Chapter 71

Polyvinyl Chloride

General Discussion of Joining Techniques

Georgia Gulf: PVC

Parts molded from Georgia Gulf rigid vinyl compounds can be fastened together in a variety of ways. Whether the methods are through mechanical or chemical means, consideration early in the design stages will facilitate a proper and economic assembly to meet intended requirements. When considering the fastening options available with rigid vinyl, a designer must decide whether parts will be assembled with or without fasteners.

Table 71.1: Available options for joining rigid polyvinyl chloride (PVC) parts.

Fasteners	Without Fasteners
- Thread Cutting Screws	- Solvent Bonding
- Thread Forming Screws	- Adhesive Bonding
- Clips	- Snap Fits
- Machine Screws	-Welding Techniques: ultrasonic, spin, vibration, heat staking

Reference: *Georgia Gulf Vinyl*, supplier technical report - Georgia Gulf, 1991.

Welding

Georgia Gulf: PVC

The use of ultrasonic, spin, and vibration welding works very well with rigid vinyl. Heat staking is also an acceptable method of joining parts.

Reference: *Georgia Gulf Vinyl*, supplier technical report - Georgia Gulf, 1991.

Huls AG: Vestolit BAU (applications: windows; chemical type: graft polymer; product form: profile extrusion)

In modern window manufacturing plants, the windows are made by the flow-line system with high production rates. Even in short-run production plants, however, the profiles also have to be drilled, routed and sawn at high operating speeds without chipping of the cut edges. Even with worn tools, high-impact Vestolit BAU allows high operating speeds without failures, unlike non-modified PVC window compounds.

The welding of the mitre-cut profiles is carried out on specially designed machines. Essential requirements for optimum welding are high dimensional accuracy of the profiles and mitre-cut surfaces without chips or fractures. The removal of the weld "flux" is usually carried out mechanically on automatic machines.

In contrast to non-modified rigid PVC, profiles made from Vestolit BAU permit high production rates of the routers, necessary to ensure minimum operation times at this station. Experience in the early development stages demonstrated that at these high cutting speeds, profiles with a notched impact strength of 20 kJ/m^2 or less showed "chatter marks" when withdrawn, or the outer corner edges of the frame chipped during routing of the weld flux.

In measuring corner weld strengths, the value obtained by slow bending-open of the corners up to the point of fracture is less meaningful than an impact test. Vestolit BAU has advantages in this respect.

PVC window sections are almost exclusively heat-welded into window frames. Mechanical connections - at least in the transom area - are less common. The welding and corner machining are carried out by sophisticated machines within short cycle times. The PVC used must meet the requirements for good weldability. From the raw material side, the following factors should be mentioned which can influence weldability:

-method of manufacturing the PVC
-modification of the PVC (modifier)
-formulation of the PVC (lubricant and chalk content)

Vestolit BAU is manufactured by the suspension method, i.e. it contains only small amounts of polymerization residuals. The nature of the modifier is selected in such a way that the weldability is not adversely affected. The impact-modified PVC resin must be adjusted by formulation to allow for the following requirements:

- Lubricant additives - to assist processability on all extruders
- Stabilizer additives - for light fastness and weather resistance
- Pigment additives - for coloring purposes

The additives used in the Vestolit BAU compounds are selected carefully with a view to not adversely affect the weldability.

The weldability is tested in the tensile test to DIN 53455 with welded and non-welded specimens. The welding factor (tensile strength (welded)/ tensile strength (no weld))is derived from the tensile strengths at break. With Vestolit BAU it is for practical purposes always about 1.0.

Other PVC compounds have distinct disadvantages here because
- the PVC used was produced by the emulsion method and therfore contains higher residual amounts of polymerization additives, which can adversely affect the weldability;
- the additives required to enhance extrusion - a combination of internal and external lubricants - were not optimized to take into account the welding operation;
- the chalk additive levels were increased to reduce raw material cost, without due regard to reduced weld strength which inevitably follows.

