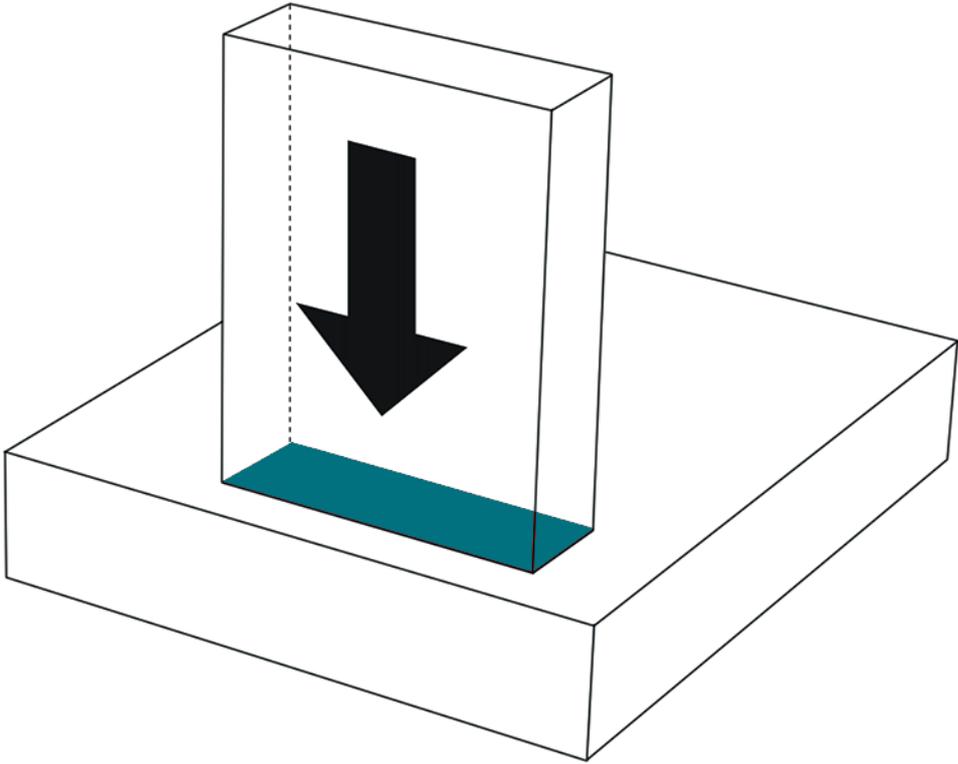


GUIDELINES FOR WORKSHOP PRACTICE

Joining PLEXIGLAS®



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1. General remarks

PLEXIGLAS® – the world's first acrylic (polymethyl methacrylate, PMMA), which we produce – can be joined permanently by bonding, heat lamination, welding or riveting and temporarily by means of clamps or screws. The joining method best suited to the application depends on the requirements. Nevertheless, the most widely used method is bonding. A range of specially formulated adhesives are available for PLEXIGLAS® GS and XT.

PLEXIGLAS® GS is an acrylic glass manufactured by casting, while PLEXIGLAS® XT is an acrylic glass made by extrusion. All materials can be joined in much the same way.

Differences in joining behaviour are noted in the respective section.

Bonding of items injection-moulded or extruded from PLEXIGLAS® moulding compound can be performed in a similar way as the bonding of extruded sheets.

1.1 Physical forms

PLEXIGLAS® GS is manufactured in the form of solid sheets, blocks and rods with smooth or matte/satin surfaces (PLEXIGLAS® Satinice).

PLEXIGLAS® XT is available in standard and impact-modified grades (PLEXIGLAS® Resist) as smooth, textured or matte (PLEXIGLAS® Satinice) solid sheet, corrugated and multi-skin sheet, mirrors, tubes and rods as well as films.

PLEXIGLAS® varieties are available in colourless, white or coloured designs. The light-permeability ranges from transparent and translucent to opaque.

Whether in standard or special sizes, all material packaged on pallets is labelled with information for correct storage and in-house transport. Generally speaking, PLEXIGLAS® is best stored indoors. All our sheets are masked with polyethylene film, which can be disposed of without any problem. In the case of outdoor storage, effective additional protection is required.

1.2 Masking film

Depending on material grade and thickness, the surfaces of our PLEXIGLAS® sheets are masked with self-adhesive film or cling film made from polyethylene (PE).

The surface masking can remain on the sheet until it is in its final place. When the masking film is removed, the PLEXIGLAS® sheet should be fixed and the film should be removed in one uninterrupted movement.

If sheets are exposed to the weather, all masking films must be **removed** regardless of their adhesive properties (with the exception of UV-resistant films). There is otherwise a risk that the masking films may become brittle or adhere to the sheet even more strongly. In either case the films can no longer be properly removed, and the sheets are likely to be damaged.

Notes:

In addition to this publication, there are similar Guidelines for Workshop Practice on

Machining PLEXIGLAS®
(Ref. No. 311-1),

Forming PLEXIGLAS®
(Ref. No. 311-2) and

Surface Treatment of PLEXIGLAS®
(Ref. No. 311-4).

You can find valuable do-it-yourself hints on PLEXIGLAS® in

Fabricating Tips for PLEXIGLAS®
(Ref. No. 311-5).

Special leaflets are available on the properties and fabricating behaviour as well as the applications of several of our products, for example,

- multi-skin and corrugated sheets,
- glazing with solid sheets,
- noise barriers,
- signage and lighting.

These can be obtained from your local authorised distributor of PLEXIGLAS®.

When using our products, please observe

- local building codes and emissions laws,
- applicable standards, e.g. DIN 1055,
- product liability imposed by law,
- the guidelines of employers' liability insurance associations.

2. Bonding

Thanks to the physical and chemical properties of PLEXIGLAS® GS and PLEXIGLAS® XT, unions of very high strength can often be achieved by bonding. The quality of the bonding depends very much on the experience of the fabricator. Therefore it is essential to test all new bonding techniques before use.

Different types of specially developed adhesives are available for bonding PLEXIGLAS® to a range of different materials (see following tables). For further important information on our ACRIFIX® adhesives please consult the corresponding **technical information** and the **safety data sheets**, which are available on request from distributors of PLEXIGLAS®. The safety data sheets contain all relevant information on health and safety measures, transport and disposal.

2.1 Adhesive systems

- **Reaction adhesives based on polymethyl methacrylate/methyl methacrylate (PMMA/MMA)** are polymerisation adhesives consisting of one or several components. They cure on exposure to UV light or when catalysts are added. They are gap-filling and thus suitable for area bonding and provide very strong and normally weather-resistant unions. Depending on where they are used, there may be some risk of the joint becoming discoloured.

- **Solvent (borne) adhesives** consist mainly of solvents and effectively work on the adherends. When the parts have been joined, the solvents escape from the adhesive by evaporation and diffusion into the material. After drying, the joint is solid. Solvent adhesives are not gap-filling. Bond strengths are lower than those

achieved with polymerization adhesives, but usually adequate even for outdoor use.

Adding MMA-based polymers (up to 20%) creates viscous solvent adhesives that are slightly gap-filling.

Solvent adhesives containing dichloromethane (= methylene chloride), i.e. ACRIFIX® 1S 0126, 1S 0127 and 1S 0109, are meant exclusively for commercial use, where adequate safety measures for the prevention of accidents and precautions against health risks can be taken for granted (see Section 2.8 and Fig. 19).

The solvent adhesives ACRIFIX® 1S 0116 and 1S 0117 do not contain dichloromethane.

| Table of recommended adhesives for bonding PLEXIGLAS® GS/XT with other plastics | | | | | | | | |
|---|-----|-----|-------|-------|-------|-------|----|----|
| | PES | PSU | ABS | CAB | PS | PVCu | UP | PC |
| ACRIFIX® 1R one-component reaction adhesive | | | x | x | x | x | | |
| ACRIFIX® 2R two-component reaction adhesive | | | x | x | x | x | | x |
| ACRIFIX® 1S solvent adhesive | | | x (x) | x (x) | x (x) | x (x) | | x |
| One-comp. silicone for small adherends (primer may be required) | x | x | x | x | x | x | x | x |
| Two-comp. silicone for large adherends (NB: primer required) | x | x | x | x | x | x | x | x |
| Double-sided adhesive tape without a carrier | x | x | x | x | x | x | x | x |
| Double-sided foam-carrier adhesive tape | x | x | x | x | x | x | x | x |
| Contact adhesive | x | x | x | x | x | x | x | x |

(x) = thin-bodied solvent adhesives not suitable for PLEXIGLAS® GS

| Table of recommended adhesives for bonding PLEXIGLAS® GS/XT with other materials | | | | | | | |
|--|-------|------|--------------------------|-------------------------|----------|---------------|------------------------------------|
| | Glass | Wood | Paper Paper- board | Felt Leather Cork | Concrete | Iron Steel | Aluminium Non-ferrous metals |
| ACRIFIX® 1R one-component reaction adhesive | | | | | | | |
| ACRIFIX® 2R two-component reaction adhesive | | x | | x | | | |
| ACRIFIX® 1S solvent adhesive | | | | | | | |
| One-comp. silicone for small adherends (primer may be required) | x | x | x | x | x | x | x |
| Two-comp. silicone for large adherends (NB: primer required) | x | x | | | x | x | x |
| Double-sided adhesive tape without a carrier | x | x | x | | | x | x |
| Double-sided foam-carrier adhesive tape | x | x | | | | x | x |
| Contact adhesive | x | x | x | x | x | x | x |

2.2 Bonding behaviour of PLEXIGLAS®

High-molecular-weight PLEXIGLAS® GS shows different bonding behaviour than low-molecular-weight PLEXIGLAS® XT and items injection-moulded from PLEXIGLAS® moulding compound.

Polymerization adhesives (e.g. ACRIFIX® 2R 0190, 2R 2019) are mainly used for edge and area bonding of PLEXIGLAS® GS. This provides bonds of high optical quality with up to 75% of the inherent strength of PLEXIGLAS®.

For PLEXIGLAS® GS, roughening the adherend improves the bond strength. This is recommended for apparatus and containers, for example. Roughening is particularly recommended for special crosslinked types of PLEXIGLAS® GS.

Pure solvents without added polymers do not work sufficiently on items made of PLEXIGLAS® GS and are therefore only suitable under certain conditions. Better suited are adhesive solutions with added polymer, like ACRIFIX® 1S 0126 or 1S 0116, for example, in which case the solvent works on the joint longer. Bonded parts of PLEXIGLAS® GS do not show a pronounced tendency to stress cracking. Therefore they do not normally have to be annealed (see Section 2.5) before bonding.

PLEXIGLAS® XT offers several advantages when it comes to bonding. Since it lends itself more readily to solvent action than cast PLEXIGLAS®, bonds can sometimes be obtained more rapidly and simply.

Polymerization adhesives (e.g. ACRIFIX® 2R 0190 and 1R 0192) are used for edge and area bonding of PLEXIGLAS® XT and items injection-moulded from PLEXIGLAS® moulding compound. For bonds only involving edges, good results can be achieved with solvent adhesives (e.g. ACRIFIX® 1S 0126 or 1S 0116, 1S 0127 or 1S 0117).

Polymerization adhesives and solvent adhesives can only be used on stress-free parts if cracking is to be ruled out. Annealing at 70 to 80 °C may therefore be required before bonding (see Section 2.5) in order to relieve stress generated during sawing, milling, polishing, thermoforming, etc.

Flat cut-to-size sheets of PLEXIGLAS® XT can normally be area-bonded without prior annealing. Sawn or milled edges of PLEXIGLAS® XT sheets can be bonded directly without prior annealing, provided they have been correctly machined with optimally ground tools (see Guidelines for Workshop Practice 311-1, Machining PLEXIGLAS®).

Besides bonding behaviour depending mainly on molecular weight, certain other influences have to be borne in mind with PLEXIGLAS® GS and PLEXIGLAS® XT:

- Adhesives may induce the colourants contained in coloured PLEXIGLAS® to bleed.
- Highly pigmented parts – e.g. densely coloured white material – may show reduced bond strength.
- Impact-modified parts – e.g. made of PLEXIGLAS® Resist – suffer a loss of impact strength and bond strength in the joint area as the Resist content increases.
- Stretched or thermoformed parts have reduced bond strength at right angles to the plane of stretch.

2.3 ACRIFIX® adhesives and additives

For our current range of adhesives and additives, please refer to the latest brochure 191-1, ACRIFIX® Adhesives and Additives.

2.4 Health and Safety Measures

All containers for ACRIFIX® adhesives and additives are labelled in accordance with GHS (Globally Harmonized System of Classification and Labelling of Chemicals).

When handling adhesives and additives together with PLEXIGLAS® GS and XT or other materials, it is necessary to take the measures provided for by:

- EC regulation 1272/2008, the German Toxic Chemicals Ordinance (GEFStoffV),
- the regulations for workplace safety and the prevention of accidents and
- generally acknowledged standards of safety engineering, industrial medicine and hygiene as well as proven ergonomic findings.

Most adhesives constitute a fire hazard. The vapours they give off may form explosive mixtures with air. Open sources of heat (flames, electric radiators) and sparking (ignition sparks, static discharges) are to be avoided. Moreover, smoking, eating or drinking at the workplaces should be prohibited.

For workplaces and storerooms, the (German) statutory order on flammable liquids (VbF) is to be observed and for electrical installations in these areas, the (German) regulations DIN EN IEC 60079.

Continuous inhalation of solvent vapours and frequent skin contact may have a mutually intensifying effect, thereby being detrimental to health and provoking allergies. Therefore, bonding work is to be performed in well-ventilated rooms without drafts.

Since the solvent vapours are heavier than air, extractors have to be installed at floor level. Where substantial quantities of adhesive are handled, an additional extractor at the workplace itself is recommended (see Fig. 18).

The ventilation system must be designed in such a way that the occupational exposure limit value (OEL) according to TRGS 900 is not exceeded. Gas detectors with test tubes specifically for different solvents are available for determining the OELs. Approved inspection institutes can, however, be commissioned with determining the occupational exposure limits.

Solvents destroy the skin's protective sebaceous layer.

Therefore, skin contact with adhesives should be avoided. Wipe affected skin immediately with a cloth, then clean with soap and water and apply a skin barrier cream.

Do not discard adhesive waste in an uncontrolled manner, but dispose of it according to the applicable national regulations – see also waste codes in the safety data sheet.

