cracking in polycarbonate and polycarbonate blend parts which are subjected to internal or external stresses. Chlorinated and aromatic solvents, as well as ketones, should therefore be avoided for these polymers.

It is important to consult the Material Safety Data Sheet of the solvent used, for health and safety information and for proper handling and protective equipment.

An automated cleaning line may be useful to speed up the cleaning process and improve quality control. An ultrasonic bath or a spraying installation could be considered.

<table>
<thead>
<tr>
<th>Table 6 Cleaning solvents for Arnitel TPE.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alcohols</strong></td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Aliphatics</strong></td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Ketones</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Others</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 7 Cleaning solvents for Xantar (PC), Xantar C (PC + ABS) and Stapron E (PC + PET).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alcohols</strong></td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Aliphatics</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Others</strong></td>
</tr>
</tbody>
</table>
Contact
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We do not settle for ordinary solutions. Instead, we strive to find Living Solutions, working together with customers in a dedicated, resourceful and reliable way.

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