Instructions for Casting and Contouring PhotoStress® Sheets

1.0 Introduction

The PhotoStress® method is a practical and versatile technique for experimental stress analysis. The method is particularly applicable to the complex three-dimensional configurations generally found in actual mechanical equipment, structural members, and machine components. The principal advantage of the PhotoStress method derives from the fact that it is a full-field technique—capable of showing the entire stress distribution over the surface of a part and thus highlighting the regions where the stresses are greatest. The direction of principal stresses, stress magnitudes (tangent to all free boundaries or edges), and maximum shear stresses can be determined quickly and easily. With proper instrumentation, individual principal stresses can be determined at locations removed from free boundaries and edges. Tech Note TN-702, "Introduction to Stress Analysis by the PhotoStress Method," presents a more complete treatment of the principles of the PhotoStress method.

Knowledge of the coating thickness is necessary if quantitative strain measurements are to be established. The contoured sheet technique described here will produce coatings of measurable thickness for quantitative strain analysis on irregularly shaped parts.

Contouring is best accomplished in a reasonably clean area at ambient temperature between 65°F [18°C] and 85°F [30°C].

Precautions should be taken to avoid or minimize:

- direct sunlight or direct radiant heat
- extreme drafts of hot or cold air
- dust or particle contamination
- moisture (rain or direct spray)
- contaminants in general

The following procedures present an organized approach that will lead to a successful contouring operation. For consistent success, the instructions given here should be followed. The procedure can be divided into six principal steps:

- Preparing the casting plate
- Preparing and pouring the plastic resin and hardener
- Polymerization cycle
- Removing these mi-polymerized sheet from the casting plate
- Contouring the sheet to the test-part surface
- Removing the cured sheet from the test part.

In this application note, each step is treated individually and a general chronological order is implied. All materials and supplies referred to have been carefully selected to

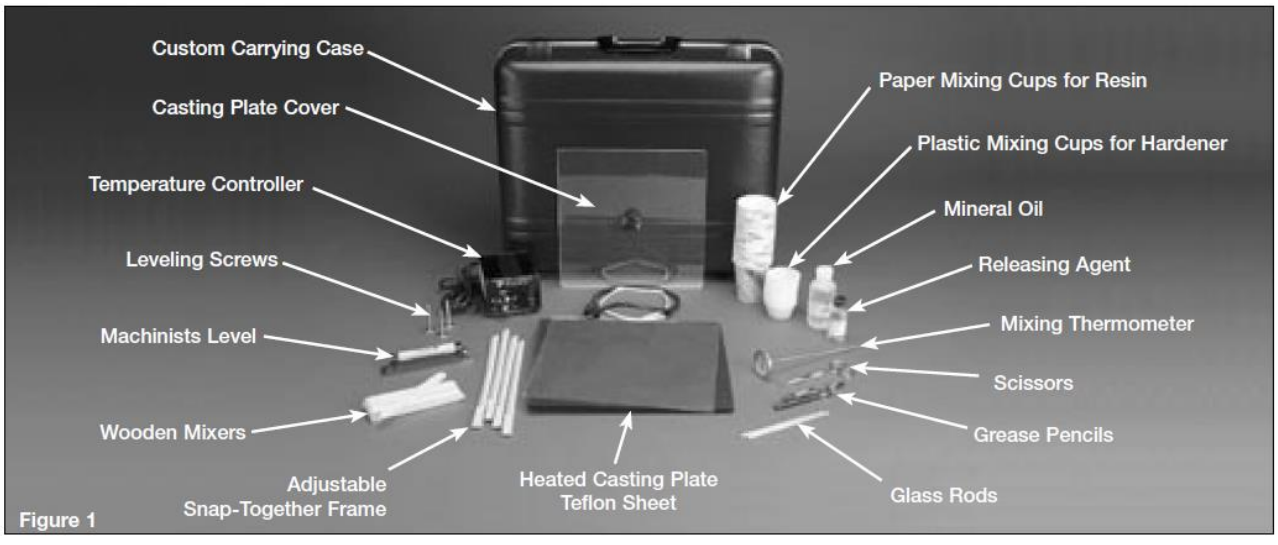


Figure 1

produce high-quality contourable PhotoStress plastic coatings. They are readily available either in kit form (Figure 1) or as individual items. The contouring procedures described here were developed with respect to these particular materials and substitutions are not recommended. (See Document 11222 for materials.)

In order to obtain a close fit between the contoured plastic coating and the test part, it is necessary to treat the surface to be coated prior to contouring the soft plastic.

If the structure is cast, forged, welded, or painted, remove all foreign matter such as paint, scale, rust, oxide or weld spatter. This should be done by hand or disc sanding, grit blasting, wire brushing or any other convenient method. Rough initial degreasing is recommended. Final cleaning will be done prior to bonding the fully cured plastic coating [see Section 2.1 in Application Note B-223 (Document 11223)]. If the structure is porous, a pre-coat of adhesive may be required to smooth out the surface for contouring. See Application Note B-223, Section 3.5.


