

TUFFAK®

Polycarbonate Sheet



FORMING AND FABRICATION

ALTUGLAS
INTERNATIONAL
ARKEMA GROUP



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INTRODUCTION

Tuffak® brand polycarbonate sheet, manufactured by Altuglas International, is used in glazing, vacuum forming and fabrication. Polycarbonate sheet is the toughest transparent sheet available.

This manual helps familiarize users with techniques for vacuum forming, fabricating and assembling Tuffak sheet.

FORMING

Tuffak sheet can be thermoformed, cold formed and brake formed to shape in one-piece configurations. One-piece configurations are important because they help retain the original tough integrity of the material. Thermoforming is divided into High Temperature and Low Temperature sections. Different conditioning and handling procedures are required at these two temperature ranges.

High-temperature thermoforming from 370°F to 415°F is required for deep draws or sharp detail. Dry sheet (less than 0.04% moisture) is essential to the success of forming without incurring bubbles. Low-temperature thermoforming from 350°F to 370°F can be used for simple drape forming. Pre-drying is not necessary at these temperatures.

Cold forming is used when a retainer frame can be used to hold Tuffak sheet to a shape. Flex forming is cold forming done at elevated temperatures from 300°F to 340°F for a few hours until the shape is set. Brake forming is used for making a straight bend and eliminates high-temperature strip heating, which can cause warpage.

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HIGH-TEMPERATURE THERMOFORMING

Polycarbonate requires special techniques for forming and is different from most thermoplastic sheets in three important ways:

- It rapidly loses its rigidity at forming temperatures above 370°F.
- It has a very narrow high-temperature forming range of 370°F to 415°F.
- Entrained moisture can result in bubbling at high thermoforming temperatures.

FIGURE 1

Drying Time vs. Thickness in 250°F Oven — TUFFAK Sheet to Dry Sheet, Below .04% Moisture

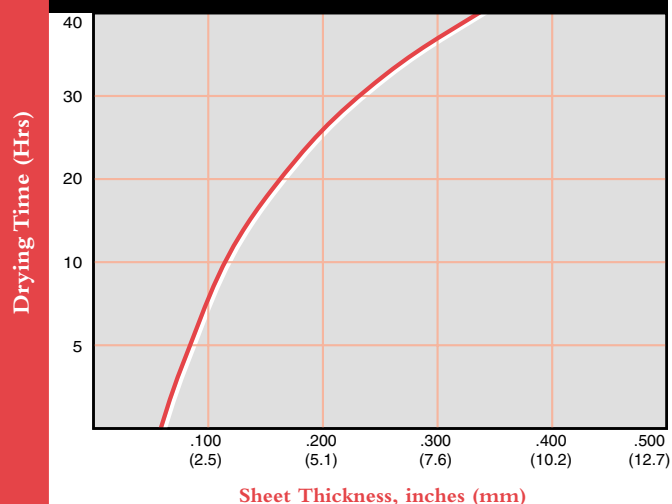
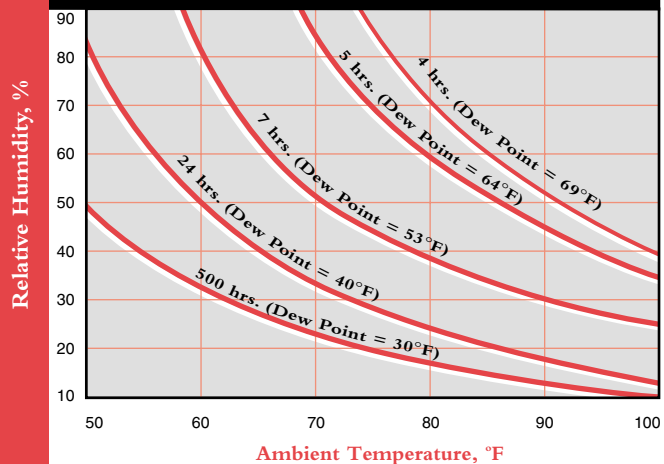


FIGURE 2

Moisture Reabsorption of Dry TUFFAK Sheet (Maximum Allowable Exposure Time at Various Ambient Conditions)



These differences affect the type of heating used for forming, the characteristics of the machine needed to form it, and the preconditioning procedures (drying) used.

