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SOLVENT CEMENTING AND ADHESIVE BONDING OF FOAMS

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INTRODUCTION

The information given in this brief chapter covers plastic foams, both thermoplastic and thermosetting, and elastomeric foams, although very little discussion is given in the latter subject.

SOLVENT CEMENTING

Solvent cementing is a process in which thermoplastics are softened by the application of a suitable solvent or mixture of solvents and then pressed together to effect a bond. The resin itself, after evaporation of the solvent or solvents, acts as the adhesive. Many thermoplastic resins are more amenable to solvent cementing than to conventional adhesive bonding (1). In many cases mixtures of solvents give better results than the individual solvents. With solid plastics, if evaporation rates are too fast due to excessive volatility of the solvent, crazing or blushing often occurs. This is not a problem with cellular materials, however. Often small amounts (1–7%) of the substrate to be bonded are dissolved into the solvent to aid in gap filling and to accelerate curing. Solvents for cementing may be brushed, sprayed, or the foam surfaces may be dipped in the solvent. The foam parts should be held firmly in place during cure.

Most thermoplastic foams can be solvent cemented. However, some solvent cements will collapse thermoplastic foams. The best way to determine if such a problem exists is to try it. In cases where the foam collapses due to softening of the foam cell walls it is desirable to use water–based adhesives based on SBR or polyvinyl acetate, or 100%–solids adhesives. In general, the relatively amorphous thermoplastics, such as the cellulosics, polycarbonate, and polystyrene are easier to solvent cement than the crystalline materials, but there are exceptions.

When two dissimilar plastic foams are to be joined, which is rarely done, adhesive bonding is generally preferable because of solvent and polymer incompatibility problems. Solvents used to cement plastics should be chosen with approximately the same solubility parameter (δ) as the plastic to be bonded. The solubility parameter is the square root of the cohesive energy density (CED) of the liquid solvent or polymer. CEDs of organic chemicals are primarily derived from the heat of vaporization and molecular volume of the molecules, and are expressed as calories per cubic centimeter (cal/cm^3). Literature sources provide data on δ's of a number of plastics and resins (2) (3) (4).

Thermoplastic Foam Substrates

Cellular Cellulose Acetate: A number of solvents can be used by themselves in cementing cellulose acetate. The following formulations involve mixtures of several solvents, including bodying resins (dope–type cements) (5).

- cellulose acetate, 18% by wt.
  acetone, 55% by wt.
  methyl CELLOSOLVE, 20% by wt.
  methyl CELLOSOLVE acetate, 7% by wt.

- cellulose acetate, 15% by wt.
  methyl CELLOSOLVE, 25% by wt.
  methyl ethyl ketone, 60% by wt.

- cellulose acetate, 10% by wt.
  acetone, 60% by wt.
  methyl CELLOSOLVE, 30% by wt.
  (This is a good "dope" for *quick bonding*.)

Acrylonitrile - Butadiene - Styrene (ABS): ABS is conventionally bonded with a dope cement containing 15–25% ABS resin in a blend of ketone solvents, e.g., acetone, methyl ethyl ketone, and methyl isobutyl ketone, or tetrahydrofuran or methylene chloride (5).

Acetal Homopolymer (DELRIN®): In general, solvent cements are relatively ineffective with DELRIN®, a highly crystalline polymer. Methylene chloride, methylene chloride mixed with ethylene chloride, and DELRIN® in methylene chloride have been used, however (6).

Acetal Copolymer (CELCON®): As with DELRIN®, this is a highly crystalline polymer with excellent solvent resistance. It is somewhat more amenable to solvent cementing than the homopolymer, however. The solvent cement recommended by the manufacturer, Hoechst Celanese, is *hexafluoroacetone sesquihydrate*, available from Allied Signal, Inc. This solvent is a severe eye and skin irritant, however, and should be handled with care (7).

Polyvinyl Chloride (PVC): A formulation that has worked satisfactorily in both rigid and flexible PVC is as follows (5):

	Parts by Weight
PVC resin (medium mol. wt.)	100
tetrahydrofuran	100
methyl ethyl ketone	200
organic tin stabilizer	1.5
dioctyl phthalate (plasticizer)	20
methyl isobutyl ketone	25

Care must be taken in handling this formulation because of the slightly toxic nature of the tetrahydrofuran. The resin solids content of this formulation is over 22%. So it is a heavy-bodied cement.