Take up liquid spillage or leakage with absorbent material (sand, fuller's earth, expanded mica), store in special containers and dispose of in compliance with the regulations.

For more information on safety measures, the exclusion of health risks and disposal, see our **safety data sheets**, which are provided to our customers by authorized distributors of PLEXIGLAS® and ACRIFIX®.

2.5 Pre- and Post-Bonding Work

The quality of bonds between parts of PLEXIGLAS® depends to a large extent on the careful preparation of these parts, on the adhesive used, the auxiliary agents and the bonding technique.

2.5.1 Preparing the Workpieces

If possible, the preparation work should be conducted in this order:

1. machining,
2. roughening (where required),
3. cleaning,
4. annealing (where required),
5. covering the surrounding area,
6. degreasing the adherends.

The pre-bonding work in detail:

2.5.1.1 Machining

When machining PLEXIGLAS®, please consult our Guidelines for Workshop Practice, Machining PLEXIGLAS®, and observe our instructions to the letter

2.5.1.2 Roughening

For PLEXIGLAS® GS, roughening the adherend improves the bond strength. Roughening is particularly recommended for special crosslinked types of PLEXIGLAS® GS. Wet sandpaper (320 to 400 grit) or grinding fleece should be used to roughen the sheet surface.

2.5.1.3 Cleaning

Coarse visible particles are cleaned away by blowing the surfaces with ionised air or with warm water and a little washing-up liquid, for example. Absorbent, non-linting cloth, e.g. washed glove-lining fabric, is best suited for wiping the material dry.

2.5.1.4 Annealing (prior to bonding)

Annealing prior to bonding serves to relieve stress: This avoids cracking as a possible result of tensile stress in the presence of monomers and/or solvents contained in polymerization adhesives and solvent adhesives.

Crazing in the bond area reduces the adhesion and affects the appearance. Therefore, it has to be avoided at all costs.

Stress is generated in all materials, including acrylics, during machining operations like sawing, milling, turning, sanding and polishing, as well as during thermoforming and cold curving.

It may, however, also be the result of deformations in the parts to be bonded, e.g. caused by weights, clips or G-clamps.

Extruded profiles, and especially tubes, as well as injection-moulded items are almost always internally stressed as a result of the cooling conditions. Annealing the bonded parts eliminates this stress.

The annealing conditions described below depend on the heat deflection temperature under load and the stress level of the parts to be bonded.

Stress test

A test for tension must be performed to determine whether a pre-processed part needs to be pre-annealed for following processing steps, such as bonding, or whether a completed part needs to be post-annealed for its use.

A simple **test methods with solvents** is available for crystal-clear or not opaquely coloured material. Although this method does not indicate the exact internal stress level, it provides information that is valuable for practical use.

This test is destructive for parts with internal stress.

Individual details are given in the table below.

Another test, which is absolutely non-destructive, for crystal-clear workpieces of PLEXIGLAS® is visual inspection between two polarizing sheets. Although this does not provide the exact stress level either, you can see the stress areas via the location and shape of the emerging rainbow colours.

Annealing conditions

Temperature:

(in the airflow oven)
 PLEXIGLAS® GS: 80 °C
 PLEXIGLAS® XT: 70 °C

Annealing time:

PLEXIGLAS® GS and PLEXIGLAS® XT: The material thickness in mm divided by 3 is the annealing time in hours, but the minimum is 2 hours.

Cooling:

- The cooling time in the oven in hours is the material thickness of PLEXIGLAS® in mm divided by 4. The cooling rate must not exceed 15 °C per hour.
- Upon removal from the oven, the temperature of the bonded PLEXIGLAS® part must not exceed 35 °C on any account.
- Cold draughts should be prevented from entering the oven, as this may cause a build-up of tension.

| Method | Workpieces made of | Test medium | Procedure | Testing time | Result | Remarks |
|--------------------|---|------------------------------|----------------------|--------------|--|------------------------------|
| Acetic ester test | PLEXIGLAS® GS PLEXIGLAS® XT PLEXIGLAS® FM | Acetic ester (ethyl acetate) | Immersion or wetting | 6 min | Crazes within testing time: too much stress! | solvent action, destructive |
| Ethyl alcohol test | PLEXIGLAS® XT PLEXIGLAS® FM | Ethyl alcohol | Immersion or wetting | 15 min | No crazes: part is ready for use. | no solvent action destroying |

2.5.1.5 Covering the surrounding area

Sometimes it may be necessary to protect the area around the joint against solvent attack or scratching. This can be done with self-adhesive films of polyethylene, masking film or compatible adhesive tapes, or by applying liquid coating systems which can later be stripped off as films (e.g. 30% aqueous solutions of PVAL).

2.5.1.6 Degreasing the adherends

When using **polymerisation adhesives**, the adherends should be precleaned, or rather degreased, just before applying the adhesive. The material must be stress-free or annealed! The pre-cleaning/degreasing is best done by wiping the surfaces with undyed absorbent paper or cloth (e.g. washed glove-lining fabric/cotton fabric) soaked with ACRIFIX® TC 0030 or isopropyl alcohol.

With ACRIFIX® TC 0030, accidentally applied traces of adhesive (“stringing”) can easily be removed from the PLEXIGLAS® surface as long as they have not hardened.

If **solvent adhesives** are used, the adherends must first be cleaned or degreased with petroleum ether or isopropyl alcohol.

2.5.2 Preparing the adhesive

The adhesives should be at room temperature (18–25 °C) before they are used.

No preparatory work is required when using solvent adhesives or one-component polymerisation adhesives.

In the case of two- and multi-component polymerisation adhesives, it is **very important to observe certain basic rules**.

The individual products should be mixed in the following order:

1. adhesive
2. thinner or thickener
3. colourant
4. reaction moderator
5. catalyst

For good bonding results it is essential to **mix the adhesive composition** very thoroughly. Therefore the following recommendations must be observed:

- Make sure to skim the wall of the container and also to lift and plunge the stirring rod, to ensure that adhesive at the bottom of the container is also mixed.

- For larger compositions use an electrically or pneumatically operated agitator. The diameter of the propeller or stirrer blade should be only slightly smaller than the diameter of the vessel. Under no circumstances may the adhesive composition be prepared in the applicators (e.g. syringes), because they do not permit thorough mixing.
- After mixing, the adhesive must be free from striation.
- Before applying the adhesive, remove the air pockets formed by stirring. To this end, leave the composition to stand for some time (observe the pot life); the air pockets will rise to the surface and disappear. Keep the vessel covered during this time to avoid skin formation on polymerisation adhesives and contamination in general.
- To speed up the process, put the covered container in a vacuum desiccator. Polymerisation adhesives (with the exception of ACRIFIX® 2R 2019) require a negative pressure of about 0.8 bar, in which case the absolute pressure is approx. 0.2 bar. The absolute pressure must never fall below this value, because otherwise the adhesive will foam due to evaporating monomer. Repeated ventilation of the vacuum vessel eventually causes the air pockets at the surface to burst.

2.5.3 Post-processing of the bonded workpiece

To post-process the bonded workpiece, it may be necessary to perform annealing after bonding. Post-annealing provides better curing of the joint with polymerization adhesives and thus leads to greater adhesive strength and a good long-term appearance with crazes. For solvent adhesives, post-annealing results in higher bond strengths. For information on bond strength values, please refer to the relevant technical information.

It is advisable to perform the annealing within 24 hours of bonding.

This also relieves stresses that may have been generated in the adhesive or the part to be joined during the bonding process and may cause subsequent damage in the material. Basic information on testing for stresses and the conditions for annealing are given in Section 2.5.1.4.

The bonded workpieces must be heated from room temperature to the required annealing temperature no faster than 10 °C per hour. Otherwise there is a risk of bubbles forming in the joint. This is particularly the case for bonds using reaction moderator ACRIFIX® MO 0070.

| Methods of pretreating PLEXIGLAS® for subsequent bonding | | |
|--|---|--|
| Method | Material | Effect |
| Cleaning with dry cloth, brush or ionised air | Wood, concrete, foam, various plastics | Removal of loose impurities from porous materials (water would seep into the surface) |
| Cleaning with water/wetting agent | PLEXIGLAS®, glass and various plastics | Removal of loose impurities and degreasing |
| Cleaning with organic solvents, e.g. petroleum ether, isopropyl alcohol and ACRIFIX® TC 0030 | PLEXIGLAS®, glass, various plastics, metals | Degreasing, removal of release agents for example |
| Roughing with grinding fleece or abrasive paper | PLEXIGLAS®, various plastics and metals | Removal of release agents and oxide layers; improved bond strength of polymerisation adhesives |
| Application of an adhesion promoter (primer) | Glass, metals and various plastics | Strengthening the bond between materials that are difficult to join |

2.6 Colouring of polymerisation adhesives

On rare occasions, when coloured parts of PLEXIGLAS® GS and PLEXIGLAS® XT are bonded together, it is necessary to colour the joint for visual reasons. This can in principle be done with any of our ACRIFIX® 2R adhesives.

For **opaque colours** various colour pastes can be used (see Fig. 1).

| Colourants for polymerisation adhesive ACRIFIX® 2R | |
|--|---|
| Colourant | Addition to adhesive |
| Opaque colours: | Normally 1%, for special cases see Fig. 2 |
| ACRIFIX® CO 9073 Black | |
| ACRIFIX® CO W074 White | |
| ACRIFIX® CO 3075 Red | |
| ACRIFIX® CO 5076 Blue | |
| ACRIFIX® CO 1077 Yellow | |
| Transparent colours: | Acc. to manufacturer specs. |
| e.g. MACROLEX® colours (Lanxess) | |

Figure 1: Colourants for polymerisation adhesive ACRIFIX® 2R

It is best to start by preparing a solution of ACRIFIX® 2R adhesive and, say, 1% colour paste (see Fig. 2). This intensely coloured masterbatch is then used for imparting colour to the adhesive quantity intended for use. The catalyst ACRIFIX® CA 0020 should be added after the colourant. A possible slowing-down of the curing process can then be balanced by slightly increasing the catalyst concentration (an extra 0.5 to 1%).

Blends of ACRIFIX® CO colourants make it possible to obtain shades similar to those of coloured PLEXIGLAS® varieties. To avoid colour fluctuations in the case of large bonding projects, the required quantity of adhesive is best coloured in one go, with the hardener then added to small portions taken from it. Coloured adhesives are normally used for:

- filling engravings,
- decorative coatings on PLEXIGLAS®,
- bonding coloured parts.

The mixing table in Fig. 2 shows some typical formulations for certain coloured PLEXIGLAS® GS varieties.

It would be very difficult to formulate colourants for adhesives in shades that accurately match a specific sheet colouring, and this would require in colour formulations too complex for adhesive processing.

Example calculation:

250 g ACRIFIX® is to be coloured for bonding of PLEXIGLAS® WH10.

| Example calculation | | |
|---|--------|-------|
| Production: Masterbatch (MB) | | |
| Colourant white ACRIFIX® CO W074 | 1 % | 1 g |
| ACRIFIX® 2R 0190 | 99 % | 99 g |
| Masterbatch White CO W074 (1 %) | 100 % | 100 g |
| Production: ACRIFIX® 2R 0190 White WH10 coloured | | |
| Masterbatch White CO W074 (1 %) | 13,6 % | 34 g |
| ACRIFIX® 2R 0190 | 82,4 % | 206 g |
| ACRIFIX® CA 0020 | 4,0 % | 10 g |
| | 100 % | 250 g |

The typical formulations can only approximately describe the colour matching and they may need to be determined precisely in preliminary trials.

For further processing information, please refer to the technical information ACRIFIX® Colourant (ID no. 391-27).

For **transparent colours**, all commercially available colourants soluble in organic solvents can be used, provided they do not interfere with the polymerisation of the adhesive.

| Content in % of ACRIFIX® CO in ACRIFIX® 2R (= Masterbatch (MB)) | | | | | |
|---|---------------|---------------|-------------|--------------|----------------|
| PLEXIGLAS® GS Grade | Colourant | | | | |
| | Black CO 9073 | White CO W074 | Red CO 3075 | Blue CO 5076 | Yellow CO 1077 |
| White WH01 | - | 3 | - | - | - |
| White WH10 | - | 1 | - | - | - |
| White WH73 | - | 1 | - | - | - |
| Yellow 1H01 | - | - | - | - | 1 |
| Red 3H25 | - | 1 | 1 | - | - |
| Red 3H67 | - | - | 1 | - | 1 |
| Red 3H01 | - | - | 3 | - | - |
| Blue 5H48 | - | 1 | - | 4 | - |
| Black 9H01 | 2 | - | - | - | - |

| Mixing ratio masterbatch (MB) to ACRIFIX® 2R and ACRIFIX® CA 0020 in % | | | | | | | |
|--|------------------------------|--------------------|------------------|-------------------|-------------------|----------------------|---------------------------|
| PLEXIGLAS® GS Grade | Masterbatch with ACRIFIX® CO | | | | | Adhesive ACRIFIX® 2R | Catalyst ACRIFIX® CA 0020 |
| | MB with Black 9073 | MB with White W074 | MB with Red 3075 | MB with Blue 5076 | Fk. mit Gelb 1077 | | |
| White WH01 | - | 96 | - | - | - | - | 4 |
| White WH10 | - | 13,6 | - | - | - | 82,4 | 4 |
| White WH73 | - | 96 | - | - | - | - | 4 |
| Yellow 1H01 | - | - | - | - | 96 | - | 4 |
| Red 3H25 | - | 19,2 | 48 | - | - | 28,8 | 4 |
| Red 3H67 | - | - | 80,1 | - | 15,9 | - | 4 |
| Red 3H01 | - | - | 96 | - | - | - | 4 |
| Blue 5H48 | - | 16,8 | - | 22,6 | - | 56,6 | 4 |
| Black 9H01 | 96 | - | - | - | - | - | 4 |

Figure 2: Typical formulations for colouring ACRIFIX® 2R adhesives

2.7 Bonding techniques

Various techniques are known for bonding PLEXIGLAS®, the choice of which depends both on the material to be bonded and on the adhesive used. Therefore a suitable bonding technique is described for each of our three groups of adhesives.

2.7.1 Solvent adhesives, thin-bodied (e.g. ACRIFIX® 1S 0117 and 1S 0127)

Solvent (borne) adhesives are preferred for **adherends that are narrow, flat and short**. This means that best results are achieved with edges that have been cut or milled as neatly as possible. A short time after applying the adhesive, the parts will be fixed together. For ACRIFIX® 1S 0117 and ACRIFIX® 1S 0127, it is advantageous to apply slight pressure to the adherend. When bonding sawn edges, bubble formation the bond can be reduced if the edges are first smoothed by wet sanding with fine abrasive paper of grit 400 to 600 (at right angles to the sheet edge if possible), milling or diamond polishing. Exerting some slight pressure on the adherends during drying will also reduce air entrapment.