Sheet conditioning

In very thin sheet (less than .060" thick), there is little concern about the moisture content of the sheet. Water vapor usually escapes to the surface before it develops a bubble in the hot sheet.

In thicker sheet, as little as 0.04% moisture can create enough pressure inside the very soft hot sheet to blow a permanent bubble inside. Most sheets have absorbed excessive moisture by the time they are received. Sheet must be dried in an oven to ensure that bubbling will not occur during thermoforming. To calculate the drying time, see Figure 1. After drying, the sheet can be formed successfully, even if held aside for a certain length of time, before it picks up enough moisture to start bubbling again. The rate of reabsorption of moisture (Figure 2) determines how long the sheet can be stored before bubbling recurs upon thermoforming and redrying is again necessary.

Dry sheet can be maintained indefinitely at a low moisture level by storing it in a room with dry air at a dew point of 0°F to 20°F.

Heating methods

The traditional method of heating thermoplastic sheet in a hot air oven is impractical for heating polycarbonate sheet, because the rapid stiffening rate demands fast action to minimize cooling. Only about six seconds are allowed between heating and forming on .118" sheet, whereas .236" sheet can be handled for about 10 seconds. An infrared oven (gas-fired or electric) is the accepted heating method.

Electric is safer, more controllable and requires less maintenance, but gas may be dramatically cheaper than electricity in some areas.

Single-sided heating is sufficient for sheet up to .080" thick, but double-sided heating is recommended for heating thicker sheet to minimize heating time. The forming temperature (for best vacuum detail) for Tuffak sheet is 415°F (213°C). Surface temperature is best monitored with a paper thermometer. Temperature can also be determined by the amount of sag,



which is related to the modulus of the hot sheet. An electric eye is set at the proper distance below the clamping frame so it will automatically set the machine in motion when the center of the hot sheet drops into the light beam. Sag is relatively independent of thickness. See Figure 3 for the relationship of sag to sheet dimension at optimum forming temperature.

Overall average sheet temperature is more important than surface temperature, because surface temperature does not consider the wide temperature gradient throughout the sheet.

A typical heating time for .118" sheet with percentage-on timers set for 20% on top and 37% on the bottom is about 3½ minutes. Increasing the timers to 25% and 50%, respectively, can reduce heating time up to 90 seconds.

Some skylights are made by sag forming using the natural sag of the sheet. Then a cold air blast freezes the shape. If the shape is not frozen, the sag will continue even when heat is removed.

Forming machine specifications

The thermoforming machine should have ample "daylight" (distance between clamping frame and mold) to allow for a deep sag, and have fast-operating platens to minimize cooling time.

It should have infrared heaters on the top and bottom with a moving oven (rather than moving frame) to prevent swaying of the sagged sheet. This enables the sheet to form while the oven is moving out of the way, and it prevents premature cooling.

Although percentage timers are commonly used to regulate the energy output of the bank of heaters, thermocouple-controlled heaters are more precise. Their separately controlled zones can be used to selectively heat areas of the sheet that are stretching and thinning too much. This method of controlling heat is more effective than screening or "shading," because screens lose their accuracy when the sheet sags. The clamping frame should also be heated to prevent warpage from differential cooling, especially if the flange is left on the part. This technique is widely used when working with skylights.

Thermoforming tooling

The higher thermoforming temperatures needed for Tuffak sheet shorten the life of wooden molds. Wood molds, particularly pine and sappy woods, should be used only for prototypes. Aluminum is the best material for permanent molds. Aluminum must be maintained at 200°F to 210°F with an oil heat exchanger to prevent chill lines and other distortions. While epoxy and polyester molds last longer than wood molds, their heat transference is much poorer than aluminum, and they require long cooling cycles. Epoxy and polyester molds must be cooled to prevent high temperatures from destroying the surface. A 5° draft angle is recommended on all vertical surfaces to allow easy removal.

Oversized tooling should be designed to compensate for the 1/8"-per-foot shrinkage for female molds and 3/32" per foot for male molds.