Figure 2

2.0 Preparing the Casting Plate

2.1 Work Table

Place the Model 012-1H temperature-controlled casting plate on a rigid table. If the plate is dirty, it may be cleaned with a gauze sponge and isopropyl alcohol (Figure 2). Connect the temperature sensor (white cable), and the power cord (black cable) from the casting plate to the temperature controller (Figure 3).

2.2 Leveling the Casting Plate

Insert the three leveling screws into the casting plate. Carefully level the plate in two perpendicular directions with the machinists level (Figure 4).

2.3 Warming the Casting Plate

During the casting process, the temperature of the casting plate is a critical factor in the production of high-quality contourable plastic sheets. For optimum results, the casting plate should be heated to within a prescribed

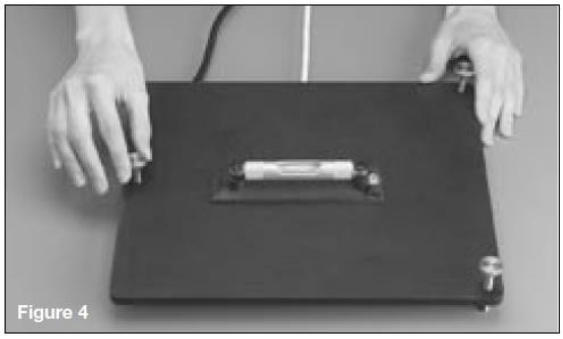
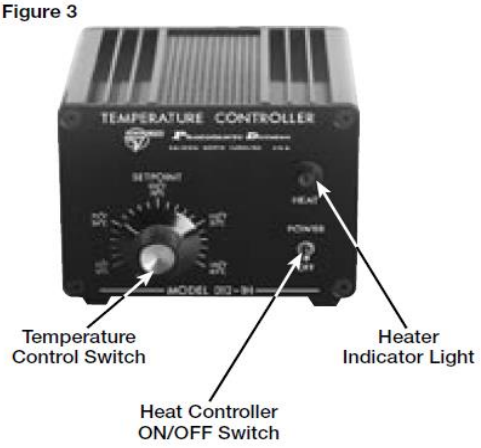
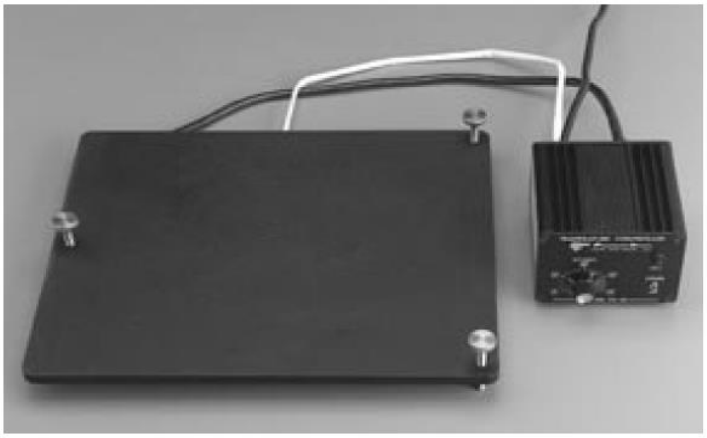


Figure 4

Figure 3





temperature range (varying with the type of PhotoStress plastic in use) prior to pouring the resin. Preheating to the specified temperature aids the flow-out of the resin on the casting plate, reduces humidity effects during curing, and significantly improves the surface quality of the cast sheet for contouring.

The Model 012-1H Casting Plate, with its integral surface heater and thermostatic controller, provides a uniform and closely regulated temperature over the entire plate area. To warm the casting plate, proceed as follows (see Figure 3):

1. Set the temperature control switch on the controller to the desired casting plate temperature for the particular PhotoStress plastic being used. (See Coating Materials chart below for recommended temperatures.)

2. Set the controller power switch to ON.

3. As the temperature of the casting plate begins to rise, the heater indicator light will be illuminated until the set temperature has been reached. The heater light will then "flicker" on and off as the pre-set casting plate temperature is being maintained.

4. Let the casting plate warm up for at least 20 minutes before applying the Teflon® carrier (see next section).

2.4 Placing the Teflon Carrier

The carrier* is a thin Teflon film that assists in transferring the coating from the casting plate to the structure to be tested.

Remove one Teflon carrier from its envelope, being careful to handle it at the edges of the sheet. Place the carrier on the casting plate (Figure 5 on page 4), and let it warm for 5 minutes. With a dry gauze sponge, wipe the carrier onto the casting plate to remove any air bubbles trapped underneath.

®Registered trademark of DuPont.
*Teflon carrier sheets are disposable. Order from Micro-Measurements.