Solvent adhesives cannot generally be used for area-bonding. It is difficult for solvent trapped that is trapped in the middle of the area to escape. This can result in air entrapment.

2.7.1.1 Dip bonding

Dip or soak bonding is the method most widely used for solvent adhesives. The edge of one of the parts to be joined is dipped directly into the adhesive and left there until it is soft and sticky. Fig. 3 details the required dipping times, depending on sheet material and adhesive used.

The surrounding areas may have to be covered with suitable adhesive polyester tape to protect them against undesired solvent action.

The soaked edge is then placed on the other part to be bonded and fixed (e.g. with clips, clamping systems).

| Recommended solvent working times (in seconds) for solvent adhesives | | | | | |
|--|----------|---------|----------|----------|----------|
| ACRIFIX® | 1S 0126 | 1S 0127 | 1S 0109 | 1S 0116 | 1S 0117 |
| PLEXIGLAS® XT | 20 to 25 | 20 | 20 to 25 | 30 to 40 | 50 to 60 |
| PLEXIGLAS® GS | 60 | (60) | 60 | 90 | (90) |

Figure 3: Recommended solvent working times (in seconds) for solvent adhesives

For dip or soak bonding of small individual pieces you need a flat sheet of PE or glass plate on which to pour and spread a small amount of adhesive. For large runs, use a shallow glass or metal pan with a flat bottom. Fill to a depth of 5 mm of adhesive. Cover the pan between dipping steps.

The maximum processing time of ACRIFIX® 1S 0117 and ACRIFIX® 1S 0127 in an open glass pan is roughly 30 minutes (or less, depending on the ambient temperature). Evaporation causes changes in the composition, which worsens the adhesive's solvent action.

2.7.1.2 Capillary bonding

Another technique is capillary bonding, during which less solvent is released. The parts are first placed together without adhesive. Then the solvent adhesive is applied around the edges of the adherend from a needle-nosed bottle (see Fig. 4).

The adhesive flows into the joint area by capillary action. Unlike the dip or soak method, capillary bonding also works with larger (longer) parts.

For wide joints, e.g. T-joints between PLEXIGLAS® XT sheets up to 25 mm thick, ACRIFIX® 1S 0117 is the adhesive of choice (preferable to ACRIFIX® 1S 0127).

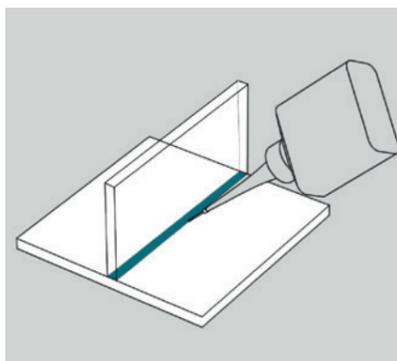


Figure 4: Capillary bonding: application of the adhesive to parts put together

Fig. 5 shows a variant of this joining method. Thin stainless steel wire brads (roughly 0.3 mm in diameter) are put between the edges of one part to be joined and a glass plate. Then the solvent is introduced into the gap thus formed and is drawn in below the edge by capillary action. After allowing some time for the solvent to work on the part (see Fig. 3), the latter is removed from the glass plate and is joined with the other part.

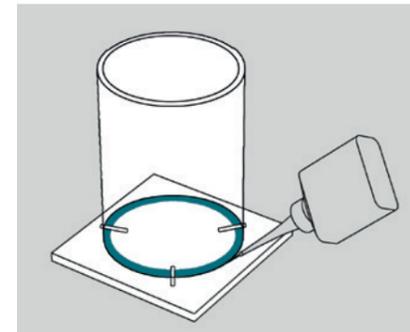


Figure 5: Solvent action on a part standing upright on a glass plate supported by wire brads (roughly 0.3 mm in diameter).

In a similar method, both – usually large – parts are put together as in Fig. 4, but are also spaced by means of thin wire brads. Then the adhesive is introduced into the open gap as in Fig. 5. After allowing adequate time for the ACRIFIX® 1S 0117 or 1S 0127 solvent to work, the wire brads are removed and the parts are joined.

2.7.2 Solvent adhesives with added polymer, low to high viscosity (e.g. ACRIFIX® 1S 0116, 1S 0126 and 1S 0109)

Unlike the thin-bodied solvent adhesives, viscous solvent adhesives containing polymer tolerate fairly pronounced irregularities in the part to be bonded. The solvent adhesive is applied from a needle-nosed PE bottle or a PE syringe and sometimes also by dipping. Capillary bonding is not possible with solvent adhesives that contain polymer. The applied quantity of adhesive has to be metered in such a way that some excess adhesive is squeezed out on either side of the joint when the parts are placed together.

The parts are joined as in dip bonding. Before putting the parts together, care must be taken that no skin has formed on the adhesive bead, as this would impair the appearance and stability of the joint.

Just like solvent adhesives, solvent adhesives containing polymer are less suitable for area bonding.

Note: ACRIFIX® 1S 0109 is a highly viscous special adhesive that is mainly used in illuminated advertising. It is used exclusively for edge fixing and edge sealing; edge and butt joints are not possible. It displays extremely fast skin formation and has no capillary effect.

2.7.3 Polymerisation adhesives (e.g. ACRIFIX® 2R 0190, 2R 2019 and 1R 0192)

The bonding technique employed for polymerization adhesives is very different from working with solvent adhesives.

The joints must be designed in such a way that the gap filled with adhesive is always clearly visible.

In many cases the bonds may not be loaded with weights, clamps, etc. as long as the adhesive is setting, as there is a risk of stress cracking.

2.7.3.1 Butt joints

To create butt joints, the sheets to be bonded are fixed to a flat support, leaving a gap between them. The optimum gap width is 2 mm, but it should not be less than 0.5 mm and not larger than 3 mm (see Fig. 7). For larger gaps, there is a risk of bubbles forming. The underside and faces of the gap are sealed with suitable adhesive tape (see Fig. 6). The adhesive is introduced into the open side of this joint by means of a suitable dispensing unit. Avoid air pockets and overfill the gap to produce an adhesive bead.

In practical trials with butt joints, the relationship between sheet thickness and shape of the bonding gap as

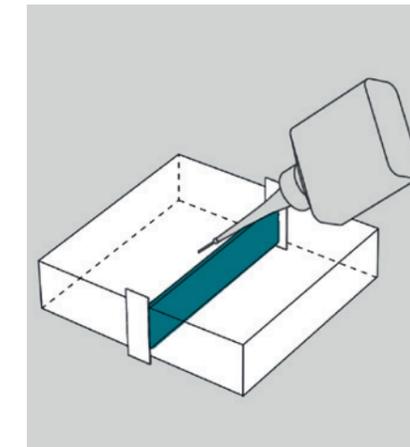


Figure 6: Introducing the polymerisation adhesive into a butt joint

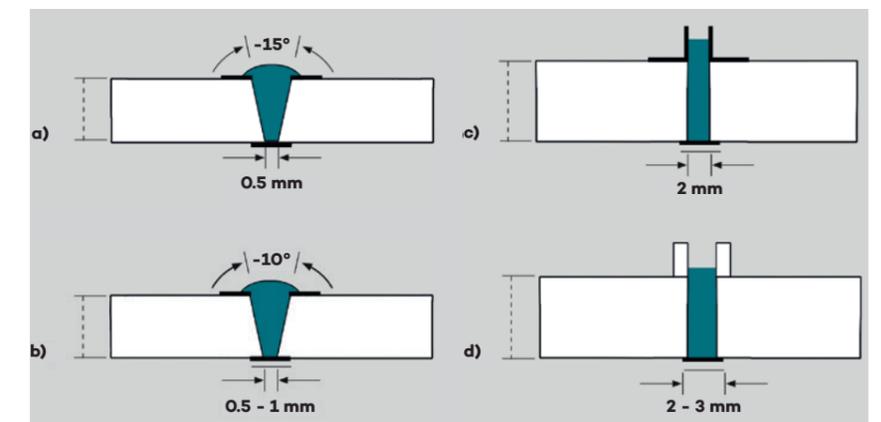


Figure 7: Bonding gaps shapes for butt joints

a) Sheet thickness ≤ 5 mm c) Sheet thickness 21 to 25 mm (addition of ACRIFIX® MO 0070)
b) Sheet thickness 6 to 20 mm d) Block thickness ≥ 30 mm (addition of ACRIFIX® MO 0070)

shown in Fig. 7 has given best results. The bonding gap should always be filled or overfilled in such a way that the adhesive does not shrink back into the gap during polymerisation and subsequent annealing. According to experience, the shrinkage is 15 to 20% by volume.

For variants 7a) and 7b), it can be useful to use adhesive polyester tape for masking. For thicknesses > 20 mm, an additional reservoir should be provided (made from adhesive polyester tape Fig. 7c), or from PLEXIGLAS® Fig. 7d)).

The layer thickness of the adhesive reservoir should be equal to the thickness of the adhesive gap (i.e. the spacing should be the same size). The reservoir should be designed with PLEXIGLAS®, to make the subsequent mechanical treatment easier.

If the joints are wide and deep (> 3 mm), we recommend adding ACRIFIX® 2R 0190 to the adhesive in order to dampen the reaction of the reaction moderator ACRIFIX® MO 0070 and thus to avoid air bubbles.

The optimum dosage is 0.1%, the maximum 0.3% and the minimum 0.05%. In this case it is advisable to anneal after bonding.

For butt joints of blocks > 50 mm, additional thinning should be considered.

2.7.3.2 T-joints

There are different variants for creating T-joints with polymerisation adhesives. In addition to the simple butt joint (Fig. 8 (1)), V-joints and fillet joints have proved suitable in practice. These can be positioned externally (Fig. 8 (2)) or internally (Fig. 8 (3 & 4)).

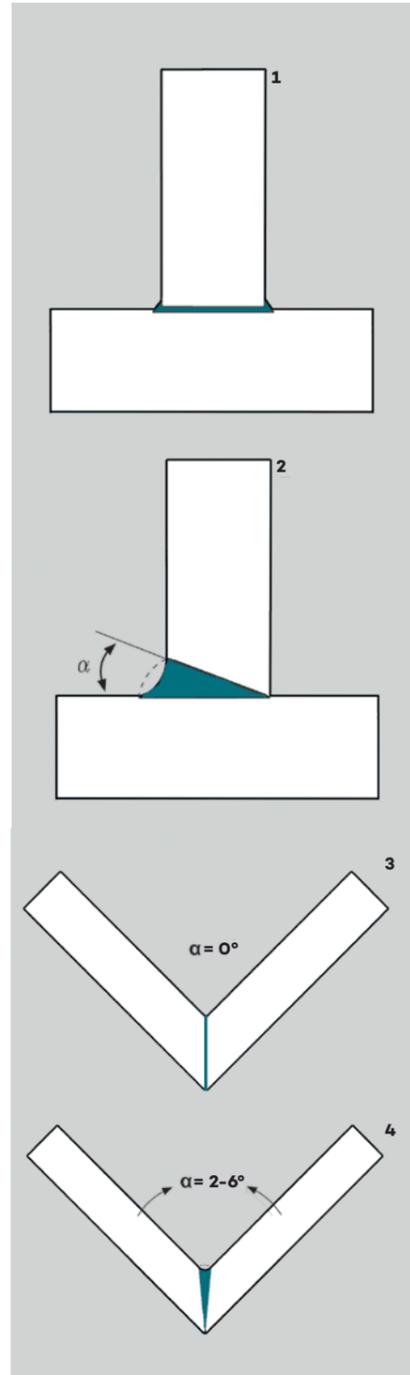


Figure 8: Seams in T-joints
1) Butt joint
2) External fillet joint
3) T-joint, internal 45°
4) T-joint, internal 46–48°

2.7.3.2.1 90° butt joint T-joints

When PLEXIGLAS® parts of bonded with a butt joint, the parts can be bonded, even under load, in such a way that deliberately prevents any major “filling” joint from being created. Instead, an extremely thin adhesive film forms between the butt-jointed parts, and the joint need not be mechanically treated if the surrounding area was thoroughly enclosed in adhesive tape beforehand. This technique, however, requires some experience in handling polymerization adhesives (see Fig. 9).

The base sheet that is to be bonded is first masked with adhesive polyester tape without creating air pockets. This polyester tape is then additionally protected by means of self-adhesive aluminium tape.

Next, the part to be bonded is positioned on the masked area and its contours are carefully marked out with a scalpel. The scalpel must return to the starting position, so it is advisable to mark this position on both of the parts to be bonded. The cut-out pieces of adhesive tape are stripped off, and the remaining edges are once more firmly pressed against the sheet. The part to be bonded is then masked all the way round with adhesive polyester tape. Excess adhesive tape is cut off with the scalpel flush with the adherend.

Before bonding, the adherends may have to be roughed and cleaned with ACRIFIX® TC 0030. The polymerisation adhesive is applied to the adherend and the part to be bonded is embedded in it. The alignment marking must be observed. The part must be held in position until it is fixed by the edge of the adhesive aluminium tape (see Fig. 9).

After curing, any excess adhesive can be detached from the aluminium tape by means of a chisel. The adhesive tapes can then be removed. Adhesive residues from the tape are washed off with petroleum ether or cleaning solvent. Subsequent annealing increases the bond strength and is strongly recommended.

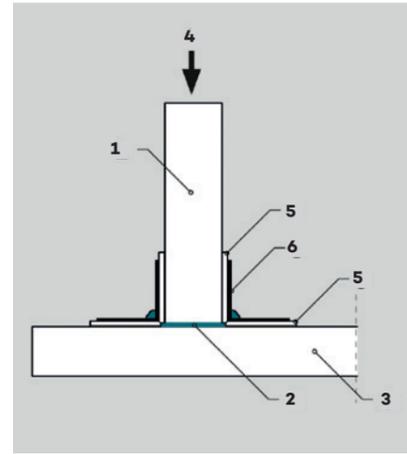


Figure 9: Butt joint for two bonded parts
1) PLEXIGLAS®
2) e.g. ACRIFIX® 2R 0190
3) PLEXIGLAS®
4) Possible load
5) Adhesive polyester tape
6) Adhesive aluminium tape

2.7.3.2.2 T-joint with external V-joint or fillet joint

The T-joint with external V-joint or fillet joint is characterized by the fact that after curing, the excess adhesive is mechanically treated, ground and polished. This creates a right-angled surface both on the inside and on the outside.