The chalk additives are, in addition, often described as "inorganic modification", although they increase the impact resistance values only very slightly in comparison with "organic modification." The corner impact strengths of window frames made from such materials decline sharply. Excessively high chalk fillings, however, also lead to a drop in the corner strength because of the effect on the weldability, despite the use of low test rates, e.g. in the corner bending test.

Reference: *Vestolit BAU For World-Wide Windows,* supplier technical report (1083e/May 1987/bu) - Huls AG, 1987.

Ultrasonic Welding

PVC (features: 5.8 mm thick)

Ultrasonic bonding of PVC sheet or fiber is difficult to predict due to the broad range of additives used in its manufacture. Plasticizers are often added to rigid PVC to impart flexibility. As the content of plasticizer increaes, the ability to ultrasonically bond PVC decreases.

Reference: *Ultrasonic Sealing and Slitting of Synthetic Fabrics,* supplier technical report - Sonic & Materials, Inc.

Radio Frequency Sealing

PVC (features: transparent)

Difficulties were encountered in regulating RF welding conditions for rigid PVC to get acceptable, aesthetically pleasing welds. Rigid PVC did not produce sound bonds to itself. Depending on welding parameters, the samples either did not melt or melted completely through before a good bond could be formed. Nevertheless, good bonds were achieved with rigid/ clear flexible PVC, rigid/ radiopaque filled flexible PVC, and rigid/ polyurethane combinations.

As with flexible PVC, heat aging had no noticeable effects, except in the case of the rigid PVC/ polyurethane combination which increased significantly in weld strength after aging. With rigid PVC, samples purposely cut through during welding produced superior welds to samples not cut through. This was probably due to the longer contact time (the time in which the pressure and RF frequency were applied to the sample) used in the purposely cut through samples.

Table 71.2: Radio frequency weld strength of rigid polyvinyl chloride (PVC) between itself and other materials. (The breaking strength per unit cross sectional area of each weld was calculated, then divided by the tensile strength of the weaker material. This number (multiplied by 100) gave the weld strength expressed as a percentage of the highest possible value or "potential.")

Material	Joining Material	RF welded without cutting through samples	Samples purposely cut through during RF welding		Change in weld strength after exposure to 5-5.5 Mrads of gamma radiation
			no aging	aged 48 hours at 60°C	
clear rigid PVC 80D	TPE alloy	no bond	no bond		
clear rigid PVC 80D	styrenic TPE	no bond	no bond		
clear rigid PVC 80D	aromatic polyester polyurethane	fair (6-15% potential)	excellent (31-50% potential)	superior (>50% potential)	
clear rigid PVC 80D	filled radiopaque PVC 75A	fair (6-15% potential)	superior (>50% potential)	excellent (31-50% potential)	
clear rigid PVC 80D	clear rigid PVC 80D	weak (<5% potential)	fair (6-15% potential)	fair (6-15% potential)	-5% potential
clear rigid PVC 80D	clear flexible PVC 80A	excellent (31-50% potential)	good (16-30% potential)	superior (>50% potential)	
clear rigid PVC 80D	clear flexible PVC 65A	fair (6-15% potential)	excellent (31-50% potential)	excellent (31-50% potential)	

Reference: Leighton, J., Brantley, T., Szabo, E., *RF Welding of PVC and Other Thermoplastic Compounds,* ANTEC 1992, conference proceedings - Society of Plastics Engineers, 1992.

Threaded Fasteners

Georgia Gulf: PVC

Self-threading screws are a popular and economical way to assemble rigid vinyl parts. The two basic options for screw fasteners are thread forming and thread cutting screws. Thread forming screws are not recommended for rigid vinyl parts as they induce high stress levels in the part. This screw displaces material as it is installed in the receiving hole and creates high stress levels on the boss. Where higher back out torques are required, thread forming screws may be necessary.