PhotoStress Coating Materials For Contouring Application

Resin Type	PL-1	PL-2	PL-3	PL-6	PL-10
Hardener	PLH-1	PLH-2	PLH-3	PLH-6	PLH-10
Handling Data					
Amount of Hardener (pph)*	20	100	150	70	25
Casting Plate Temperature °F [°C]**	90-110 [32-43]	115-125 [46-52]	150 [66]	125-135 [52-57]	90-110 [32-43]
Mixing Temperature °F [°C]**	90-110 [32-43]	115-125 [46-52]	130-135 [52-57]	125-135 [52-57]	90-110 [32-43]
Pouring Temperature °F [°C]	125-130 [52-55]	125-135 [52-57]	140 [60]	125 [50], Typical	125-130 [52-55]
Approximate Time on Casting Plate† to contourable stage (ready to remove from mold and shape)	1.5 hr	2-3 hr	1 hr	2.5 hr	2 hr
Time to Complete Polymerization†	18-24 hr	18-24 hr	24 hr	12-18 hr	18-24 hr
FINISHED MATERIAL DATA, TYPICAL (Precise Values Determined by Calibration)					
"K" Factor	0.10	0.02	0.006	0.001	0.08
Modulus of Elasticity, psi [GPa]	$0.42(10)^6$ [2.9]	30,000 [0.21]	2,000 [0.014]††	100 [0.0007]††	$0.42(10)^6$ [2.9]
Maximum Elongation	3-5%	50%	> 50%	>100%	3-5%
Poisson's Ratio	0.36	0.42		0.50	0.36

* Parts per hundred by weight.
** Proper selection of the casting plate temperature, and beginning mixing temperature of the resin/hardener combination, will depend on the overall size and thickness of the sheet to be cast. For thick sheets, nominally 0.080 to 0.120 in [2.0 to 3.0 mm], lower temperatures should be selected. For thinner sheets, higher temperatures can be selected. The selection criteria will become more obvious after some experience has been gained.
† Typical for room temperature of 72°F [22°C]. Polymerization time is shortened by higher temperature and/or thicker sheets. Thin sheets and lower temperatures lengthen polymerization time.
†† After one minute at constant strain.

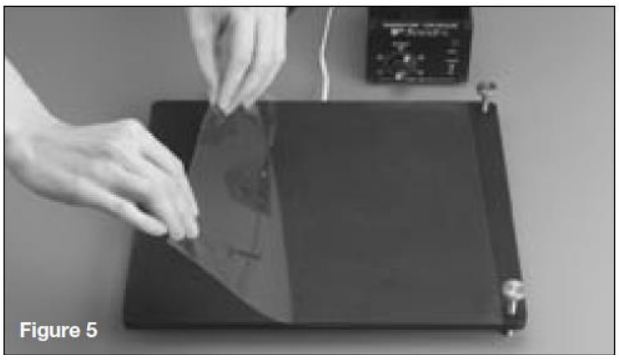


Figure 5

2.5 Preparing and Assembling the Snap-Together Frame

The snap-together frame is made of silicon rubber and should be cleaned using a gauze sponge and isopropyl alcohol. If the frame was previously used, ensure that no solid pieces of plastic remain stuck to it. A thin film of releasing agent should be applied to the bottom and inside edge of each piece of the frame (see insert in Figure 6). This is done using a gauze sponge lightly soaked with release agent.

Important Note: Without a thorough application of releasing agent, the rubber frame will stick to the plastic liquid and render it useless.

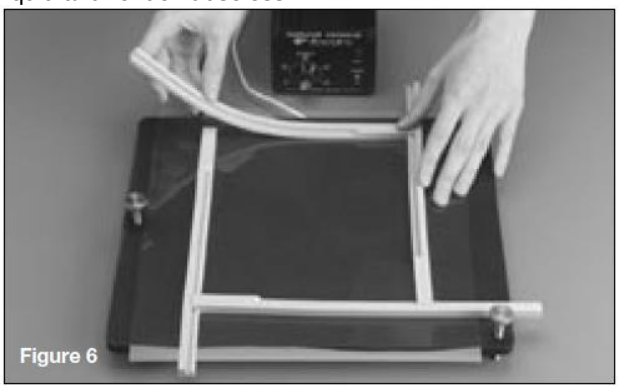


Figure 6

Assemble the frame on the Teflon carrier to the desired size (see Figure 6). The frame dimensions should be at least 0.25 in [6 mm] larger on all sides than the desired size. This dimensional increase compensates for the meniscus that forms during polymerization of the liquid plastic. If calibration is required, an additional 1 in [25 mm] should be added to either the length or width. This increase provides for the 1-x-3-in [25-x-76-mm] calibration strip used with the Model PSC-1 Calibrator. After assembling the snap-together frame, recheck the level of the casting plate as in **Section 2.2**. Cover the plate with the plexiglas cover to protect it from dust or other contaminants.