The parts to be bonded are first cleaned with ACRIFIX® TC 0030 and placed on each other “dry”. For optimum bonding, the opening angle of the fillet joint must be configured in accordance with the viscosity of the polymerisation adhesive used and the thickness of the parts being bonded. This is shown in Fig. 10.

Fundamentally, the opening of the joint should be at least 1–2 mm depending on the viscosity of the adhesive (ACRIFIX® 2R 0190 (viscous) 2 mm opening, ACRIFIX® 2R 2019 (low-viscosity) 1 mm opening). The bonding gap should always be overfilled in such a way that the adhesive does not shrink back into the joint gap during polymerisation and subsequent annealing. In order to produce the required adhesive bead, the horizontal sheet should project slightly. The V-groove shown in on the left in Fig. 8 (2) then forms as the adhesive shrinks while curing.

If the adhesive is applied in layers 20 mm thick or more, or in the case of voluminous joints, ACRIFIX® MO 0070 should be added to the mixture, as described for butt joints. The largely prevents the formation of bubbles. Post-annealing is recommended and should be performed as described in Section 2.5.3.

T-joints with external fillet joint must be produced with suitable jigs. This ensures that the parts are fixed during bonding and curing (for an example jig, see Fig. 11). The upright part should be held very firmly, since the slightest change in angle may, for example, result in air entrapment.

| PLEXIGLAS® | ACRIFIX® 2R 0190 ACRIFIX® 1R 0192 (viscous) | ACRIFIX® 2R 2019 (low viscosity) |
|---------------------------|--|--|
| Material thickness d [mm] | Opening angle α [°] | |
| 3 | 30 | 15 |
| 4 | 26 | 13 |
| 5 | 21 | 10.5 |
| 6 | 17 | 8.5 |
| 8 | 13 | 6.5 |
| 10 | 11 | 5.5 |
| 20 | 6 | 3.0 |
| 30 | 3.5 | 1.75 |
| 50 | 2.5 | 1.25 |
| 70 | 1.5 | 0.75 |

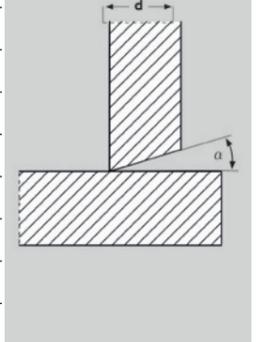


Figure 10: External V-joint, recommended opening angle for various sheet thicknesses and viscosities

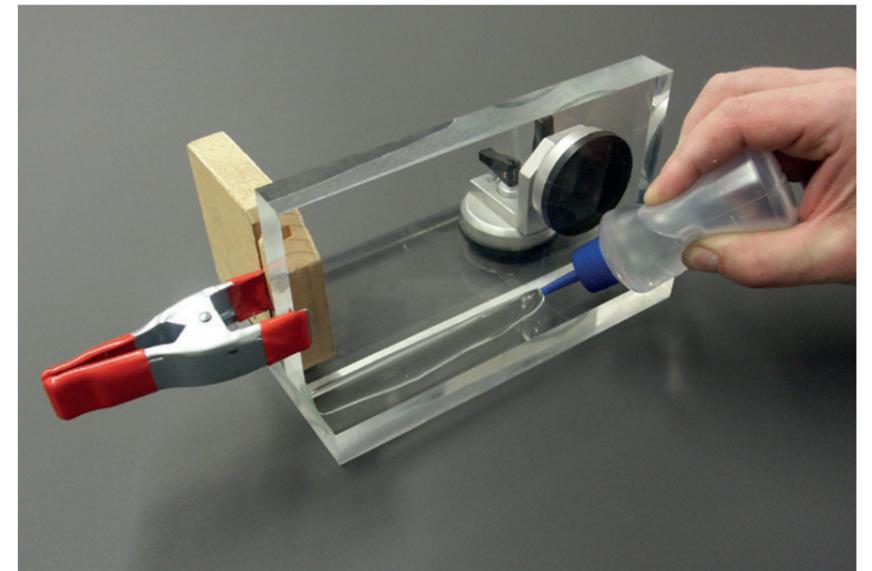


Figure 11: Jig

2.7.3.2.3 T-joint with internal joint and 45° mitre

For T-joints with 45° mitre, the edges to be bonded are sawn or milled to a 45° mitre. In particular, this type of bond can also be used for material thicknesses of > 20 mm. Edges not meant for bonding have to be polished beforehand and must then be annealed free from stress.

Then all areas around the joint – each cut individually – have to be carefully masked with adhesive polyester tape cleanly and without any air bubbles. The side from which the adhesive is introduced is additionally covered with self-adhesive aluminium tape. This serves to provide protection from mechanical influences when the excess cured adhesive bead is removed subsequently. After masking, the faces to be bonded have to be cleaned with ACRIFIX® TC 0030. The PLEXIGLAS® parts are put together in a jig, in such a way that the adherends butt against each other (see Fig. 12).

For bonding, the gap is opened to about 1 to 2 mm and the adhesive (e.g. ACRIFIX® 2R 0190, mixed with 3%–6% ACRIFIX® CA 0020) is introduced with minimum air entrapment. The two parts are put together again. This presses the excess adhesive out from the adherend. Directly after curing, the adhesive bead is carefully detached with a chisel and the adhesive tape is removed. The bonded part is then annealed. Post-annealing is recommended and should be performed as described in Section 2.5.

2.7.3.2.4 T-joint with internal V-joint or fillet joint and 46–48° mitre

This T-joint is characterized by the fact that after curing, the excess adhesive does not need to be mechanically treated. The basic requirement is that a reaction adhesive is used that cures with a smooth surface, for example ACRIFIX® 2R 2019.

The internal fillet joint has a smooth V-groove after curing. This T-joint is often used for bonding in display cabinets.

Before masking, the areas to be bonded have to be cleaned with ACRIFIX® TC 0030. The parts to be bonded (cabinet sides including base) are placed together “dry” in advance and fixed with suitable adhesive tapes, for example adhesive polyester tape.

When the parts are placed together, stress crack can occur in the tip of the fillet joint, particularly in the case of extruded PLEXIGLAS®. It must therefore be ensured that the adhesive tape used can stretch.

The PLEXIGLAS® parts that have been put together must be placed in a suitable jig (90° prismatic mount, similar to Fig. 12) in such a way that the adherends butt up against each other at the tip, creating a small gap at the top (V-joint). The adhesive is introduced by means of PE metering bottles (see Fig. 23, Section 2.8).

The next bonding step can only be performed once the joint has fully cured. After curing, annealing is recommended (see Section 2.5.3).

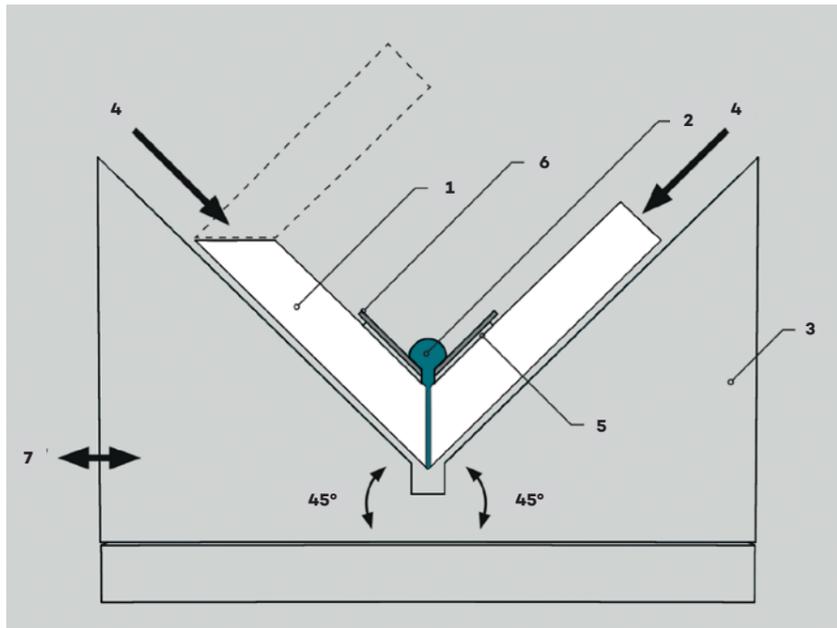


Figure 12: Mitre joint of PLEXIGLAS® GS block material to a universal stage

- 1) PLEXIGLAS® bonded part
- 2) e.g. ACRIFIX® 2R 0190
- 3) Jig
- 4) Pressure min. 100 g/cm²
- 5) Adhesive polyester tape
- 6) Adhesive aluminium tape
- 7) Guide mechanism

2.7.3.2.5 Bonding tube ends and open containers

When bonding tube ends and open containers (with a T-joint), arrange the joint in such a way (inside or out) that the smallest possible area of cured adhesive is exposed to other chemical substances (including water).

Fig. 13 shows possible shapes of bonding gaps for tubes.

Flushing with air is the easiest way to prevent solvent vapours (monomers) from escaping into the container (tube). The monomer vapours can otherwise trigger stress cracks.

Tubes, which are always internally stressed as a result of the manufacturing process (e.g. extruded tubes) must be annealed prior to bonding.

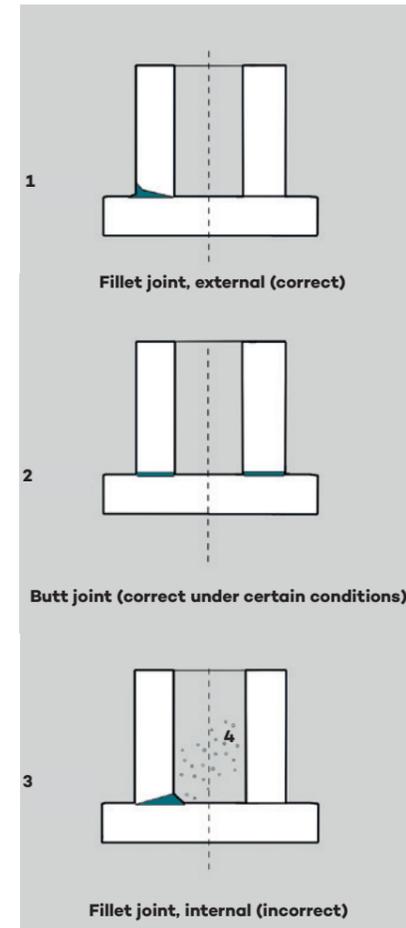


Figure 13: Creating containers by bonding:

- 1) Fillet joint, external
- 2) Butt joint
- 3) Fillet joint, internal
- 4) Monomer vapours

2.7.3.3 Area bonds

Area bonds can be designed in a horizontal or a vertical position with polymerisation adhesives. The challenge here lies in avoiding air bubbles.

2.7.3.3.1 Horizontal area bonds

This design is mainly used for thinner materials (up to roughly 30mm). The structure of a horizontal area bond is shown in Fig. 14.

A spacer plate is placed on a flat work surface. This plate must be roughly 3–5 cm smaller than the sheet to be bonded, all the way round. The spacer plate allows the excess adhesive to flow away instead of being drawn underneath the base plate.

The bubble-free adhesive is poured on the cleaned base panel, passing roughly from the top corners to the diagonally opposite bottom corners (see Fig. 15 a).

Starting from one long edge, the cover panel is lowered from one side onto the cleaned adhesive bed. Once the flow fronts have come together, the cover panel must be removed promptly (see Fig. 15 b).

Any entrapped air will then escape towards the edges. In certain cases, e.g. for larger areas or longer flow paths, it is advisable to thin the adhesive composition, to ensure simpler processing. This can be done with the thinners ACRIFIX® TC 0030 (up to 10%) and ACRIFIX® TH 0032 (> 10%). To ensure that the adhesive is spread evenly, it can be useful to additionally load the panel surface with a cover panel with sufficient inherent rigidity.

To prevent the underside of the base panel from being soiled with adhesive, the measures diagrammed in Fig. 14 a) and b) can be applied.

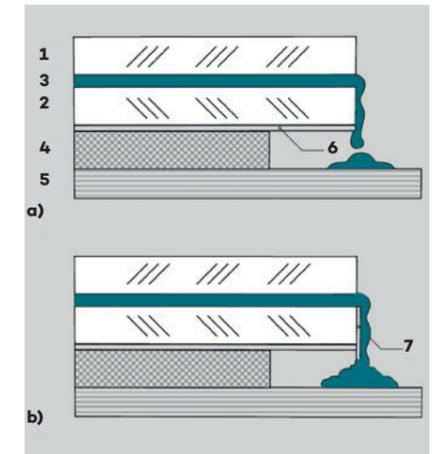


Figure 14:

Edge protection in horizontal area bonding

- 1) Cover panel
- 2) Base panel
- 3) Adhesive layer
- 4) Spacer panel
- 5) Flat work surface
- 6) Surface masking of the base panel
- 7) Adhesive tape

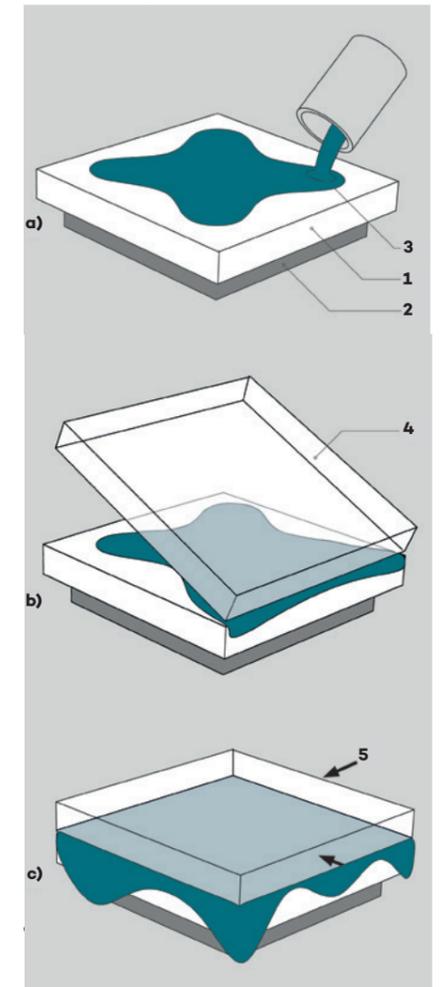


Figure 15: Procedure for horizontal area bonding

- 1) Base panel
- 2) Spacer panel
- 3) Adhesive mixture
- 4) Cover panel
- 5) Stop to prevent the cover panel from sliding

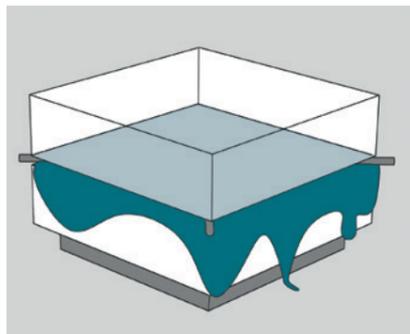


Figure 16: Spacing of thick sheets or blocks for horizontal area bonding

Thick, i.e. heavy, cover panels and blocks of PLEXIGLAS® should be kept at about 0.5 to 1.5 mm from the base panel by suitable elastic spacers such as polyethylene cords (see Fig. 16). This prevents the adhesive from being squeezed out excessively. If air pockets become entrapped during closure, they can be removed from the adhesive layer while it is still liquid. The bubbles can be pricked with a fine stainless steel wire introduced from the edge and this wire can then pulled out **abruptly several times, if necessary.**

Horizontal area bond with rolling unit (lamination):

This type of area bond is used for thin materials.