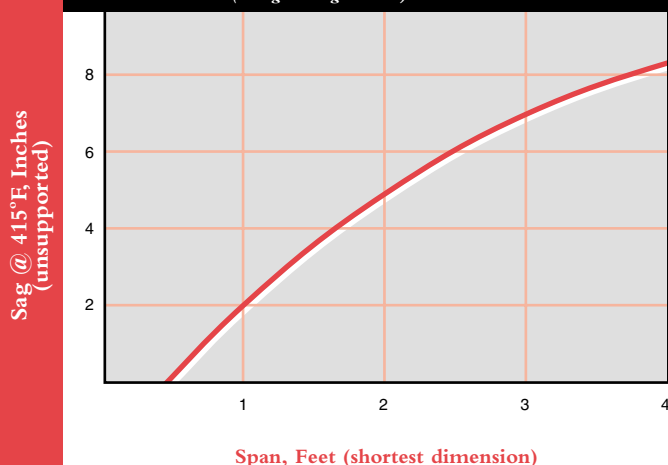
Thermoforming techniques

Tuffak polycarbonate sheet must be clamped on all four sides during heating to control the blank size.

Some thermoforming techniques rely on the plastic memory of the sheet. These techniques, which include vacuum snap back and bellows forming, are not appropriate for polycarbonate. Also, free-blown domes are difficult to form. Sag forming often yields better parts.

FIGURE 3

Determination of Optimum Forming Temperature of TUFFAK Sheet (Using the Sag Method)



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Troubleshooting Forming Problems

■ **Webbing**—Webbing is a common thermoforming problem caused by excess material. An air pillow is sometimes used to prevent sagging of the sheet during heating, which minimizes pre-stretching. However, this technique will not allow the sag method of determining sheet temperature and limits the heating source to one-sided heating, which takes longer. Take-up blocks and pushers are more effective methods of taking up excess material around the web.

■ **Mark-Off**—Use a temperature below 350°F, if possible. If this is not possible, apply a soft rubber coating to the mold surface or form the part out of material having a matte finish, keeping the matte side next to the mold.

■ **Bubbling**—Since Tuffak polycarbonate seldom degrades at thermoforming temperatures, bubbling is almost always caused by moisture in the sheet. When this condition is borderline, bubbling can sometimes be eliminated by heating faster, rather than having to pre-dry the sheet. A lower forming temperature also eliminates bubbling.

■ **Mold Hang-up**—Because Tuffak plastic forms to such fine detail, imperfections in the mold (such as undercuts) can lock the part to the mold. Use generous radii with adequate draft, smooth all surfaces, and do not use a mold (such as wood) that can easily chip out during thermal cycling at high temperatures. Also, remove the part from the mold as it cools.

■ **Tearing**—Tearing at the mold edge is sometimes caused by inadequate clearance between the frame and the mold. Hot sheet may stretch too much if a 1/2"–1" clearance is not allowed.

■ **Sheet Pulling Out of Frame During Forming**—Sheet pullout is usually caused by trying to form a sheet that has cooled below its forming temperature. After locking on clamping devices and the frames, heat the sheet to a higher temperature. The sheet will then form faster. If you are using a thicker sheet, the sheet will hold the heat longer.

■ **Warpage**—Do not cool the part for a long time on the mold. When the part cools to 250°F, remove it so air can be directed to both surfaces at the same time to even

the cooling process. Heated frames should also be used. To ensure a flat flange, frames should be heated to at least 250°F.

■ **Uneven Detail**—Uneven sheet temperature causes uneven forming detail. Check the temperature of the heaters and the spacing of the heaters from each other versus the spacing from the sheet. Do not bring the sheet closer than the heater spacing. Any air drafts originating from open doors can chill the sheet before it can be formed. Screen areas that are too hot and stretch too much.

LOW-TEMPERATURE THERMOFORMING

Low temperatures (350°F–370°F) are used to form single drape-formed shapes and optical parts with little forming required. At low temperatures, Tuffak sheet loses its rubbery nature, so it will not stretch. While Tuffak polycarbonate will not stretch at low temperatures, it can be formed to any shape a piece of paper can be formed to, such as a cylinder, cone or other drape-formable shapes. At lower temperatures, its modulus is so high it eliminates mark-off problems as long as the mold surface is softened with felt and sharp corners are eliminated.