3.0 Preparing and Pouring the Plastic

If the resin and/or hardener were kept refrigerated*, they should be brought to room temperature prior to opening the containers. To accelerate warming, the hardener and resin can be placed in an oven at 100°F [40°C], or on top of the casting plate set to the same temperature. To prevent humidity condensation, the lids on the containers should be loosened but not removed. If paper cups were used, cover them with aluminum foil. If the hardener was not refrigerated or has been stored for an extended period, it is important to check its appearance. If it is cloudy, or contains foreign particles, it should be discarded in favor of a new bottle.

3.1 Determining Amount of Resin and Hardener

The total amount (weight) of plastic is determined by:
$W = d \times A \times t$
where: W = total amount needed (in gm)
d = plastic density, 18.5 gm/in3 [1.13 gm/cm3]
A = area of sheet to be cast (width x length)
t = desired thickness of sheet

Example: For a sheet 7 x 8 x 0.10 in thick [180 x 200 x 2.50 mm], the total amount of plastic required is:

$W = 18.5 \times 8 \times 7 \times 0.10 = 104$ gm
[$W = 1.13(10)–3 \times 180 \times 200 \times 2.50 = 102$ gm]

The amount of hardener is indicated in “parts per hundred,” or “pph,” by weight. For example, 20 pph of hardener means 20 gm of hardener for 100 gm of resin. Refer first to the Coating Materials chart on page 3 to determine the proper proportion of hardener to resin. Then, continuing with the above example, for a total of 104 gm of Type PL-1 plastic, the resin and hardener calculations are made as follows:

$$\text{PL-1 Resin: } 104 \times \frac{100}{100+20} = 86.7 \text{ gm}$$

$$\text{PLH-1 Hardener: } 104 \times \frac{20}{100+20} = 17.3 \text{ gm}$$

$$104 \text{ gm total}$$

3.2 Weighing and Warming the Resin and Hardener

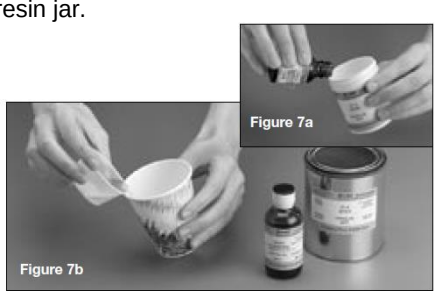
Six-ounce [170-ml] plastic-coated cups are recommended for mixing the resin and hardener (see Figure 1). Avoid using uncoated or wax-coated paper cups, or shallow, large diameter containers. For weighing purposes, any scale with a resolution of 0.01 gm is acceptable. Remember to account for the true weight of the empty cup.

*Hardener should be stored at 40°F [5°C].

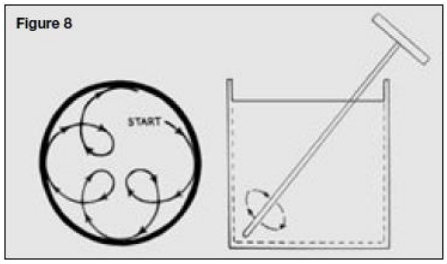
Prior to adding the hardener to the resin, warm them to the temperature indicated in the Coating Materials chart on page 3. Intermittent, gentle stirring with a stem thermometer will help to maintain uniform temperature during warming, as well as check the temperature. Warming the resin lowers its viscosity and facilitates a more uniform mix with the hardener. Warming can be accomplished by placing the resin and hardener containers in an oven set to the recommended mixing temperature, or on a heated casting plate. It is recommended that the containers be loosely covered during warming. This can be done using aluminum foil.

3.3 Mixing the Hardener and Resin

When the resin and hardener reach the temperature indicated in the Coating Materials chart, pour the hardener into the resin, being careful to avoid the introduction of air bubbles (see Figure 7). **Note:** When mixing an 80-gm preweighed kit, pour all the hardener into the resin jar.



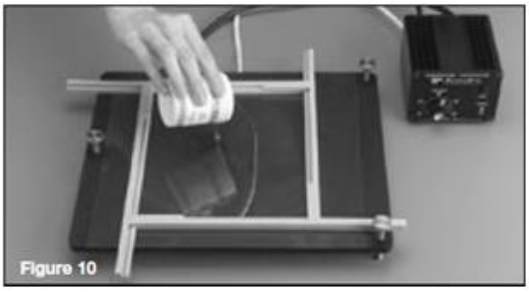
Mixing the resin and hardener is a crucial step in obtaining a quality contoured sheet. It is essential to stir thoroughly, but slowly. Do not use a whipping action, which will introduce air bubbles. Stirring to produce a clear, non-streaking mixture is best accomplished using the technique illustrated in Figure 8. Non-uniform mixing will most likely occur at the inside surfaces of the mixing container. The stem thermometer should be brought into line contact with the sides of the container several times during mixing. Line contact should be maintained while making several passes around the inside of the container.