The sheets to be adhered are cut with some excess.

The sheets are fixed on a PE or PET film, with the side edges of the panel fastened with adhesive tape all the way round. This prevents the adhesive from being drawn in underneath the sheet later on.

The fronts of the sheet are joined together with suitable adhesive tape used as a hinge. The adhesive is applied generously at the hinge and fed through the rolling unit. Calculate the required adhesive quantity (in ml) according to the formula "length [cm] x width [cm] x 0.1".

After curing, the sheet is cut to the required net dimensions.

One special variant of **horizontal area bonds** is the **embedding of photographs**. Photographs or other solvent-resistant materials like paper, cardboard, film, nonwovens, textiles etc. are encapsulated between PLEXIGLAS® sheets or blocks, with the aid of ACRIFIX® 2R 0190, for example. The base panel (back of the picture) and the transparent cover panel (front of the picture) are cut larger in size all around than the item to be embedded. The sheets to be bonded are then stripped of their masking and cleaned with suitable cleaning agents (see Section 2.8). The material to be embedded is placed flat in a receptacle before being bonded/embedded in ACRIFIX® TC 0030. This serves to release any air entrapped in the item to be embedded. The receptacle has to be covered during this process.

For the embedding, calculate the required adhesive quantity (in ml) according to the formula "length [cm] x width [cm] x 0.3". First, the first half of the adhesive composition is poured onto the base sheet, as for horizontal area bonding (see Fig. 15). Then insert the object for embedding into the adhesive, without creating air pockets. Then pour on the second half of the adhesive composition (use spacer cord, see Fig. 16), lower the cover panel as described for area bonding and spread the adhesive uniformly by pressing the cover panel carefully against the base. Once this is done, fix or correct the position of the embedded item by means of an inserted stainless steel wire or release trapped air bubbles (similar procedure to that for horizontal area bonding).

2.7.3.3.2 Vertical area bonds

This design is mainly used for thicker materials (roughly 30 mm and more). For bonding in a vertical position, the sheets or blocks to be joined are spaced with an elastic cord (PE or silicone, for example), so as to provide a cell that is open at the top (see Fig. 17).

The prepared adhesive is poured into this cell. To allow the adhesive to flow in with ease, the adhesive layer or the elastic cord should have a minimum thickness of about 1.5–2.0 mm. The viscosity of the adhesive may need to be adjusted. As the adhesive shrinks while curing, it may be necessary to create a reservoir – see Section 2.7.3.1 Butt joints.

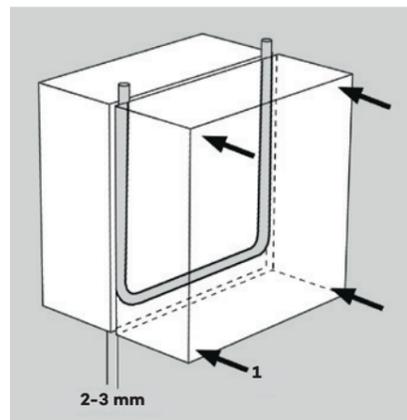


Figure 17: Spacing for vertical area bonding. Pressure, e.g. by G-clamps

To prevent bubble formation during horizontal or vertical area bonding, it is important to ensure that the polymerisation reaction occurs at the same rate over the entire area to be bonded. The basic requirements for this are:

- Catalyst ACRIFIX® CA 0020 must be distributed homogeneously (striation-free mixture),
- Consistent thickness of the adhesive layer, and thus uniform heat dissipation,
- Use of reaction moderator ACRIFIX® MO 0070 (up to max. 0.3%), for thick adhesive layers (> 1.5 mm).

Once the bonding has been completed, this should be followed by careful post-annealing (see Section 2.5).

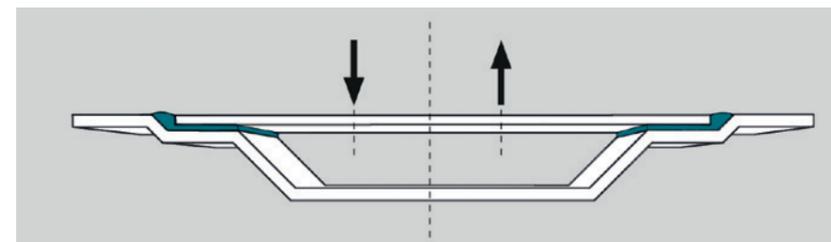


Figure 18: Extraction of solvent-laden air in cavity bonding (caravan window)

For **cavity bonds**, two mouldings are joined together to create a cavity between them. These bonds can be created in various ways. Usually it is a matter of bonding a moulding to a flat piece, e.g. for making a caravan window (see Fig. 18).

An inevitable side effect of this bonding technique is entrapped solvent vapours (monomers) that hinder polymerisation. Moreover, they may cause crazing in the adhesive joint and the bonded parts.

Therefore it is necessary to drill vent holes into the cavities before bonding, through which air can be sucked or blown after curing in order to remove these solvent vapours (min. 15 to 30 minutes).

For optimum adhesion for cavity bonds, do not use ACRIFIX® MO 0070, and anneal for two hours at 70–80°C as soon as possible after curing (see Section 2.5.3).

NB:

As a general rule, when using polymerisation adhesives, further processing should not be performed until 3 hours after bonding.

These adhesives reach their final bond strength after 24 hours. The bond strength can be further improved by annealing, as described in Section 2.5.3.

2.8 Workplace, equipment, service products

This section is meant to help you in designing the correct workplace and in selecting the equipment and service products needed for bonding.

Countertop:

Suitable countertops are insoluble and non-swelling materials like those coated with melamine resin, silicate glass, PP and PE panels or polyester sheeting. Often it is advisable to protect the work surface additionally against soiling, traces of adhesive etc., by covering it with suitable film, e.g. PET or PE film.

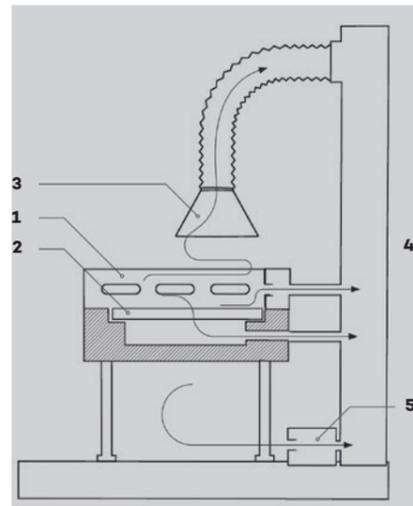


Figure 19: (2), (3), (4), exhaust filter assembly (5), floor extractor (5).

Recommended solvent vapour extraction measures at the workplace

- 1) Peripheral extraction
- 2) Work surface
- 3) Vapour recovery unit
- 4) Exhaust filter assembly
- 5) Floor extractor

Fig. 19 shows various possibilities for **extracting** the solvent vapours. Commercially available extraction systems also offer a solution. To extract the vapours, the work surface can be perforated, provided with suction slots or with a peripheral, lateral air extraction system, or else you can install a vapour recovery unit over the work surface as is commonly used in welding shops.

Since solvent vapours are heavier than air and therefore settle to the floor, it is particularly important to extract the air at floor level. The ventilation facilities in all types of equipment must be explosion-proof / meet the TEX guidelines, and we refer you to the corresponding regulations of the employers' liability insurance association. Depending on the solvent quantities emitted outwards, it is essential to observe the legal technical regulations for the avoidance of air pollution etc.

Annealing ovens:

Suitable for use are airflow ovens adjustable from 20 to at least 120°C. Fabricators normally use the same ovens as for thermoforming.

Scales:

Electronic scales with an accuracy of 0.1 gram are recommended for weighing out the adhesives and additives – especially where large runs have to be bonded.

Mixing vessels:

Use only round cups made of

- polyethylene, polypropylene
- glass
- stainless steel (free from copper)
- paperboard with PE coating (no wax or paraffin coating)

for mixing the adhesive compositions.

Cups made of polystyrene, PVC or other dissolvable or swellable materials must not be used on any account. Metals and equipment containing copper must also be avoided.

Agitators:

Small quantities are stirred by hand, using rods made of

- glass
- PLEXIGLAS® strips or
- stainless steel (free from copper)

Making open stirrer blades from 3 mm-thick copper-free stainless steel is also a suitable solution.

For large quantities from 200 grams or millilitres onwards, an electric or pneumatic agitator (max. 2,000 rpm) should be used, provided with a stainless steel propeller or, better still, a stirrer blade, each of copper-free stainless steel. Since the blade cannot be bought, you have to make it yourself as shown in Fig. 20, using 5–8 mm thick stainless steel.

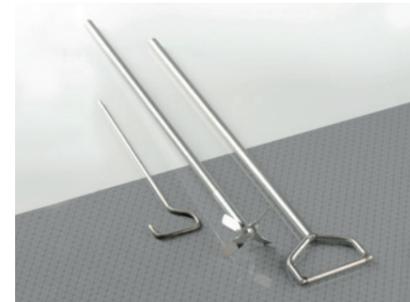


Figure 20: Various agitators (from left to right): open stirrer blade, propeller blade, closed stirrer blade

Metering equipment for additives:

In many cases it is easier, but still accurate enough, to meter the additives by means of volumetric devices instead of weighing them out (see Fig. 21). The following are suitable:

- plastic syringes (disposable ones) made of PE, PP, PA,
- graduated or piston pipettes made of glass or PP and
- dispensers, especially for large runs.

For volumetric metering with pipettes and burettes, be aware of overrun, particularly at low temperatures.



Figure 21: Disposable syringe, graduated and piston pipettes, dispenser

Degassing:

If the air pockets in the adhesive composition do not escape unaided, use a commercially available, implosion-proof desiccator (Fig. 22) that is evacuated by a water jet pump made of plastic or metal and provided with a check valve, or alternatively by a small vacuum pump. In accordance with our hints for adjustment of the negative pressure in Section 2.5, paragraph "Preparing the adhesive", a bleed valve should be installed between pump and desiccator.



Figure 22: Vacuum desiccator

Fixturing:

For large runs we recommend the use of bonding jigs. They ensure reproducible arrangement of the parts to be bonded. Suitable materials for these jigs are wood, metal, PP or PE or other plastics not susceptible to solvent attack. Clips, G-clamps, metal weights or suction cups (vacuum) can be used for fixing, as shown in Fig. 11 (Section 2.7.3.2.2).

Avoid deforming the bonded parts in any way, since this may cause stress cracking in conjunction with adhesives (solvents).

Sealing and spacing:

For area bonding use a PE or silicone cord (as previously described). For sealing joints and protecting surfaces, we advise you to choose adhesive tape with a non-adhesive centre strip, e.g. so-called rivet hold-down tapes or adhesive polyester tapes whose adhesive layer does not interfere with the curing of ACRIFIX® reaction adhesives. Any other types of adhesive tape may crimp or come loose when exposed to solvents, thereby losing their effect and impairing the adhesive.

Application of the adhesive:

For area bonding, pour the adhesive onto the adherend from the mixing vessel.

For introduction into joints use:

- Needle-nosed PE bottles
- Disposable syringes made of PE, PP or PA

When working with low-viscosity adhesives like ACRIFIX® 1S 0127 and 1S 0117, an extra injection needle should be placed on top of the needle-nosed PE bottle in order to meter more accurately. Laboratory supply companies offer such needles in various diameters (Fig. 23).

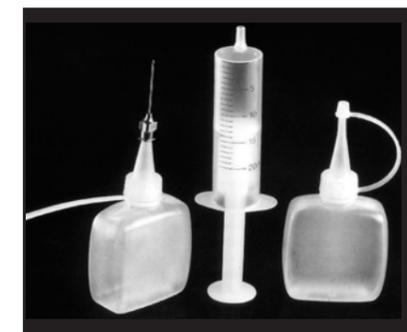


Figure 23: PE bottles and disposable syringe

Cleaning agents:

Suitable cleaning methods for the joined parts and their adherends are

- blowing with ionized air
- additional wiping with warm water.

For wiping or drying, use a highly absorbent, non-linting cloth, e.g. glove-lining fabric or microfibre cloth. For more severe soiling, e.g. cooling lubricants and greases, PLEXIGLAS® adherends should be cleaned/degreased with ACRIFIX® TC 0030 (see Table "Methods for treating PLEXIGLAS® prior to bonding").

Soiled equipment is cleaned with ACRIFIX® TC 0030 or ethyl acetate (acetic ester). For health reasons and out of concern for the environment, refrain from using chlorinated or aromatic hydrocarbons like methylene chloride, chloroform or toluene.