Remember that 2–5% shrinkage takes place above the glass transition temperature of Tuffak sheet (which is below 300°F). Pre-drilled holes may be out-of-register after the forming operation.

Air ovens are recommended for low-temperature heating and forming, because closer temperature control prevents mark-off on optical parts.

COLD FORMING

Cold forming can be done with Tuffak sheet. A permanent frame is necessary to hold edges in shape, as long as stresses will not cause crazing. The minimum radius of curvature is 100t, where t = sheet thickness. For example, a 0.100"-thick face shield cannot have a radius tighter than 10"—unless it is first heated to 300°F (150°C) for about 10 minutes in an air oven. Cold forming is any forming done below a 300°F sheet temperature.



BRAKE FORMING AND STRIP HEATING

Strip heating requires pre-drying the sheet (as needed for thermoforming). It frequently results in warped bends due to differential shrinkage.

A combination of brake forming and strip heating is recommended to reduce warpage. In this case, the temperature of the strip heating element is reduced – by using a voltage regulator to produce about 80% of line voltage – to a surface temperature of about 500°F.

Although cold brake forming is common with thin sheet, thick sheet may crack when brake-formed cold. Thus, the combination of strip heating the sheet to 300°F–350°F and hand braking the material along the heated edge gives highly satisfactory bends. Sheet that is $\frac{3}{16}$ " can be heated single-sided, but thicker sheet should be flipped at mid-heating time, or use two-sided heating.

CAUTION: FORMING-RELATED PROPERTIES

Service Temperature – The maximum continuous service temperature (MCST) of Tuffak sheet (before an objectionable shape change occurs) is a measure of the stability of a *formed* part in service. The higher the forming temperature (up to 415°F), the higher the MCST, because of the lower forming stresses. Thus, the MCST of formed Tuffak parts varies from 230°F (110°C) at low forming temperatures (unannealed) to 250°F (120°C) at high forming temperatures.

Tuffak polycarbonate parts that have been formed at low temperature without being annealed have a high craze potential if exposed to crazing agents. The probability that a liquid cleaning agent or solvent may cause crazing in a thermoformed part depends on the amount of stress in the part.

F A B R I C A T I O N

MACHINING

All machining procedures commonly used with other plastics can also be performed on Tuffak polycarbonate. The following recommendations will help you optimize your operations.

Circular saws

The horizontal overhead panel saw gives a superior cut compared to table, portable, or under-the-table panel saws, at sheet thickness down to .015". The square and advanced (triple chip grind) 60-tooth 14" carbide-tipped blade (see Figure 4) is best. This saw eliminates the chatter and chipping caused by other saws due to "hold-down" of the blade action from above. In table or bench circular saws, severe chipping is noted on sheet thinner than .118". A narrower blade and the practice of setting the blade height no more than $\frac{3}{8}$ " above the sheet give a slightly improved cut. Using a -5° rake angle on the saw blade and a hold-down will eliminate the chipping.

If smearing occurs (from heat), check fence alignment and teeth sharpness. Hollow ground, carborundum or steel blades give inferior cuts. Portable saws give the poorest cuts because of their poor control and accuracy. They should be used only for rough cuts.

Band and reciprocating saws

Band saws frequently cause smearing at low speeds. Fewer teeth per inch minimize this problem. See Table 1 for recommendations.

Scroll (jig) saws with 10 teeth/inch provide an average cut on a single sheet, but stacked sheets will weld.