The temperature increase produced by the exothermic chemical reaction during mixing is easily observed on the stem thermometer (Figure 9). Continue stirring until the pouring temperature is obtained. (See Coating Materials chart on page 3 for correct pouring temperatures.) The mixed plastic is now ready to be poured onto the previously prepared casting plate.

3.4 Pouring

Remove the cover from the casting plate and pour the plastic. When pouring, hold the mixing cup close to the casting-plate surface and pour gently (Figure 10). This procedure will minimize bubble formation. While pouring, it is advisable to move the cup to form an “X” or “S” pattern, which will improve flow to fill the mold. This is particularly advantageous when pouring thinner sheets (0.065 in [1.5 mm] or less). Thin sheets do not flow out and cover the casting plate as freely as thicker sheets. The final portion of the plastic should be poured along the outside boundary close to the frame.



DO NOT scrape excess plastic from the cup sides and bottom onto the casting plate, as these are areas where a non-uniform mix is most likely to occur. As illustrated in Figure 11 on page 6, the stem thermometer or a wooden tongue depressor may be used to help spread the plastic over the entire plate surface (the liquid will level with time). Place the cover over the poured sheet to protect it from dust and other foreign matter during polymerization and switch the temperature controller off.

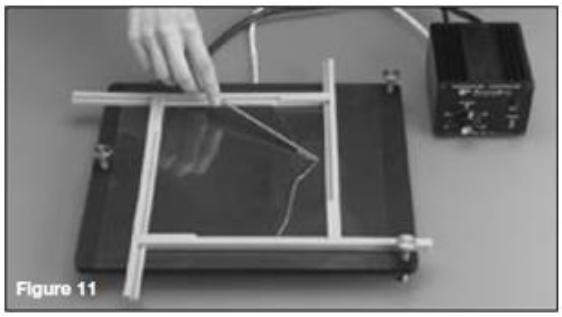


Figure 11

If air bubbles are present, wait a few minutes and burst them with a dental probe or a similar pointed object. Replace the cover over the casting plate.

4.0 Polymerization Cycle

The liquid plastic will pass through several steps before arriving at the desired semi-polymerized condition for contouring. At the contouring stage it is semi-stable, but also highly flexible and formable. It has no geometric or memory and can be readily contoured to conform to both simple and compound curved surfaces. The time required to reach this contourable state is dependent upon the:

- ambient room temperature
- casting-plate temperature
- type of plastic
- thickness
- plastic temperature when poured onto the casting plate

These parameters make it difficult to accurately predict the time span between pouring and removal of the sheet from the casting plate. However, guidelines exist that make it possible to recognize when the sheet is ready for contouring. The time span is shortened with higher temperatures and/or thicker sheets; and is longer at lower temperatures and when casting thinner sheets. Information in the following table should be used only as guidelines when casting Type PL-1 and PL-10 liquid plastics.

Conditions	**PL-1**	**PL-10**
Room Temperature	72°F [22°C]	72°F [22°C]
Casting Plate Temperature	100°F [38°C]	100°F [38°C]
Plastic Temperature When Poured	125°F [52°C]	125°F [52°C]
Sheet Thickness	0.090 in [2.3 mm]	0.10 in [2.5 mm]
Time Until Contourable	1.5 hr (typical)	2 hr (typical)

The following sections present a chronological sequence of the states of polymerization leading to the time when the partially polymerized sheet is ready for contouring.

4.1 Early Stage of Polymerization

Figure 12 shows the early stage of polymerization, with the plastic in a viscous liquid state. When probed, the plastic still behaves as a liquid. It adheres to the probe and no dent is formed; plastic can be pulled up with the probe.

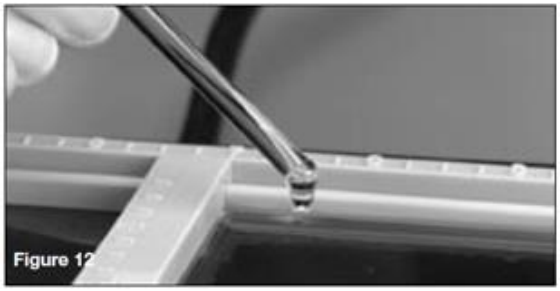


Figure 12

4.2 Second Stage of Polymerization

The plastic approaches a gel state and adheres to the probe. The surface is easily deformed with little or no pressure on the probe and feels very sticky to the touch (Figure 13).