2.9 Bonding faults

Here are a few tips for avoiding or eliminating bonding faults:

| Fault | Cause | Remedy |
|---|---|--|
| 1. Polymerisation adhesives | | |
| 1.1 Craze in untreated surface | Local contact pressure too high | Distribute pressure evenly |
| | Cooling stress due to unskilful annealing | Allow adequate time for cooling in the closed oven |
| | Prolonged exposure to solvents or monomers | Check hardener dosage; increase ambient temp., adhesive temp. + material temperature. |
| | Material internally stressed due to production process (injection mouldings and extrusions) | Anneal, make sure solvents or monomer vapours can flash off well |
| 1.2 Craze in machined surface | See 1.1 | See 1.1 |
| | Stress in the material generated by machining | Optimise machining steps, anneal before bonding |
| 1.3 Craze around the joint (inside/cavity in bonded parts) | Stress within the material, corrosive agent (monomer/solvent) did not flash off | Flush with air, change position to favour flashoff, anneal before and after bonding |
| | Joint applied incorrectly, e.g. tube bond | Position joint so as to allow solvent flashoff and to reduce corrosive influence |
| 1.4 Craze in cured adhesive | Crazing at the surface: Stressed skin due to shrunk adhesive and influence of corrosive media | Anneal after curing |
| | Crazing within the adhesive: Post-bonding of thick joints without annealing in between | Anneal after each bonding step. Bond "wet on wet", i.e. let first adhesive bead set partially, then apply second bead on top |
| 1.5 Bubbles and detachments | Entrapped air | Degas adhesive composition (apply vacuum e.g. with vacuum pot or allow to stand in covered container briefly – observe the pot life) |
| | Bonding with air pockets | Apply adhesive without air entrapment; if necessary, enhance wetting-out by pretreating the surface with ACRIFIX® TC 0030. Smooth adherends. Clean adherend more thoroughly. |
| | Excess heat development during polymerisation (evaporating monomer) | Reduce layer thickness. Slightly reduce hardener quantities. Add ACRIFIX® MO 0070. Apply adhesive in several steps (wet on wet), i.e. let first adhesive bead set partially, then apply second bead on top |
| | Uneven joint | Treat adherends mechanically to make them plane; space more accurately |
| | Air sucked in by shrinking adhesive or parts recovering elastically | Increase or improve regularity of layer thickness. Increase contact pressure throughout until adhesive has cured completely. Enable shrinkage. Add reaction moderator ACRIFIX® MO 0070 |
| | Irregular distribution of the hardener (ACRIFIX® CA 0020) in the adhesive or irregular polymerisation | Mix adhesive more thoroughly |
| | Adherends not clean | Clean thoroughly |
| | Impurities | Exclude soiling and contact with nonferrous metals |
| | Bonded material is crosslinked (e.g. PLEXIGLAS® GS 209 or GS 249) | Roughen surface |

| Fault | Cause | Remedy |
|---|--|--|
| 1. Polymerisation adhesives | | |
| 1.6 Curing unsatisfactory or too slow | Inadequate hardener quantity (ACRIFIX® CA 0020) | Add more hardener or meter as instructed |
| | Wrong adhesive used for prefixing | Use different fixing adhesive. Allow more time for flashoff or curing |
| | Temperature of bonded parts and/or adhesive too low. Draughts. | Ensure a temperature of at least 15°C and normally 20 to 25°C. Work in draft-free rooms. |
| | Polymerisation hindered by copper, brass, rubber, adhesive from adhesive tapes | Use suitable/compatible materials |
| | Hardener old or wrongly stored | Use fresh hardener |
| | Monomer/solvent vapours cannot escape (cavities/pockets) | Flush with air, change position to promote flashoff |
| 1.7 Soft spots in the joint | Uneven hardener distribution | Mix more thoroughly |
| | Entrapped air bubbles | Apply adhesive more carefully |
| 1.8 Discolouration in the joint | Too much or too little hardener (ACRIFIX® CA 0020) | Meter hardener as instructed |
| | Detached impurities in the adhesive (rubber, metal ions) | Exclude impurities; use suitable equipment made of glass, stainless steel, PE, PP or PA |
| | Hardener old or wrongly stored | Use fresh hardener |
| | Cold adhesive, reaction too slow | Ensure minimum temperature of 15°C for the adhesive composition and normally 20 to 25°C. Do not store in fridge. |
| 1.9 Yellow joint (directly after curing) | Too much or too little hardener (ACRIFIX® CA 0020) | Meter hardener as instructed |
| | Annealing results in unavoidable slight yellowing, even at the correct annealing temperature. The yellowing is more intense at higher temperatures | Select correct annealing temperature |
| | Higher percentages of thinner (especially ACRIFIX® TH 0032) cause more intense yellowing | Use thinner only where vital and keep percentage as low as possible |
| | Excess percentage of ACRIFIX® MO 0070 | Use ACRIFIX® MO 0070 only where vital and keep percentage as low as possible |
| 1.10 Yellow joint (delayed to a later point in time) | Items 1, 3 and 4 under 1.9 can cause even stronger yellowing with a delay | |
| | Weather exposure with UV radiation/sunlight/UV-emitting lights can cause yellowing of the joint | Avoid exposing the joint to UV rays |
| | Inadequate ventilation of the joint (particularly in cavities and in combination without annealing) can cause yellowing of the joint | Ensure adequate ventilation and anneal bonded parts |

| Fault | Cause | Remedy |
|---|--|--|
| 1. Polymerisation adhesives | | |
| 1.11 Blushing/whitening of the joint (directly after curing) | At high atmospheric humidity, latent heat of vaporisation induced water to condense on adhesive surface, where it was entrapped | Work with reaction adhesive or solvent adhesive and bonded parts at higher (room) temperatures |
| | Water in adhesive (adhesive in some cases slightly cloudy rather than clear) | Discard adhesive |
| 1.12 Blushing/whitening (delayed to a later point in time) | Very fine stress cracking, microcracks or crazing in the joint | Anneal immediately after bonding. Store in rooms where corrosive influences are excluded. |
| | Effect on water on joint | Use water-resistant adhesive (e.g. ACRIFIX® 2R 0190), be sure to anneal joint |
| 1.13 Warping of bonded parts | Shrinkage stress due to curing of adhesive | Anneal |
| | Different moments of resistance of the bonded parts | Adjust moments of resistance, e.g. by using sheets of identical thickness. Anneal after bonding with applied load. |
| | Varying temperatures of the bonded parts | Adjust temperatures |
| | Varying water contents of the bonded parts | Store parts without protective masking for some time (1 week) before bonding or anneal parts in advance |
| | Excess percentage of ACRIFIX® CA 0020 causes joint to cure too strongly/too fast | Meter hardener as instructed, or use ACRIFIX® MO 0070 |
| 1.14 Inadequate bond strength | Pot life exceeded. Inadequate time allowance for solvent to work on part. | Depending on hardener quantity, make sure to use adhesive composition within its pot life. |
| | Adherend soiled with grease, sweat, residues of masking film | Clean adherends thoroughly; roughen slightly, if necessary. |
| | Inadequate wetting-out due to skin formation on adhesive as a result of prolonged flashoff period. | Put parts together as soon as adhesive has been applied. Moisten with ACRIFIX® TC 0030 to act on skin. |
| | Condensation at the surface of the adhesive or bonded part. | Work at higher (room) temperatures. |
| | Bonded material is crosslinked (e.g. PLEXIGLAS® GS 209, or GS 249) | Roughen surface |
| 2. Solvent adhesives | | |
| 2.1 Blushing/whitening | a) Room and material temperature too low. b) Caused by humidity: At high atmospheric humidity, latent heat of vaporisation induced water to condense on adhesive surface, where it was entrapped. | Work at higher temperatures. |
| 2.2. Crazing in adherend | Parts too highly stressed | Machine correctly Stress-free structure Anneal bonded parts in advance |
| 2.3 Bubble formation in adherend | a) Inadequate contact pressure b) Bonding gap too large or inadequate fit c) Adherend too rough d) Heating for post-annealing too fast | a) Increase contact pressure b) Improve fit c) Smoothen adherend d) Anneal more slowly, in temperature steps |
| 2.4 Inadequate bond strength | Adherend soiled with grease, sweat, residues of masking film | Clean and degrease adherends thoroughly; roughen slightly, if necessary. |
| | Change in solvent composition caused by solvent components evaporating | Always store original container closed. Avoid prolonged storage in PE bottles or syringes. Avoid excess room temperature (> 25 °C). For dip bonding, replace solvent adhesive more often |
| 2.5 Discolouration of the adhesive | Influence of light on the adhesive (e.g. sunlight exposure) | Store in original container |

2.10 Adhesive tapes

Nowadays it is common practice to use the same double-sided adhesive or self-adhesive tapes for fabricating PLEXIGLAS® GS and PLEXIGLAS® XT as are employed in other branches of industry.

This bonding method

- is faster and possibly more economical than using liquid adhesives, because the tape can be simply applied from the roll,
- serves particularly well for invisible, i.e. hidden, bonds, e.g. in opaquely coloured sheets,
- and all it takes is pressure.

The conditions under which good bonding results are achieved:

- dust-free, dry and degreased adherends
- Working at room temperature, if possible

For intermediate storage of parts prepared for bonding, the masking strip on one side of the adhesive tape is left in place.

Since many different types of tape are offered in the market, care must be taken to select those compatible with the plastic sheets concerned and with a comparable service life. This applies as much to the carrier material (e.g. paper, polyester, fabric, PE or PUR foam – caution with plasticised PVC!) as to the adhesive layer on one or both sides (e.g. acrylate or synthetic rubber).

There are roughly three types of double-sided adhesive tape suitable for bonding sheets of PLEXIGLAS® to each other and to different materials. They are not identical to sealing strips, which are usually self-adhesive on one side only:

- Adhesive films **without** carrier material: Very thin (several hundredths of a millimetre to 2 mm), for smooth surfaces,
- Double-sided adhesive-coated tapes with **thin** carrier materials: several tenths of a millimetre thick, also suitable for perfectly flat surfaces
- Double-sided adhesive-coated tapes with **thicker** foam carrier materials: several tenths of a millimetre up to several millimetres thick, for larger work-pieces, to balance differences in thermal expansion via the foam; also suitable for less smooth surfaces, which must however be clean and pore-free.

If self-adhesive tapes are applied to the surface of flat cut-to-size sheets, they should not be more than 300 mm apart and they should be perpendicular to the sheet.

Many tapes can tolerate a permanent load of 0.2 to 0.25 N/cm². The required length of the tape to withstand the sheet's own weight, for example, can be determined on this basis. The manufacturer's instructions for use have to be observed.

3. Welding

PLEXIGLAS® XT and injection mouldings of PLEXIGLAS® can be welded with ease. This is because these materials, when heated, pass a narrow range of rubber-like elasticity before they become soft and formable over a wide temperature range, as required for welding.

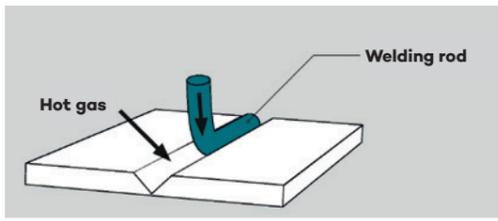
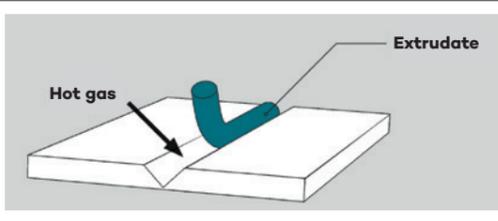
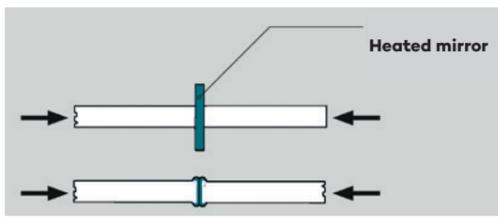
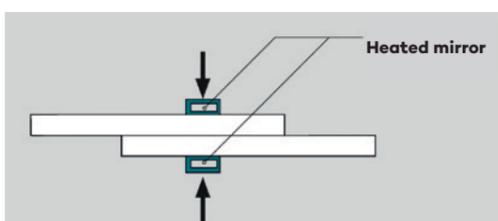
PLEXIGLAS® GS can only be welded with the aid of welding fillers (e.g. filler rods made of PLEXIGLAS® XT or PVCu).

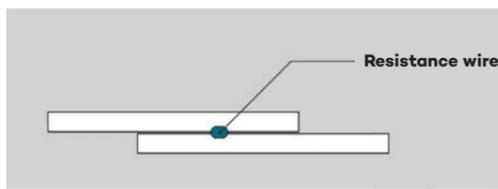
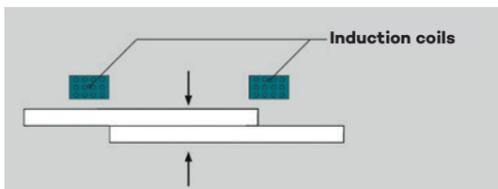
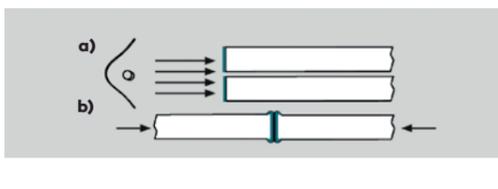
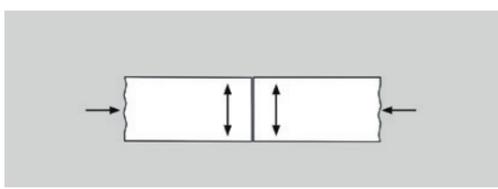
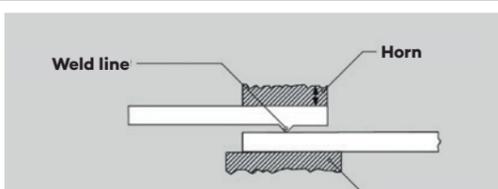
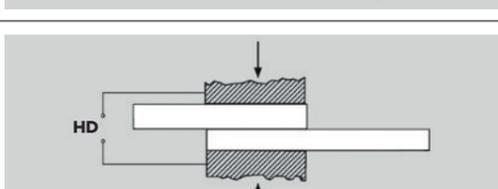
PLEXIGLAS® GS stays rubbery-elastic over a wide temperature range and first shows some plasticity in the transition range to decomposition, which is normally not adequate for welding. A further rise in temperature does not cause softening, but decomposition and thus bubble formation by evaporating methyl methacrylate.

Welding, i.e. fusion in the weld zone, can be performed in different ways. The technique used depends mainly on the shape and size of the work-pieces to be joined and on the fabricating process into which the welding operation has to be integrated.

A disadvantage of welding is the generation of high **tensile stress** in the weld zone as the latter cools down from the high localised temperatures produced for welding to occur. This stress has to be relieved by annealing, especially if the joined parts are expected to come into contact with corrosives. The stress level can be reduced by heating the parts to the highest possible temperature just before starting the welding operation.