Polycarbonate: Solvent cementing is the most common method of bonding polycarbonate. Bonding can be carried out with specific solvents, mixtures of solvents, and mixtures of polycarbonate and solvents. Methylene chloride, when used by itself, has an extremely fast evaporation rate and is recommended for fast assembly of polycarbonate parts. A solution of 1–5% polycarbonate resin in methylene chloride has a decreased evaporation rate. Parts bonded with methylene chloride are usable at elevated temperatures after approximately 48 hours, depending on the bonding area. Ethylene dichloride is also used (5).

Polystyrene: Polystyrene may be bonded to itself by solvent cementing, conventional adhesive bonding, thermal welding, spin welding, ultrasonic welding, or electromagnetic bonding. Solvent cementing is the most effective method, however. Solvents recommended are (8) (9) (10):

methylene chloride	ethylene dichloride
ethyl acetate	trichloroethylene
methyl ethyl ketone	

All these are fast-drying (20 seconds or less) solvents, and in solid plastics would present a crazing problem. However, in foamed plastics this is not a problem. *Aromatic* hydrocarbon solvents, such as toluene and xylene, should not be used since they would cause a collapse of the cellular material.

Polysulfone: Polysulfone can be solvent cemented with chlorinated hydrocarbons. A solution of 5% resin in methylene chloride can be used to bond polysulfone to itself. High pressures (500 psi) are required for *solid plastics* (5).

Modified Polyphenylene Oxide (NORYL®): Solvent cementing is by far the simplest and most economical method of joining this material to itself. The resin can be readily softened and dissolved by some aromatic and chlorinated hydrocarbons. The latter are preferred because of their better solubility and stronger bond formation. Solvent-cemented parts of NORYL® are less sensitive to thermal shock than adhesive-bonded joints. The bonds are unaffected during extended aging or prolonged exposure to steam. The solvent should be applied in a thin uniform layer and the parts should be rapidly positioned and clamped. This material requires very little solvent for softening the surface to be bonded. Excess soaking is undesirable. The best results are obtained by applying the solvent to only one mating surface. In solid materials a four-minute holding time in the clamp at 400 psi is recommended (5).

The following solvents and solvent combinations are recommended:

methylene chloride
chloroform/carbon tetrachloride (95/5)
chloroform + 2% NORYL®
ethylene dichloride
xylene/methyl isobutyl ketone (25/75)
trichloroethylene with 1–7% NORYL® for bodying
methylene chloride/trichloroethylene (85/15)

Polybutylene Terephthalate (PBT): Solvents recommended by General Electric for their VALOX® thermoplastic polyester are (11):

hexafluoroisopropanol
hexafluoroacetone sesquihydrate

The solvent is brushed on the mating surface and dried under pressure. These solvents are toxic and should be applied only in areas of positive ventilation.

Polyetherimide (ULTEM®): Methylene chloride, with or without a 1–5% solution of ULTEM®, is recommended. Moderate pressures of 100–600 psi for 1–5 minutes are required (12).

ADHESIVE BONDING

Adhesive bonding of plastic and rubber foams is used where it is not possible to use solvents or thermal means of dissolving or melting both adherend surfaces. Examples of such bonding are: polystyrene to metal, polycarbonate to phenolic, polyethylene to itself (no solvent can be used to solvent cement polyethylene because it is highly insoluble). Before attempting to adhesive bond any material attention should be paid to the problem of adherend surface preparation. If the surfaces are not properly prepared, usually by solvent cleaning, chemical oxidation, and/or roughening, the bonds will not be durable. There are a number of sources of information in this area. The details of individual procedures are too lengthy and complex to be presented here.

Thermoplastic Foam Substrates

Some solvent cements and solvent–containing adhesives, such as pressure–sensitive adhesives (PSAs), will collapse thermoplastic foams by dissolving the cell walls. In such cases water–based adhesives based on SBR or polyvinyl acetate, or 100%–solids adhesives are often used (1).

Acetal Copolymer (CELCON®): Two types of non–solvent adhesives are used, structural and non–structural. Most structural adhesives are based on thermoset resins and require the use of a catalyst and/or heat to cure. This type of adhesive is normally used in applications which require maximum bond strength and minimum creep of the adhesive joint under sustained loading. Many structural adhesives can be used continuously at temperatures up to 350°F, which is higher than the recommended continuous-use temperature of the copolymer. Structural adhesives recommended are:

epoxy (to 160F°)
polyester with isocyanate curing agent (to 200°F)
polyvinyl butyrate, modified with a thermosetting phenolic (to 250°F)
cyanoacrylate (to 181°F)

Non-structural adhesives used on CELCON® are usually one-component, room-temperature-curing systems based either on thermoplastic resins or elastomeric materials dispersed in solvents. They are normally used in applications which will not be exposed to temperatures over 180°F. Neoprene rubber adhesives are examples. (7).