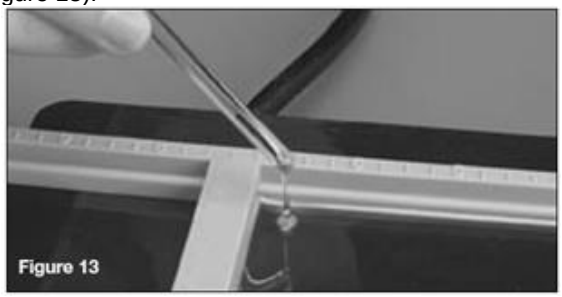


Figure 13

4.3 Approaching the Contourable Stage

This is a critical state, and care should be taken when following the next set of instructions.

Using a plastic probe or a wooden tongue depressor, apply light to moderate pressure to a corner of the cast plastic (see Figure 14). If a dent can easily be formed and the probe does not stick to the plastic, it is time to attempt to remove one section of the rubber frame. Carefully try to separate one section of the rubber frame at one corner, using fast whipping movements (see Figure 15). If the rubber frame **easily** separates from the cast plastic, keep pulling until it is removed from the casting plate. This

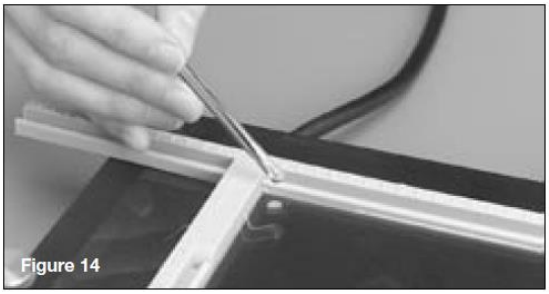


Figure 14

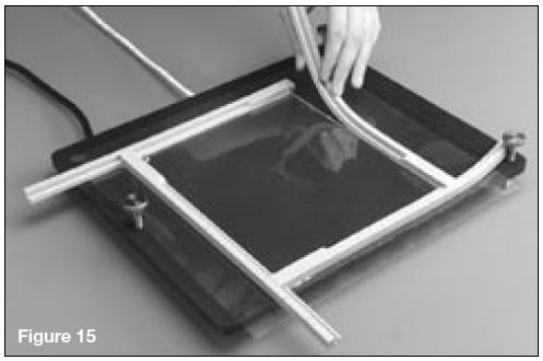


Figure 15

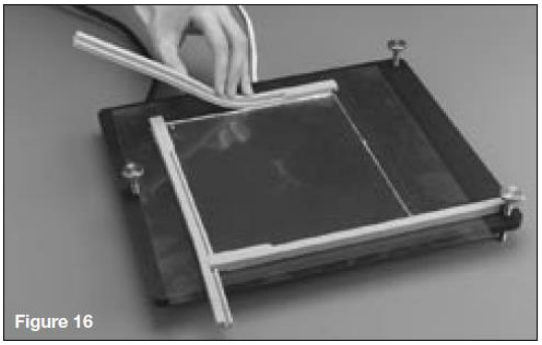


Figure 16

last procedure may require holding down the Teflon carrier at the same corner. In the same manner, remove the adjacent rubber frame section (see Figure 16).

Now that one corner of the cast plastic is free of the rubber frame, it is easy to lift the Teflon carrier and cast plastic together at that location. At this stage, the cast plastic is stable and will not flow, but it may not be ready for contouring.

Lift the Teflon carrier at the free corner until the cast plastic is about 1 in [25 mm] above the plate. With one hand, hold the Teflon carrier and, with the fingertip of the other, attempt to separate the cast plastic from the Teflon carrier. Curl about 1 in [25 mm] of the corner of the cast


Figure 17

plastic (see Figure 17) and lay the Teflon carrier back on the casting plate. If the curled corner has a tendency to collapse or sag to the surface of the plastic sheet, the plastic is too soft and not ready to be contoured. When the curled corner of the cast plastic reaches a stage when it has a tendency to fold back onto the Teflon carrier, the plastic is ready for contouring. Another test of readiness is to touch the underside of the cast plastic. If it feels dry (not sticky), it is ready for contouring. Determining when the plastic is at the desirable stage for contouring is subjective, but this will become apparent with a practice. Remove the other two rubber frame sections.

5.0 Removing the Semi-Polymerized Plastic Sheet From The Casting Plate

As noted previously in Section 1.0, the surface of the test part should be prepared well in advance of sheet removal for contouring. All foreign matter such as paint, scale, rust, oxides, weld splatter, etc., must be removed (see Application Note B-223). Surface preparation prior to contouring consists of first degreasing and cleaning the surface with acceptable solvents, and then applying mineral oil to the cleaned surface.

5.1 Lifting the Cast Plastic Sheet

Lubricate the scissors blades and the surface of the structure with mineral oil. The top surface of the cast plastic sheet should also be coated with mineral oil (Figure 18). This last step should be done carefully, avoiding pressure to the cast plastic. Wipe your hands to remove any traces of mineral oil.