The following overview shows the generally feasible welding techniques.

| Method | Principle | Brief description |
|------------------------------------|---|---|
| Hot-gas welding |  | Heating of the weld zone and filler rods with hot gases (air, CO ₂ , N ₂) |
| Extrusion welding |  | Filler material is extruded into the weld seam in plasticised form. Occasionally it may be necessary to heat the joint additionally with hot gas. |
| Welding by heated mirror/hot plate |  | a) The weld zones are heated by contact with hot surfaces b) Upon removal of the heated mirror, they are joined under pressure |
| Thermal impulse welding |  | The weld is heated through the material by means of electric strip heaters – only suitable for film |

| Method | Principle | Brief description |
|------------------------|---|--|
| Resistance welding |  | A resistance wire inserted in the weld zone is heated electrically or inductively. Wire remains in the welded material. |
| Induction welding |  | Welding filler with metal dust is heated inductively in HF magnetic field – EMA welding – |
| Radiation welding |  | a) The areas to be joined are heated by radiation (dark radiator, bright radiator, laser) and b) joined under pressure |
| Friction welding |  | Heating of the weld zones by friction and pressure at the same time – Rotation, vibration – |
| Ultrasonic welding |  | Mechanical ultrasonic vibrations under static pressure cause internal and partly also external friction as well as heat generation |
| High-frequency welding |  | Heating in a high-voltage alternating field (f = 27.12 MHz) by dielectric loss |

Of the techniques listed, hot-gas welding, ultrasonic welding, heated-mirror welding and friction welding are most widely used for PLEXIGLAS® XT, and are described in further detail below.

Hot-gas welding

Welding of PLEXIGLAS® XT in general is governed by the guidelines of DIN 16930. Electric and gas-heated hot-air or hot-gas welding equipment continuously adjustable from 250 to 500 °C is suitable for heating the water- and oil-free gas.

Normally the welding gas is air.

The parts to be joined are best placed in a horizontal position, but other welding positions are also possible – which may be an advantage over bonding, e.g. under construction-site conditions.

The filler rod is attached to one end of the weld and is then introduced into the groove under permanent uniform pressure. While this is done, the welding nozzle is to describe a fanning movement between the material and the filler rod.

The latter is held more or less at right angles to the joint (see Fig. 24). An obliquely guided filler rod causes tensile stress in the joint.

Further characteristic data on hot-gas welding:

| Hot-gas welding | |
|---|---|
| Welding fillers for PLEXIGLAS® XT and GS | Strips with a square cross section or round rods made of PLEXIGLAS® XT or PVCu (diameter 2 to 4 mm) |
| Welding pressure | Roughly 2.8 MPa = 20 N contact pressure for 3 mm thick rod |
| Welding speed | Roughly 150 to 250 mm/min |
| Distance nozzle/welding point | Roughly 15 mm |
| Nozzle diameter | Roughly width of welded joint |
| Air quantity | Roughly 25 l/min |
| Number of welding passes | As few as possible; depends on the sheet thickness as well as the shape and size of the filler rod |
| Short-term strength of PLEXIGLAS® XT welds | 35 to 45% of material strength |

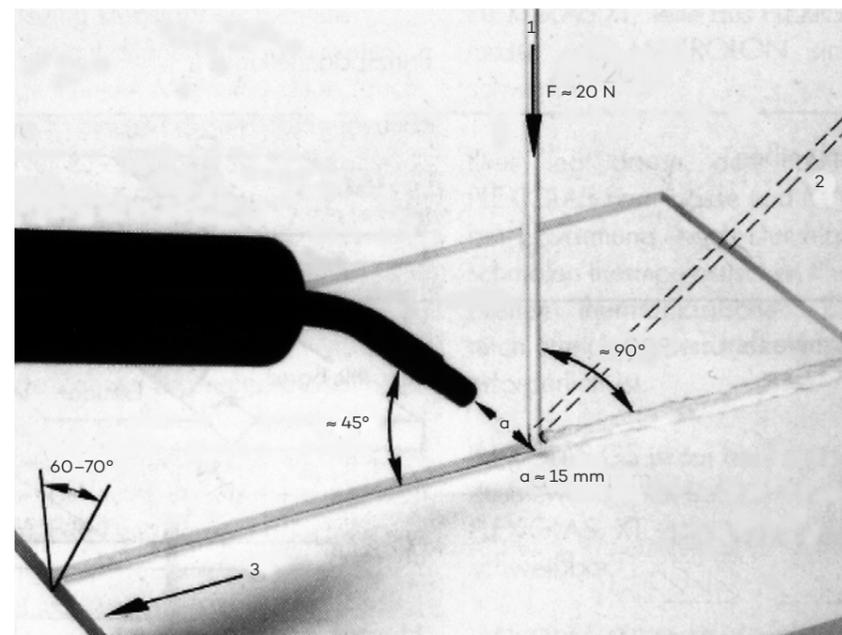


Figure 24: Hot-gas welding: correct (1), incorrect (2), direction of welding (3)

Ultrasonic welding

This technique is almost exclusively used for welding injection-moulded items like automotive rear reflectors, for example.

Good results are achieved when PLEXIGLAS® XT is welded to itself or to ABS and SAN. Ultrasonic welding of PLEXIGLAS® GS depends upon the conditions. This technique requires some experience, which can be acquired by trial. Special attention is to be paid to the following factors: amplitude, frequency, static pressure (contact pressure), type of horn, welding time, shape of the surface to be welded.

Fig. 25 shows the principle of welding, riveting and inserting metal parts by means of ultrasound.

The horn or the metal part to be embedded is designed in such a way that heating occurs within the PLEXIGLAS® surface. Notches must be avoided at all costs since they reduce the strength. Subsequent annealing of the workpiece is often advisable.

Welding by heated mirror/hot plate

The parts of PLEXIGLAS® XT to be joined are gently pressed against a mirror/hot plate heated to 400 °C until they are sufficiently soft and formable. The contact areas on the parts to be welded must match those of the heated mirror/hot plate. The workpieces are quickly arranged in the desired position towards each other and pressed together with so much force that the molten material is squeezed out at the sides. The pressure has to be maintained until the material has become solid again (see Fig. 26). Dexterity alone is usually not enough to join the parts at the requisite speed, so it is important to have the corresponding jigs at hand. Subsequent turning of the welded parts is impossible. The heated mirror/hot plate should be Teflon-coated for easy cleaning.

Friction welding

For this technique, which works very reliably with PLEXIGLAS® XT, the surfaces to be welded are first turned with a high spot on the face. Then both workpieces are clamped into a lathe between three-jaw chuck and live centre in such a way that they are bound to stay aligned. Sometimes it may be necessary to guide the initially fixed workpiece by means of a steadying rest. The workpiece clamped in the chuck then revolves at a speed of about 360 rpm, whereas the other part is pressed against it by hand via the tail spindle and kept there until the welding process has been completed.

The following data can be regarded as typical:

| Value | |
|------------------------|-------------------------------|
| Frequency | 20 to 30 kHz |
| Amplitude | 5 to 15 µm |
| Welding time | 1 to 4 s |
| Energy director | Minimum height roughly 0.2 mm |

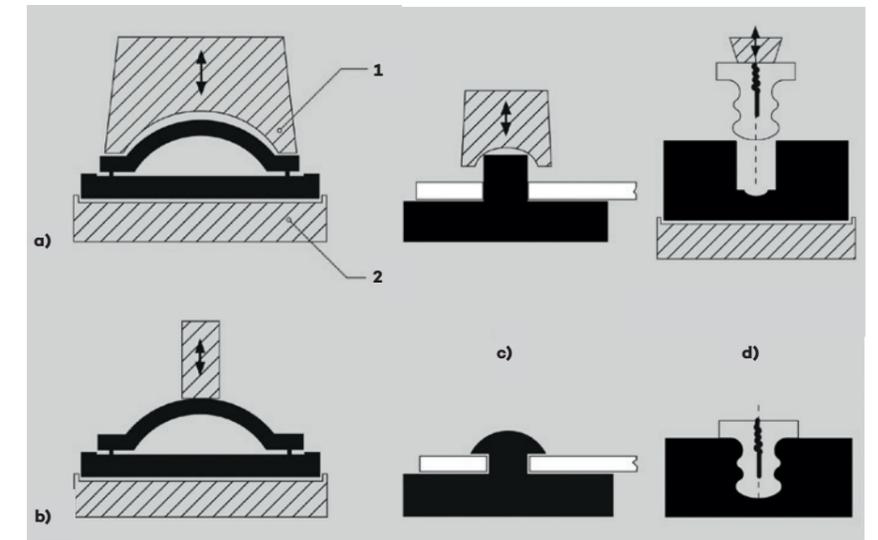


Figure 25: Ultrasonic welding: Horn (1), anvil (2), near-field welding (a), far-field welding (b), heat clenching (rivets) (c), embedding (d)

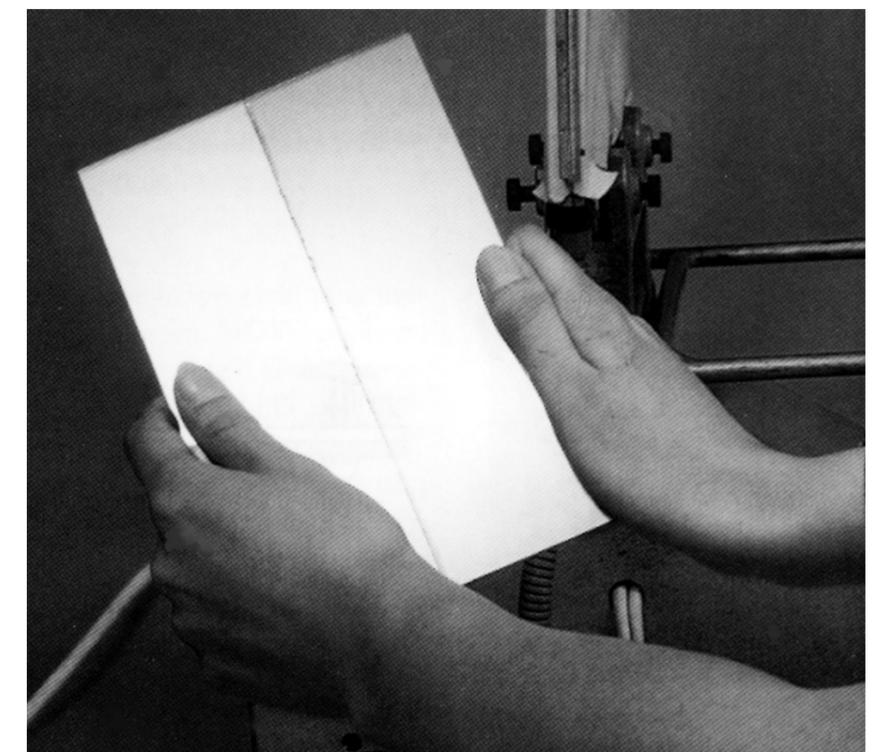


Figure 26: Welding by heated mirror/hot plate

4. Riveting

Although this joining method is not generally recommended for PLEXIGLAS® GS and PLEXIGLAS® XT sheets, special compatible metal rivets – e.g. tubular aluminium rivets – are available for the purpose, which require only moderate force (see Fig. 27 a). Pronounced stress peaks at the rivet points are to be avoided by all means, as they may cause the joined parts to break.

Well-suited, on the other hand, are shrink rivets (cf. Fig. 27 b and Guidelines for Workshop Practice, Forming, Sec. 5.7) made of round rods of PLEXIGLAS®. This fastening method utilises the elastic memory

of the material, or its tendency to shrink, in that the rods are heated and stretched by about 70% – e.g. on a lathe, clamped between chuck and tail stock. The rivets are then cut to a length corresponding to the rivet joint plus the two heads to be obtained by shrinking. In this case it is advantageous to polish the flat end faces of the rivets before they are heated. Suitable for heating the ends are hot-air guns with a nozzle opening not larger than the diameter of the rivet. To shrink the rivet head, pass the gun over it with fanning movements. Do not heat the adjoining areas unnecessarily in order to avoid stress generation.

A different riveting method uses so-called drive rivets (see Fig. 27 c) or clip rivets (see Fig. 27 d), which the trade offers in metal or plastic. Care has to be taken that the expansion forces are absorbed by the metal, so as not to expose the riveted work-piece to unnecessarily high stresses.

Moreover, the rivets used for PLEXIGLAS® must be free from dirt, grease, protective coatings etc. to rule out stress cracking in the plastic material.