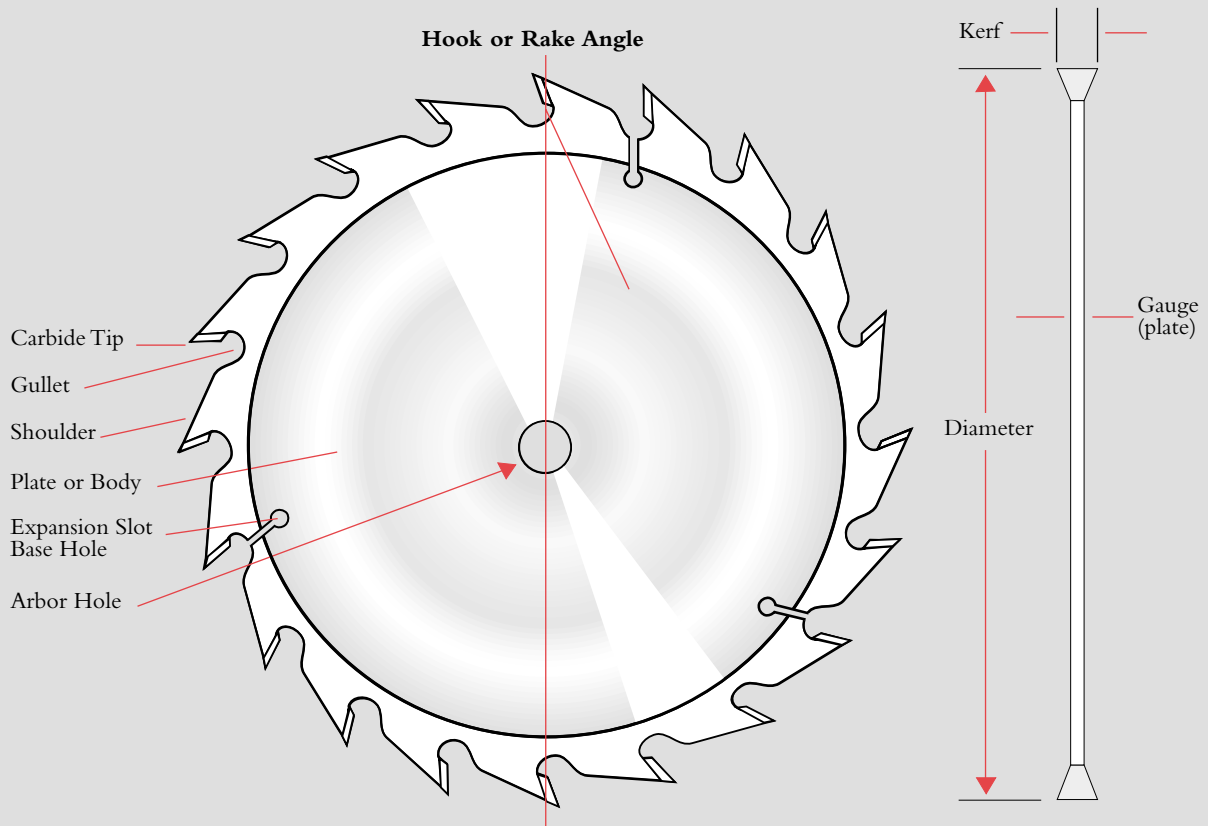
A 4 teeth/inch *saber saw* will cut faster than a scroll saw, but stacked sheets will also weld.

Drilling

A standard 118° point angle twist drill is used for drilling Tuffak sheet with the following modifications:

Grind a 10° back clearance at the cutting lip. This eliminates friction. Dub off the 12° positive rake at 0° so there will be a scraping rather than digging action. Do not use a drill designed for acrylic on Tuffak polycarbonate. This will produce a burr at the exit edge of the hole. Without these modifications, the drill will seize at any speed or feed and cause gumming and smearing. For a $\frac{1}{4}$ "-diameter drill, a medium feed (.015"/rev) and slow speed (1,800 rpm) produce the best holes with the least stress. Drill slightly oversized holes to accommodate mechanical fasteners.

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FIGURE 4
Circular Saw Blade Information


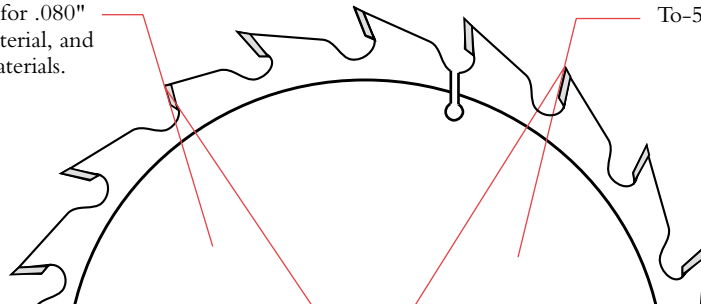
Saw Blade Diameter	Number of Teeth
8"	80
10"	60 to 80
12"	60 to 80
14"	60 to 80


Triple Chip Grind*

When cutting abrasive and/or brittle material such as aluminum or plastics. The triple chip ground teeth produce three chips, which tends to stabilize the cut by reducing side pressure.