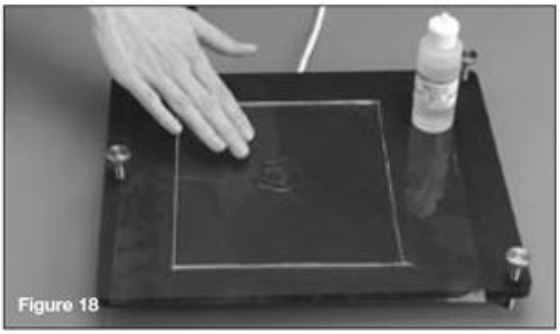


Figure 18

Hold one free end of the Teflon carrier and lift it slowly (see Figure 19). Continue lifting until the Teflon carrier with the cast plastic sheet are completely free of the casting plate. Immediately place the palm of your other hand under the Teflon carrier (see Figure 20). If a calibration strip is required, use the scissors to first remove 0.25 in [6 mm] from one edge of the cast plastic sheet (see Figure 21). Next cut a strip of slightly more than 1 x 3 in [25 x 76 mm] and place it flat on the casting plate. These cuts are done by cutting both the Teflon carrier and the cast plastic (see Figure 22).

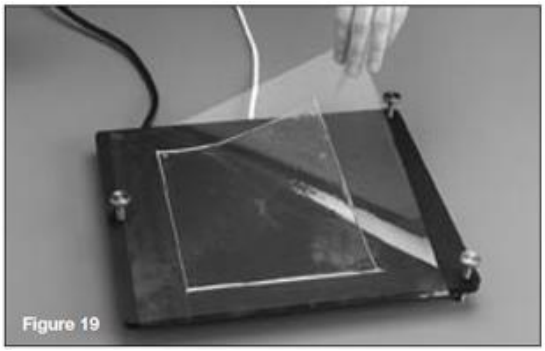


Figure 19

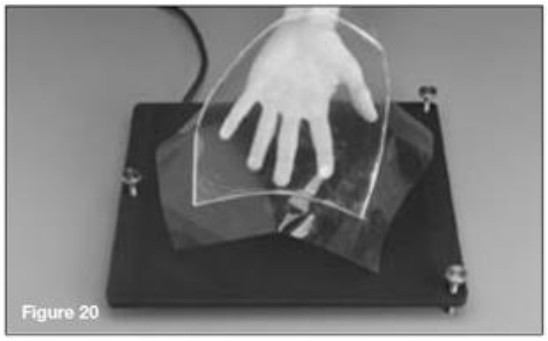


Figure 20


Figure 21


Figure 22

6.0 Contouring

Two situations exist that require different contouring techniques.

6.1 Use of the Complete Cast Plastic Sheet

Important Note: Always use a larger plastic sheet than the area to be coated. Overhang material can be trimmed later.

While the Teflon carrier with the cast sheet rests on the palm of your hand, take hold of a free end of the Teflon carrier and lift it in the air. Take hold of the other free end of the Teflon carrier with your free hand (see Figure 23). Using the Teflon carrier as a transfer vehicle, move the plastic sheet to the structure to be coated. Carefully place the oiled side of the plastic sheet onto the structure (see Figure 24). Smooth the plastic sheet onto the structure surface by lightly moving your fingers over the Teflon carrier. Once the plastic sheet is positioned over the area to be coated, strip the Teflon carrier from the plastic sheet.

Using your fingertips, spread a small amount of mineral oil over the plastic sheet and, with light pressure and a rubbing motion, work the plastic sheet into place. **Do not push, stretch, or press the plastic into place.** Do not leave large sections of the plastic sheet hanging over the edge of the structure. As soon as most of the curved areas are covered, use oiled scissors to trim any overhang,

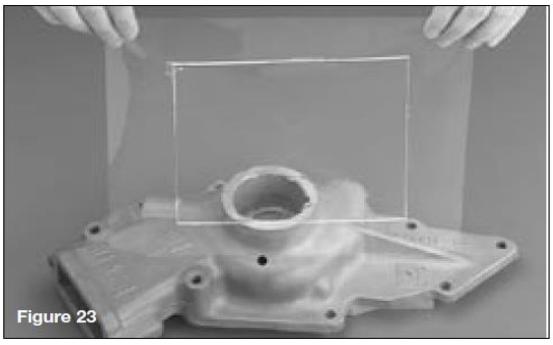


Figure 23

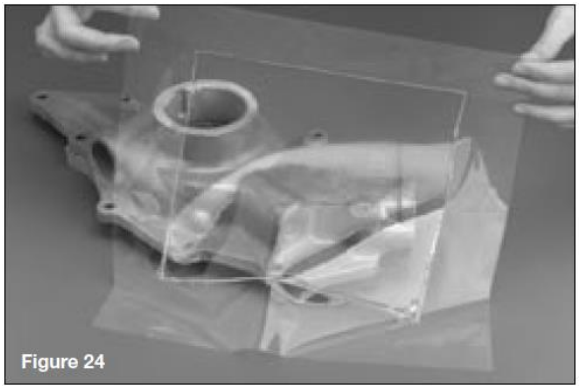


Figure 24

leaving approximately 1/8 in [3 mm] extending beyond the edge of the structure. Final trimming can be done after full polymerization (see Application Note B-223). If small air pockets form under the plastic, carefully lift the edge of the plastic sheet up to the air pocket and, with oiled fingertips, smooth back the plastic, pushing the air pocket to the edge of the sheet.