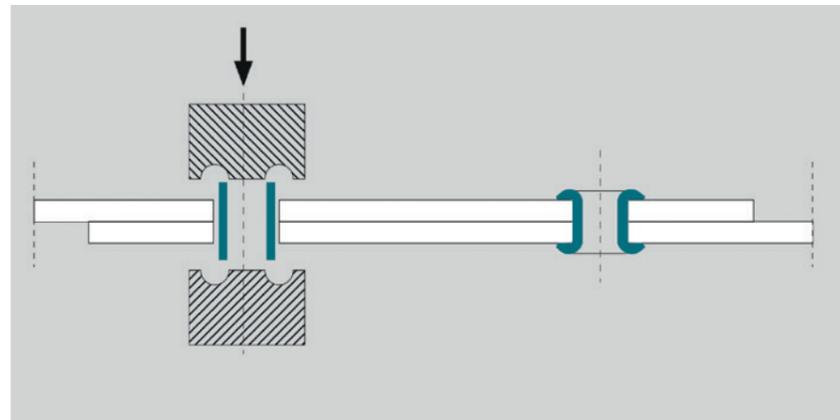


Figure 27 a: Tubular rivet

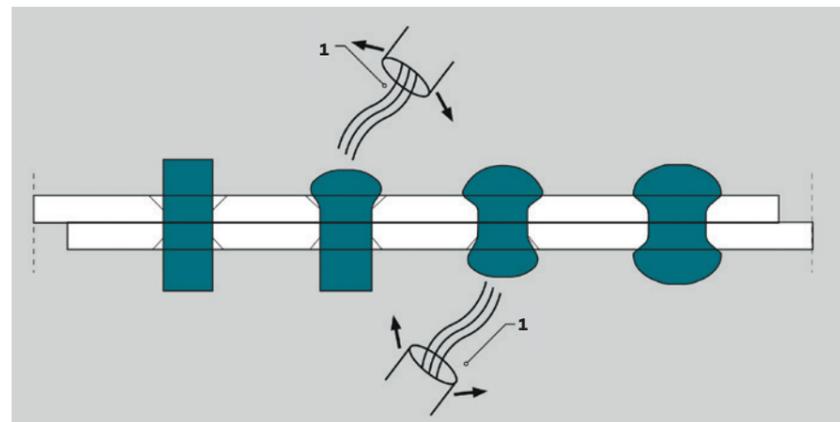


Figure 27 b: Shrink rivet: Hot air (1)

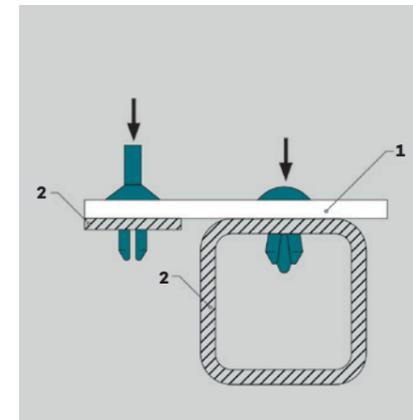


Figure 27 c: Drive rivet: Plastic (1), metal (2)

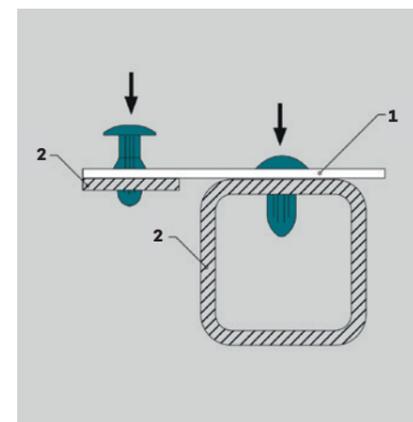


Figure 27 d: Clip rivet: Plastic (1), metal (2)

5. Clamping

PLEXIGLAS® is **best installed by clamping**, because this avoids stress, distributes the applied forces over the largest possible area and makes adequate allowance for expansion.

The elastic seals should be selected with a view to avoiding stress cracks. Moreover, the clamping pressure should not be higher than necessary, as this might cause pronounced friction between the plastic and the seal, thereby preventing the former from sliding and the latter from flexing.

In view of the special importance of clamped fastening, this subject is discussed in detail in our brochure Hints for Installing Solid Sheets (Ref. No 311-8), which is available from your local authorised PLEXIGLAS® distributor.

6. Screw unions

When plastics are drilled for **screw union**, great care must be taken to install them stress-free – much more so than in the case of metals – in order to avoid undue tendency to buckling and bending. Moreover, the screws should not be over-tightened, and any applied forces should be distributed evenly across the plastic parts.

Another aspect to be borne in mind is that PLEXIGLAS® GS and PLEXIGLAS® XT – like all thermoplastics – have a relatively high coefficient of thermal expansion and may also expand due to moisture. Assuming an ambient temperature on installation of, say, 10 °C, acrylics contract in the cold by up to 2.5 mm per metre. For their expansion due to heat and moisture, a **general allowance should be made of 5 mm/m for PLEXIGLAS® (up to 8 mm/m for PLEXIGLAS Resist®), which is the distance to the “clear cross-section” of the frame.**

Large drill holes, scope for movement at the ends and systematic installation with fixed and sliding points prevent harmful stress generation within the plastic material (see Fig. 28).

Whether metal or plastic screws are used depends on the requirements. Whereas plastic screws are light in weight, less susceptible to corrosion and noise-abating, for example, metal screws transmit higher forces.

Moreover, metal screws are not subject to stress relaxation, can tolerate high temperatures permanently, and their expansion or contraction due to temperature change is less pronounced. This is particularly important for screw unions that must be permanently tight.

By comparison, the varying thermal expansion of PLEXIGLAS® GS and XT reduces the clamping force with falling temperatures and increases it with rising temperatures. This effect can be balanced by inserting compatible washers made of EPDM, PE, PTFE etc. (never plasticised PVC!). (See also Fig. 29).

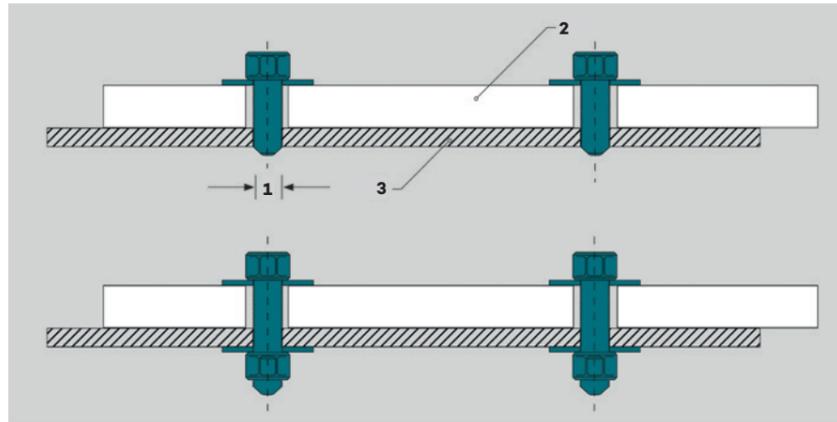


Figure 28: Simple screw union:
1) Drill hole with clearance
2) Plastic
3) Metal

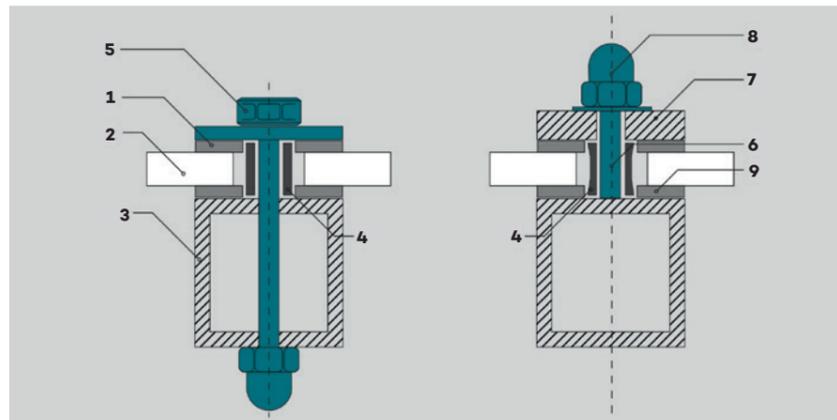


Figure 29: Examples of suitable screw unions
1) EPDM washers
2) PLEXIGLAS® XT, 8 mm
3) Banister
4) Protective sleeve (e.g. PE)
5) Screw with large washer and cap nut
6) Welded-on bolt
7) Flat metal section
8) Cap nut
9) EPDM strip

Drill hole diameter [mm] = bolt diameter + (L [m] x 5*)

(* for basic grades of PLEXIGLAS®, up to “8” PLEXIGLAS® Resist)

L = length of sheet in metres

Min. distance of hole from sheet edge: min. 1.5 x hole diameter

We advise against cutting inside or outside **threads** in PLEXIGLAS®, as the resultant stress is usually underestimated and special threading dies, e.g. with rounded threads and a coarse pitch, are often not at hand. We recommend the use of threaded inserts where threads are exposed to wear and tear.

Self-tapping screws are unsuitable if they are meant to cut into PLEXIGLAS®. They can be used however, if their thread engages in a supporting structure made of metal, for example, and sufficiently large throughholes are provided in the PMMA sheet.

A suitable joining method that requires no threads in PLEXIGLAS® but permits both stable and aesthetic **T-joints** for furniture, shelves etc. is shown in Fig. 30. It uses a countersunk screw and an internally threaded secondary metal part that accommodates the screw. Thus, a second vertical drill hole is required in the horizontal PLEXIGLAS® sheet, but thread-cutting and the resultant risky notch effect in acrylics is avoided.

PLEXIGLAS® fabricators can use either commercially available parts for T-joints or parts specially designed and manufactured to suit their (serial production) needs.

Butt joints between PLEXIGLAS® sheets can be produced with a so-called “hot bolt”. The sheets are placed together and locked in position.

Then a hole is drilled directly into the joint, so that a semicircular hole is obtained in each sheet (see Fig. 31). The connecting element is a metal bolt with nut and washer whose shank diameter is smaller

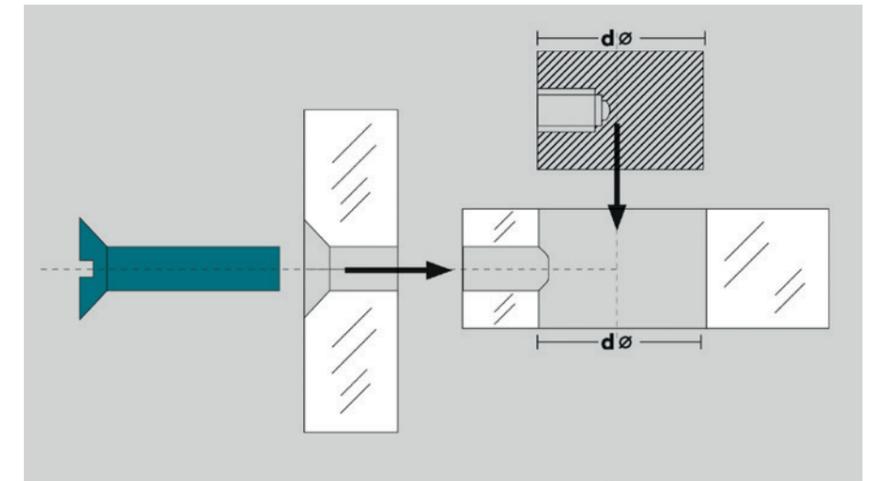


Figure 30: T-joint

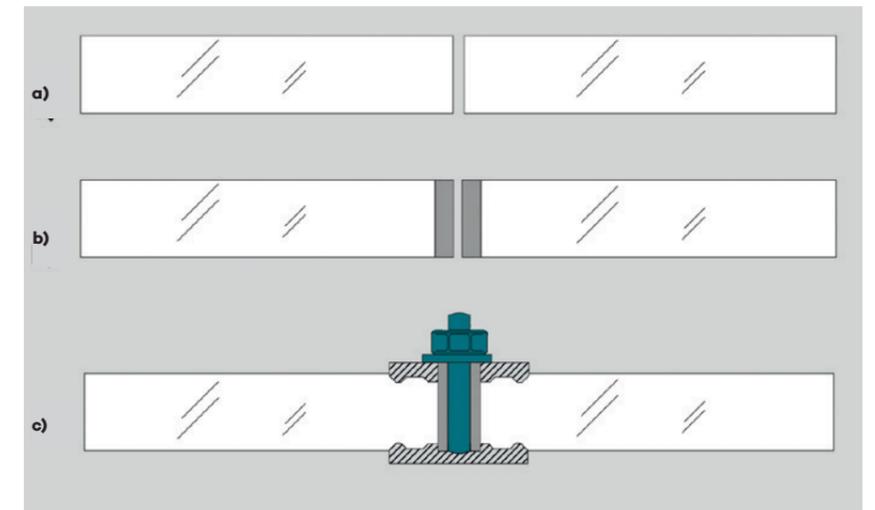


Figure 31: Butt joint with “hot bolt”:
Butt joint (a), drill hole in the joint (b), pressed-in bolt with nut and washer (c)

than the drill hole. The screw head has several concentric beads on its underside around the shank, and so has the washer. For joining, the screw is heated to approx. 160 °C, passed through the hole, the likewise heated washer slid over the shank and the nut fastened. While this is done, the PLEXIGLAS® sheet warms up to forming temperature in this region and the polished surfaces of the two metal parts press into the sheet.

Upon cooling, a solid joint has been obtained. Sheets placed on top of each other can be joined in the same way. Subsequent annealing is recommended to avoid stress cracking. The advantage of this form of screw union lies in the even distribution of force without any notch effect. The pressed-in metal parts furthermore enhance the quality and serviceability of the material.

7. Heat lamination

The further development of fabrication techniques for PLEXIGLAS® gave rise to the **heat lamination method**, an adhesive-free technique for a durable union between flat PLEXIGLAS® sheets for displays, advertising elements and technical components, usually involving the embedding of message carriers.

Cut-to-size sheets of PLEXIGLAS® (up to size DIN A2) are subjected to controlled heating by IR radiators of the adherends, and then rolled into a laminate under linear pressure. This technique provides optimal results when uniting PLEXIGLAS® **XT with XT**, under certain conditions also **XT with GS**, but not for joining **GS with GS**.

The following elements can be incorporated or embedded in the composite of two or three, usually crystal-clear, PLEXIGLAS® sheets:

- engravings,
- recesses (cavities),
- digital transfer prints,
- screen prints,
- paper or
- thin objects,
e.g. up to the thickness of a coin

Compared with conventional methods such as

- encapsulation,
- area bonding
(see Section 2.7.3.3),
- hot press moulding,

heat lamination offers several advantages, provided the fabricator has the appropriate equipment:

- shorter cycle times for one-offs and series,
- no emissions caused by casting resins and adhesives,
- screening and transfer printing inks are not attacked,
- Sizes of DIN A5 to DIN A2 are possible,
- mobile elements (balls, sand, liquids) can be incorporated in appropriate cavities.

To obtain satisfactory results by means of heat lamination, a special system consisting of three items of equipment is required:

1. a heating station,
2. a rolling unit,
3. a cooling jig.

In heat lamination (see Fig. 32 for principle), two cut-to-size sheets of PLEXIGLAS® XT are heated horizontally on their upper surfaces by means of IR radiators, while their undersides are kept as cool as possible. Once the optimal temperature has been reached, the two sheets are conveyed to the rolling unit. The uppermost element is inverted so that the two hot surfaces of the parts meet between the rolls. The message carriers and/or objects to be embedded are rapidly positioned between the two sheets beforehand. The laminated part should be uniformly flat at room temperature, which is achieved by controlled cooling of the laminate in the cooling jig.

Many PLEXIGLAS® fabricators have PLEXIGLAS® XT heat lamination performed by toll manufacturers to provide virtually any design imaginable. As the company that developed and manufactures PLEXIGLAS®, we offer a comprehensive, cost-effective licensing package to fabricators who would like to perform heat lamination technique themselves, including the described equipment and the requisite process know-how. Those interested are welcome to contact our Technical Service department or our sales team.



Figure 32: Equipment for heat lamination: heating station, rolling unit, cooling jig (from left to right)

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