Thread cutting screws such as the Hi-Lo, Type F, Type 25, and Type 23 are preferred. These screws actually remove material as they are installed, thus avoiding high stress build up. If the part will be assembled and disassembled several times, Type 23 and Type 25 screws should not be used. The recutting of threads will not offer the required assembly strength and, therefore, a standard machine screw with a brass insert should be used for these applications.

Some general design considerations for mechanical fasteners are as follows:

- The outside diameter of the boss should be equal to 2.25 times the diameter of the cored hole.
- The diameter of the hole [boss] should be equal to the pitch diameter of the screw.
- The thread engagement should be a minimum of twice the screw diameter. A slight increase in the thread engagement will offer a significant increase in pull-out strength.
- Repeated use of the same boss should be avoided.
- Minimum torque should be used to keep stress levels within acceptable limits for rigid vinyl.

Reference: *Georgia Gulf Vinyl,* supplier technical report - Georgia Gulf, 1991.

Adhesive and Solvent Bonding

Dexter Composites: Alpha 2212 (features: transparent)

In tests conducted to evaluate the solvent bondability/compatibility of plasticized PVC tubing to rigid, transparent thermoplastics, as might have been predicted, PVC bonds quite well to PVC. All solvents but acetone allowed for easy assembly. The 1,2-dichloroethane and straight methylene chloride did not provide acceptable bond strengths, but all of the other cocktails did yield acceptable bonds. No initial crazing was observed for any of the solvents. The instance of a rigid PVC substrate is one case where straight cyclohexanone will provide results which are as good as those for any of the blends.

Reference: Haskell, A., *Bondabilitly/Compatibility of Plasticized PVC to Rigid, Transparent Thermoplastics,* ANTEC 1989, conference proceedings - Society of Plastics Engineers, 1989.

Georgia Gulf: PVC

Rigid vinyl can be easily bonded to virtually all materials including other thermoplastics and metal, as well as itself. Common adhesives such as epoxies, urethanes and acrylics perform well with vinyl.

Solvent Cement Bonding

Solvent bonding is a very effective method for joining several rigid vinyl parts or other thermoplastics soluble in the same solvent. The procedure involves treating the surface to be bonded with a small amount of solvent to etch the contact area. A fixture is recommended to hold mated parts together until the solvent has evaporated and the parts joined. It is important that the mating surfaces fit well so that pressure can be evenly distributed over the entire surface area to be bonded.

A 5 to 20 percent solution of PVC resin in methylene chloride and THF provides an effective solvent bonding system. Proper ventilation of the work area and adherence to plant safety should always be followed when working with solvents. The amount of cement should be kept to a minimum and applied only to clean surfaces to insure high quality aesthetics and proper bonding.

Contact Adhesive Bonding
Many adhesives are available from varied sources that work well with rigid vinyl. The following procedure should be followed with the use of solvent cement or contact adhesive:

Cleaning
Step 1 Clean sufaces to be bonded with MEK or methylene chloride.

Application
Step 2 Apply contact cement to both sides. Allow proper "set up" time and apply solvent cement to one side.

Clamping/Fixture
Step 3 Clamp or fixture mating surfaces together (minimum 60-90 seconds). Longer clamp time may be necessary dependent upon bonding system and nature of the bonding surface area.

Drying
Step 4 For application to be used at room temperature, dry at ambient for 24 hours. Follow manufacturers instruction with contact adhesives.

Solvent Cement/Contact Adhesive Surface Joint Design
Performance of parts mated by a solvent or contact adhesive can be greatly enhanced by proper joint design of the mating surfaces. A strong surface bond is directly related to the size of the surface mating area of the parts.

Bonded joints under compression perform optimally; therefore, compression should be utilized whenever possible in joint design. Under conditions of tension, lap joints perform with more reliability due to increased surface contact area in lap joint configurations.

Reference: *Georgia Gulf Vinyl,* supplier technical report - Georgia Gulf, 1991.