Note: In the case of a flat surface or a single curvature (such as a pipe), the Teflon carrier may be left in place, and removed after full cure.

Figure 25 shows the application of a plastic sheet to a typical complex structure.


Figure 25

Note: The working time available for contouring the plastic after removal from the mold is approximately 10 to 20 minutes. After this time, the plastic will begin to stiffen, making it more difficult to manipulate and cut with scissors. After contouring is complete, the formed sheet will retain its shape while final polymerization takes place. If the plastic has been contoured to a vertical or overhead surface, it may be necessary to mechanically hold it in place for complete cure. If so, this may be done with a few pieces of pressure-sensitive tape. However, under no circumstances should the plastic be subjected to a clamp-type pressure, as this will introduce undesired birefringence in the plastic that will be retained after full polymerization.

6.2 Using Small Pieces of the Cast Plastic Sheet

In some instances it is necessary to use smaller plastic pieces rather than the full cast sheet. Since the Teflon carrier is an important transfer vehicle, it is recommended that the full cast sheet first be cut in half. Each half can then be cut into smaller strips, leaving each strip with a piece of Teflon carrier extending beyond the cast plastic (see Figure 26a and b), thus allowing the user to handle the plastic by holding the Teflon carrier.

The rest of the instructions are similar to those in **Section 5.1**, but here we are dealing with small pieces of plastic rather than a full cast sheet.

6.3 Final Polymerization

After the plastic has been contoured to the shape of the test part, it must be allowed to finish polymerizing to a full cure for an additional 18 hours (or longer for temperatures below +75°F [+24°C]) before removing it for trimming, cleaning and eventual bonding. At the end of this 18-hour period, or anytime thereafter, the plastic will be hard, and of the same size and shape as the surface of the test part.


Figure 26a

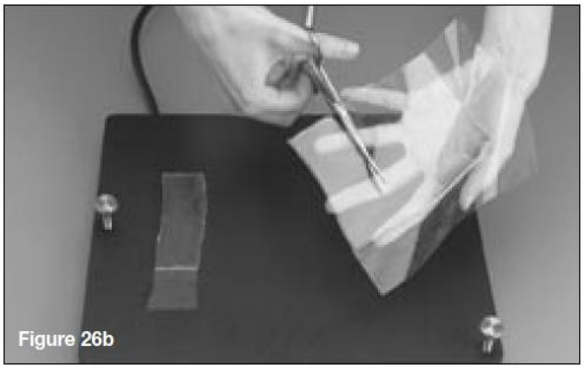


Figure 26b

7.0 Removing the Cured Sheet from the Part

The hardened sheets can be removed by carefully raising one edge or corner. This breaks the surface adhesion introduced by the mineral oil, and the sheet will lift off freely. It sometimes happens that, after hardening, a contoured sheet has captured itself on the part and cannot be removed without some mechanical assistance. In many instances, release can be accomplished by simply filing or sanding those edges of the plastic that have inadvertently been shaped around the edge of the part, and "locked" it in place. In more extreme cases, the captured sheet may need to be cut into two or more sections before it releases. Small hand-held routers with fine point-shaped cutters are convenient for separating the captured sheet.

The sheet is then ready for final preparation for bonding in accordance with the instructions in Application Note B-223. Figure 27 shows the final results of the contoured sheet first illustrated in Figure 25.

Figure 27

CAUTION

Epoxy resins and hardeners may cause dermatitis or other allergic reactions, particularly in sensitive persons. The user is cautioned to: (1) *avoid contact with either the resin or hardener;* (2) *avoid prolonged or repeated breathing of the vapors;* and (3) *use these materials only in well-ventilated areas.* If skin contamination occurs, thoroughly wash the contaminated area with soap and water immediately. In case of eye contact, flush immediately and secure medical attention. Rubber gloves and aprons are recommended, and care should be taken not to contaminate working surfaces, tools, container handles, etc. Spills should be cleaned up immediately. For additional health and safety information, consult the Safety Data Sheet.

Supplemental instructions for each type of liquid plastic are provided with the liquid plastic package.

Refer to the publications below for detailed information on:

Tech Note TN-704, "How to Select PhotoStress Coatings."

"PhotoStress® Coating Materials" (Document 11222).

Application Note B-223 (Document 11223), "Instructions for Bonding Flat and Contoured PhotoStress Sheets."