* Same as square and advance

To -5° Negative angle for .080" and thinner material, and high-impact materials.



To -5° Positive hook or rake angle for 0.118" and thicker material.



Routing and jointing

Double and triple straight-fluted router bits, $\frac{1}{2}$ " to $\frac{3}{4}$ " diameter, with a 10° back lip clearance and a positive rake angle up to 5° , give a good cut without grabbing. A spiral, four-fluted, carbide end mill, used on an overhead router, produces a semi-polished edge. A slower feed rate is necessary for a superior finish. Choose an end mill with a down-cutting action to prevent chatter. A feed rate of 3" to 4"/sec is recommended.

Steel routers give a satisfactory edge, but will not last. Use 20,000 rpm spindle speed with a smooth, constant feed so heat will not build up. Hold the Tuffak sheet stationary by clamping tightly. In jointing, a smooth, constant feed is paramount to a good edge surface.

Cutting large holes

Hole saws cause severe chipping and smearing and should not be used. A special, heavy-duty circle cutter (see Figure 5) produces a good hole in Tuffak sheet when a predrilled $\frac{1}{4}$ " hole is used as a lower bearing, and the tool is mounted in a Stanley No. 419 circle cutter. The drill press must run true. Larger holes should use a slower spindle speed and a feed of .002"/rev.

Scribing and breaking

Scribing and breaking Tuffak sheet is not practical unless very thin gauges (.060") are used. The force necessary to propagate the notch in Tuffak polycarbonate is considerable.

Shearing

Tuffak sheet up to .125" thick can be sheared at room temperature on ordinary sheet metal shears. Unless a tight (.002") clearance is used, a rolled edge and some burring will occur in heavier gauges. Paper cutters and hand shears can only be used in very thin gauges of Tuffak sheet. Hot blade shearing creates other problems and is not recommended.

Punching and steel rule die cutting

Thin sheet (.030") punches as clean as a drilled hole. Punching thicker sheet may cause rolling and burring. Small clearances are recommended to minimize edge problems. Steel rule die cutting of Tuffak sheet is the best high-production method of cutting finished shapes from sheet up to $\frac{1}{2}$ " thick. Ordinary 4-pt. steel rule dies can be used to die-cut sheet up to $\frac{1}{8}$ " thick. Heavier steel dies (with stronger backing and special ejection packing) are necessary for more complicated dies. Increases in sheet thickness cause a minimal increase in die costs. Professional guidance in die design, machine tonnage, and packing design is necessary. For sources of die-cutting equipment and supplies, contact the companies listed in the Appendix.