Acetal Homopolymer (DELRIN®): Adhesives recommended for this material include (6):

polyester with isocyanate curing agent
rubber-based adhesives
phenolics
epoxies
modified epoxies
vinyls
resorcinol
vinyl-phenolic
ethylene vinyl acetate
cyanoacrylate
polyurethane

Acrylonitrile-Butadiene-Styrene (ABS): Conventional adhesives recommended include epoxies, urethanes, thermosetting acrylics, elastomers, vinyls, nitrile-phenolics, and cyanoacrylates (8) (13).

Cellular Cellulose Acetate: Conventional adhesives recommended include polyurethanes, synthetic resins, thermoplastics, resorcinol-formaldehyde, nitrile-phenolic, and rubber-based materials (8).

Polyvinyl Chloride (PVC): With PVC plasticizer migration to the adhesive bond line can cause difficulties, especially in the softer, highly plasticized materials. Adhesives must be tested for their ability to resist the plasticizer. *Nitrile-rubber adhesives* are resistant to plasticizers. *Polyurethanes* and *neoprenes* are also used. Even rigid PVC contains up to 5% plasticizer. Most vinyl materials are fairly easy to bond with elastomeric adhesives. The highest bond strengths for rigid or semi-rigid PVCs are obtained with two-component, RT-curing *epoxies*. Other adhesives recommended for rigid PVCs are (8):

polyurethanes	nitrile-rubber phenolic
modified acrylics	polyisobutylene rubber
silicone elastomers	nitrile rubber
anaerobic structural adhesives	neoprene rubber
polyester-polyisocyanates	epoxy polyamide
polymethylmethacrylate	polyvinyl acetate

Polycarbonate: Conventional adhesives recommended include epoxies, modified epoxies, polyurethanes, acrylics, RTV silicones, cyanoacrylates, one-part elastomers, some epoxy-polyamides, and hot melts (13).

Modified Polyphenylene Oxide (NORYL®): Conventional adhesives recommended include epoxies, polysulfide-epoxies, silicone, synthetic rubber, acrylics, cyanoacrylates, and hot melts (14).

Polystyrene: Although polystyrene is usually bonded by solvent cementing, it can be bonded with vinyl acetate/vinyl chloride solution adhesives, acrylics, polyurethanes, unsaturated polyesters, epoxies, urea-formaldehyde, rubber-base adhesives, polyamide (Versamid-base), poly-methylmethacrylate, and cyanoacrylates. The adhesives should be medium-to-heavy viscosity and room-temperature and contact-pressure curing. An excellent source is a Monsanto Company technical information bulletin which recommends particular commercial adhesives for bonding polystyrene to a number of different surfaces. Adhesives are recommended in the fast-, medium-, and slow-setting ranges (10).

Polyethylene and Polypropylene: Acceptable bonds have been obtained between treated polyolefin surfaces with polar adhesives, such as epoxies, or solvent cements containing synthetic rubber or phenolic resin. The solvent adhesives are applied to both surfaces and the solvents allowed to evaporate before the parts are joined. Recommended epoxies are the anhydride-cured and amine-cured types. Also suitable is a two-component, polyamide-modified epoxy compound. Other adhesives that provide adequate bond strength to treated polyolefins include styrene-unsaturated polyester and solvent-type nitrile-phenolic (15).

Ionomer: Adhesives recommended for duPont's SURLYN® ionomer are epoxies and polyurethanes.

Nylons (Polyamides): There are a number of nylon types, but the most important and most widely used is nylon 6/6. The best adhesives for bonding nylon to nylon are generally solvents. Various commercial adhesives, especially those based on phenol–formaldehyde (phenolics) and epoxy resins, are sometimes used for bonding nylon to nylon, although they are usually considered inferior to the solvent type because they result in a brittle joint. Adhesives recommended include nylon–phenolic, phenolic–nitriles, nitriles, neoprene, modified epoxy, cyanoacrylate, modified phenolic, resorcinol–formaldehyde, and polyurethane. Bonds in the range of 250–1000 psi (1.7–6.9 MPa) have been obtained with solid nylons (8) (13).