Adhesive Bonding

Georgia Gulf: PVC

Rigid vinyl parts can be bonded to other materials such as metal, glass, other plastics and wood. There are a variety of adhesives that will work well with rigid vinyl, such as epoxies, urethanes, contact glues and two-part adhesive systems.

The following bonding procedure should be used:

Step 1. Clean parts to be bonded.
Step 2. Apply adhesive to one side only.
Step 3. Clamp the two parts together [minimum 60-90 seconds].
Step 4. If part is to be used in a room temperature environment, dry at room temperature for 24 hours.

Reference: *Georgia Gulf Vinyl,* supplier technical report - Georgia Gulf, 1991.

Occidental: Oxychem 160

A study was conducted to test for bond strength on a representative matrix of commonly used plastics and the adhesives best suited to them. For many of the plastics evaluated, the effect of polymer composition on bond strength was evaluated by compounding plastic formulations with each of the most commonly used additives and fillers for that plastic; common grades were used for the remaining resins. The effect of each additive and filler was determined by comparing the bond strength achieved with the specially compounded formulations to that of the neat plastic. In addition, the effect of surface roughening and chemical treatment of the plastic surface on bond strength was examined.

The block-shear (ASTM D 4501) test was chosen as the test method because it places the load on a thicker section of the test specimen that can withstand higher loads before experiencing substrate failure. In addition, the geometry of the test specimens and the block-shear fixture helps minimize peel and cleavage forces in the joint. How well the block-shear test method reflects the stresses that an adhesively bonded joint will experience in real world applications should be considered. Also, limitations on the data due to the variety of additives and fillers used by different companies should not be ignored.

Black Max 380, a rubber toughened cyanoacrylate adhesive, Prism 401 and Super Bonder 414, both cyanoacrylate adhesives, Depend 330, a two-part no-mix adhesive, and Loctite 3105, a light curing adhesive, all created bonds which were stronger than the rigid PVC substrate for most of the formulations tested. However, Black Max 380 and Depend 330 typically achieved substrate failure at much lower bond strengths than Prism 401, Super Bonder 414, and Loctite 3105.

Surface Treatments
Surface roughening and/or the use of Prism Primer 770 resulted in either no statistically significant effect or, in the rigid PVC, failing at a statistically significant lower bond strength than the untreated PVC.

Other Information
PVC can be stress cracked by uncured cyanoacrylate adhesives, so any excess adhesive should be removed from the surface immediately. PVC is compatible with acrylic adhesives but can be attacked by their activators before the adhesive has cured. Any excess activator should be removed from the surface of the PVC immediately. PVC is incompatible with anaerobic adhesives. Recommended surface cleaners are isopropyl alcohol and Loctite ODC Free Cleaner 7070.

Table 71.3: Shear strengths of polyvinyl chloride (PVC) to PVC adhesive bonds made using adhesives available from Loctite Corporation. Values are given in psi and (MPa).[b,c]