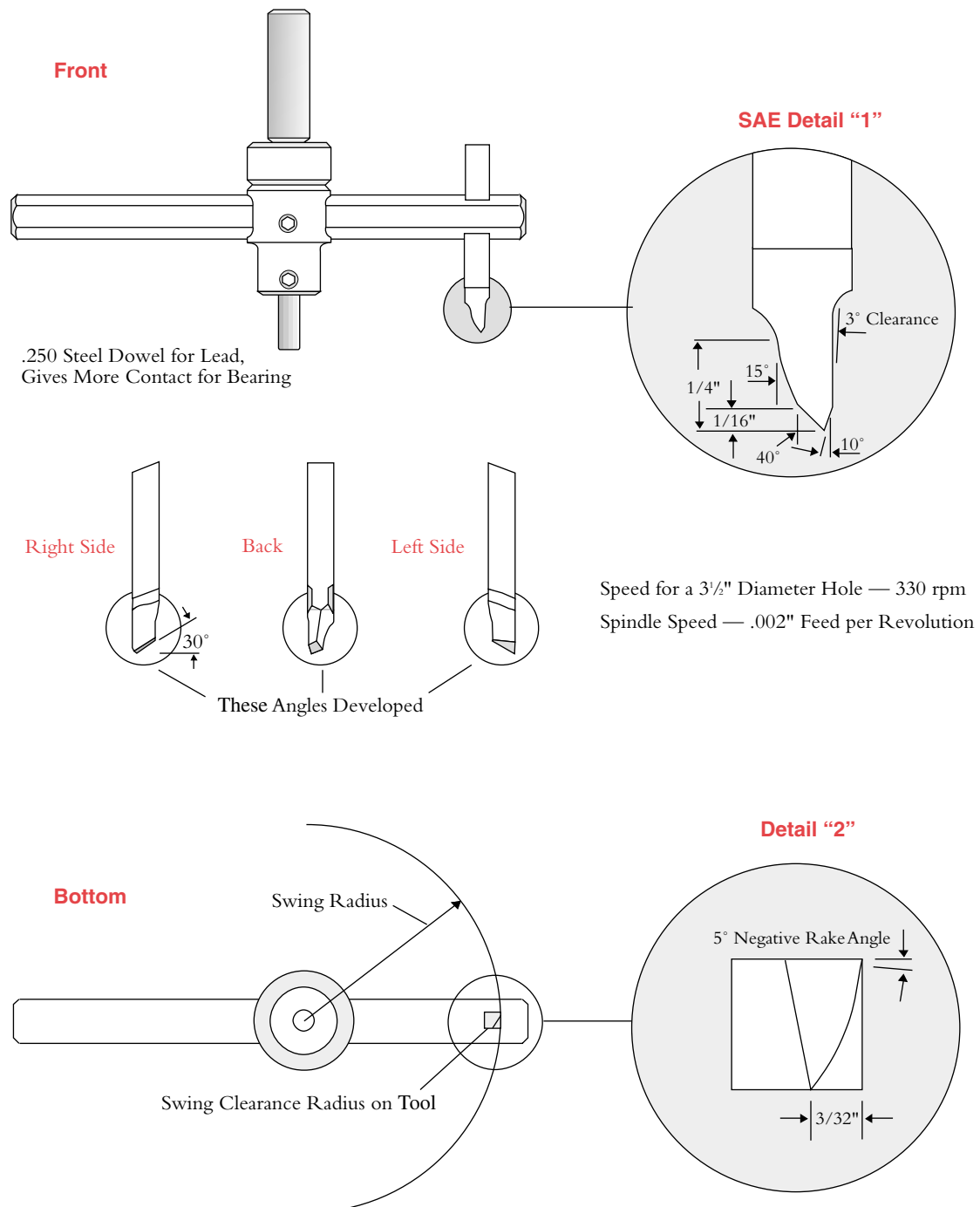
Laser cutting

Tuffak sheet can be cut with industrial cutting lasers. Cutting polycarbonate sheet using a laser produces an edge that may have an amber or brown appearance. For this reason, this procedure is not commonly used, although it is gaining acceptance and its use is growing. For information on suppliers of laser-cutting equipment, see the Appendix.

TABLE 1: Sawing Recommendations

Type of cut	Tool	Blade type	Blade parameters	Blade speed
Straight Cut	Table circular saw (panel saw best for sheet thicknesses less than .118").	Carbide-tipped, square and advance tooth.	60-80 teeth, 14" diameter. 60-80 teeth, 10" diameter. 0° rake angle.	3,400 rpm.
Curved Cut	Band saw.	STD metal cutting.	10 teeth/inch steel with raker set.	7,500 feet/minute.
Curved Cut	Saber or jig saw.	Metal cutting.	10 teeth/inch steel.	1,200 strokes/minute.
Trimming and Deflanging	Router.	Carbide-tipped, double or triple straight-fluted.	$\frac{1}{2}$ " diameter, 5° positive rake angle.	18,000 rpm.

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FIGURE 5*Heavy-Duty No. 419 Stanley Circle Cutter*



FINISHING

Both hand and machine finishing can be used to finish machined holes or edges on Tuffak sheet. Light pressure is necessary to minimize friction from heat. Care must be taken during handling to avoid surface scratching. If scratch resistance is mandatory, Tuffak CM-2-grade sheet is recommended.

Sanding and polishing

Before polishing out scratches, the area should be sanded to a final 600 grit. This minimizes buffing time, which minimizes heat buildup, which causes stresses that could later cause crazing.