Polyetherimide: A wide variety of commercially available adhesives can be used in bonding polyetherimide to itself or to dissimilar materials. Among these are polyurethane [(cure at RT to 302°F (150°C)], RTV silicones, hot melts (polyamide types) curing at 401°C (205°C) and epoxies (non–amine type, two–part) (12).

Polybutylene Terephthalate (PBT): Commercial adhesives recommended include modified epoxies, cyanoacrylates, acrylics, polyurethanes, silicone, and polyesters.

Polysulfone: A number of adhesives have been found useful for joining polysufone to itself or to other materials. These include 3M Company's EC 880 solvent–base adhesive, EC 2216 room–temperature–curing epoxy two–part paste, Bloomingdale Division, American Cyanamid Company BR–92 modified epoxy with DICY curing agent, or curing agent "Z" (both spreadable pastes), vinyl–phenolics, epoxy–nylons, epoxies, polyimide, rubber–based adhesives, styrene polyesters, resorcinol–formaldehyde, polyurethanes, and cyanoacrylates. The EC 880, EC 2216, and the two BR–92 adhesives are recommended by the polysulfone manufacturer, Union Carbide (16) (17).

Thermosetting Foam Substrates: Most thermosetting plastics are not particularly difficult to bond. Obviously, solvent cementing is not suitable for bonding thermosets to themselves, since they are not soluble. In some cases solvent solutions can be used to join thermoplastics to thermosets. In general, adhesive bonding is the only practical method of joining a thermoset to itself or to a non–plastic material. Epoxies or modified epoxies are the most widely used adhesives for thermosets (1).

Polyurethanes: Rigid urethane foam can be adhered to most materials through the use of adhesives. In this manner the foam can be bonded to glass, metals, gypsum board, plastics, paper, wood and brick. Hot melts (not over 250°F melting temperature) may be used, along with solvent contact adhesives which can be flash–dried to permit rapid bonding of the foam. Pressure–sensitive rubber emulsion adhesives may also be used, but they have the disadvantage of being considerably slower–drying than the rubber solvent contact adhesives. Solvents in solvent contact adhesives must be removed by evaporation before the adhesive joint is completed because they cannot evaporate through the foam. For high–temperature applications thermosetting adhesives, such as polyesters or epoxies, must be used. Other thermosetting adhesives used include phenolics, resorcinol, resorcinol–phenolic, internal–setting asphalt, mortar modified with additive, and mineral cements. Flexible polyurethane foams can be bonded with butyl, nitrile and polyurethane adhesives (18).

Epoxies: For maximum adhesion to epoxies, epoxy adhesives with primers are used. In general, the curing temperature should be as high as possible, allowing for the distortion of temperature. In this way maximum strength and heat resistance are obtained. Fast–bonding nitrile–phenolics with curing resins can give excellent bonds if cured under pressure at temperatures of 300°F. Bonds of lower strength can be obtained with most rubber–based adhesives. Other adhesives used are: modified acrylics, polyesters, resorcinol–formaldehyde, phenol–formaldehyde, polyvinyl formal–phenolic, polyisobutylene rubber, polyurethane rubber, neoprene rubber, melamine–formaldehyde, silicone and cyanoacrylates (1).

Polyester: Adhesives used include neoprene or nitrile–phenolic, epoxy, epoxy–polyamide, phenolic–epoxies, polyesters, modified acrylics, cyanoacrylates, polyurethanes, butyl rubber, polyisobutylene, neoprene, and polymethylmethacrylate (1).

Phenolic: Adhesives recommended are neoprene and urethane elastomer, epoxy and modified epoxy, phenolic–polyvinyl butyral, nitrile–phenolic, polyester, cyanoacrylates, polyurethanes, resorcinols, modified acrylics, polyvinyl acetate, and urea–formaldehyde (1).

Silicone: Silicone resins are generally bonded with silicone adhesives, either silicone rubber or silicone resin (1).

Urea–Formaldehyde: Adhesives used are epoxies, nitrile–phenolics, phenol–formaldehyde, resorcinol–formaldehyde, furan, polyesters, butadiene–nitrile rubber, neoprene, cyanoacrylate, and phenolic–polyvinyl butyral (1).

Syntactic Foams: Adhesives should be selected based on the resin matrix, which is usually *epoxy* or *phenolic* (18).

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