Plastic Material Composition (Occidental Chemical Oxychem 160)		Loctite Adhesive					
		Black Max 380 rubber toughened cyanoacrylate (200 cP)	**Prism 401** surface insensitive ethyl cyanoacrylate (100 cP)	**Prism 401/ Prism Primer 770** polyolefin primer for cyanoacrylate	**Super Bonder 414** general purpose cyanoacrylate (110 cP)	**Depend 330** two-part no-mix acrylic	**Loctite 3105** light cure acrylic (300 cP)
Unfilled resin	3 rms	>1600[a] (>11.0)[a]	>3650[a] (>25.2)[a]	>2850[a] (>19.7)[a]	>2900[a] (>20.0)[a]	>2650[a] (>18.3)[a]	>2550[a] (>17.6)[a]
Roughened	27 rms	>1600[a] (>11.0)[a]	>1850[a] (>12.8)[a]	>1400[a] (>9.7)[a]	>2900[a] (>20.0)[a]	>1550[a] (>10.7)[a]	>2550 (>17.6)
UV stabilizer	1% UV-531	>1600[a] (>11.0)[a]	>2800[a] (>19.3)[a]	>1400[a] (>9.7)[a]	>2900[a] (>20.0)[a]	>1850[a] (>12.8)[a]	>2550[a] (>17.6)[a]
Impact modifier	7% Paraloid BTA753	>1100[a] (>7.6)[a]	>4300[a] (>29.7)[a]	>3650[a] (>25.2)[a]	>2900[a] (>20.0)[a]	>1050 (7.24)	>3000[a] (>20.7)[a]
Flame retardant	0.3% Antimony Oxide	>1600[a] (>11.0)[a]	>3050[a] (>21.0)[a]	>2850[a] (>19.7)[a]	>2900[a] (>20.0)[a]	>2050[a] (>14.1)[a]	>2550[a] (>17.6)[a]
Smoke suppressant	0.3% Ammonium Octamolybdate	1250 (8.6)	>3650[a] (>25.2)[a]	>2850[a] (>19.7)[a]	>2900[a] (>20.0)[a]	>1800 (>12.4)[a]	>2550[a] (>17.6)[a]
Lubricant	1% Calcium Stearate 24-46	>1600[a] (>11.0)[a]	>3650[a] (>25.2)[a]	>2850[a] (19.7)[a]	>2900[a] (>20.0)[a]	>1900[a] (>13.1)[a]	>2550[a] (>17.6)[a]
Filler	9% OmyaCarb F	>1600[a] (>11.0)[a]	>4250[a] (>29.3)[a]	>1750[a] (>12.1)[a]	>4400[a] (>30.3)[a]	>2650[a] (>18.3)[a]	>3150[a] (>21.7)[a]
Plasticizer	5% Drapex 6.8	>1600[a] (>11.0)[a]	>2250[a] (>15.5)[a]	>1550[a] (>10.7)[a]	>2900[a] (>20.0)[a]	>1500[a] (>10.3)[a]	>2550[a] (>17.6)[a]
Colorant	0.5% FD&C Blue #1	>1600[a] (>11.0)[a]	>3650[a] (>25.2)[a]	>2850[a] (>19.7)[a]	>2900[a] (>20.0)[a]	>1050[a] (>7.24)[a]	>2550[a] (>17.6)[a]
Antistatic	1.5% Markstat AL48	>1600[a] (>11.0)[a]	>3650[a] (>25.2)[a]	>1200[a] (>8.3)[a]	>2900[a] (>20.0)[a]	>900[a] (>6.2)[a]	>2550[a] (>17.6)[a]

[a] The force applied to the test specimens exceeded the strength of the material resulting in substrate failure before the actual bond strength achieved by the adhesive could be determined.
[b] All testing was done according to the block shear method (ASTM D4501).
[c] For more information on data presented in this table, contact Loctite Corporation at 800-562-8483 (1-800-LOCTITE). Request the "Design Guide for Bonding Plastics."

Reference: *The Loctite Design Guide for Bonding Plastics,* supplier design guide (LT-2197) - Loctite Corporation.

Solvent Bonding

Georgia Gulf: PVC

Solvent bonding is a popular method for joining rigid vinyl to itself or to another plastic soluble in the same solvent. A 5 to 20 percent solution of PVC resin in methylene chloride is recommended as the optimum solvent bonding system.

When using the solvent bond method, the amount of solvent should be kept to a minimum and applied to clean surfaces. The two parts should fit well so that pressure is evenly distributed over the entire area. The following solvent bonding procedure should be used:

1. Clean the parts to be bonded.
2. Apply solvent to one side only.
3. Clamp the two parts together [minimum 60-90 seconds].
4. If part is to be used in a room temperature environment, dry at room temperature for 24 hours.

Reference: *Georgia Gulf Vinyl,* supplier technical report - Georgia Gulf, 1991.