Flame polishing

Flame polishing is not recommended, because of the high cooling stresses imposed and the resulting vulnerability to crazing. Furthermore, scratches are not removed, only polished, by flame. If, however, you attempt to flame polish parts made from Tuffak sheet, the parts should be annealed at 260°F for 45 minutes.

Automatic edge-finishing equipment

A glossy edge similar to the edge obtained with the discontinued vapor-polishing process can be achieved with an automatic edge-finishing machine outfitted with a diamond-tipped spindle. Carbide spindles will produce an edge with a matte finish. See the Appendix for suppliers.

Surface cleaning and restoration

Normal periodic cleaning of Tuffak polycarbonate signs and other exposed parts must be done with care, lest any wiping action rescratch the surface by

grinding the dust into the surface. Use rubber gloves and splash goggles. A soft cloth saturated with a 5% solution of butyl Cellosolve® solvent in water is recommended before soap and water is used to remove stubborn dirt. After cleaning, a deep, aging haze may be noticed. It may require a combination of sanding and polishing if it is several mils deep. Yellowness is not just a surface phenomenon; it is evenly distributed throughout the sheet.

Never use solvents for cleaning Tuffak sheet unless they are very mild, such as VM&P naphtha, kerosene or isopropyl alcohol.

DECORATING

Tuffak polycarbonate can be surface-decorated by spray painting and screen printing. However, specific paints, solvents and procedures are required to accommodate special polycarbonate properties.

Surface preparation

The first step is to remove static and surface contamination with a damp chamois, followed by wiping with a soft cotton flannel cloth dampened with a 50% IPA solution.

Paint systems

Table 2 lists two sign paint systems recommended for use on Tuffak sheet. Applications of both Spraylat's Lacryl® 400 and Wyandotte's Grip-Flex® FR-2 paints are covered in detail by technical bulletins from their manufacturers. Brochures cover all aspects of spray masks, equipment and techniques for spraying each paint. Read the appropriate manual before attempting any decorating job.

TABLE 2: Paints Recommended for TUFFAK Polycarbonate Sheet

Manufacturer	Spray	Screen
Spraylat Corporation Mount Vernon, NY (914) 699-3030	Lacryl 400 Series 205-T Thinner 206-T Cleaner/Remover	Lacryl 800 Series 208-T Thinner 218-R Retarder 205-T Thinner 206-T Cleaner/Remover
AKZO Coatings Inc. Norcross, GA 30092 (770) 662-8464	Super Grip-Flex FR-2 Series T-1003 Retarder T-2003 Reducer T-2004 Reducer T-4000 Remover	Super Grip-Flex FR-1 Series Super Grip-Flex SM-1 Series T-1003 Reducer T-1008 Retarder

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Mask, cut, and spray techniques

Lower-volume decorating jobs (custom signs) are usually done by cutting out the desired design from the masking and spraying onto the Tuffak sheet. Grip-Flex GM2-501 and Spraylat New Blue Size Strip are good.

If Tuffak polycarbonate is thermoformed, proper techniques must be used to minimize stresses so crazing will not result when paint is applied. Pre-decorating flat sheet, in a distorted pattern, will eliminate this problem.

When using a frisket tool to cut masking, care must be taken to minimize cuts or notches in Tuffak polycarbonate. Cuts or notches weaken the material. To minimize the depth of cut, round off sharp edges of the tool. Edges should not exceed 3 mils in depth.

Spraying is done with several light passes to prevent uneven color buildup and sagging. It also allows a faster drying time.

Screen printing

Screen printing is recommended for high-volume production of decorated Tuffak sheet. It is highly

economical, and it is done on flat, cut-to-size sheet. The inks used in screen printing are different from those of sprayable paints, but are suitable for Tuffak polycarbonate.

Polyester screens, with a mesh size of 8xx to 16xx, produce satisfactory results. Distorted screens (when the sheet will be thermoformed) must be designed specifically for Tuffak polycarbonate.

Screens made for acrylic sheet will not register correctly on Tuffak polycarbonate, because it sags more and has less elastic memory than acrylic. The grid system of making a screen should be used for polycarbonate. Also, because of the directional shrinkage of Tuffak sheet, always screen in the same direction on the sheet (either machine or cross direction). Never mix directions.

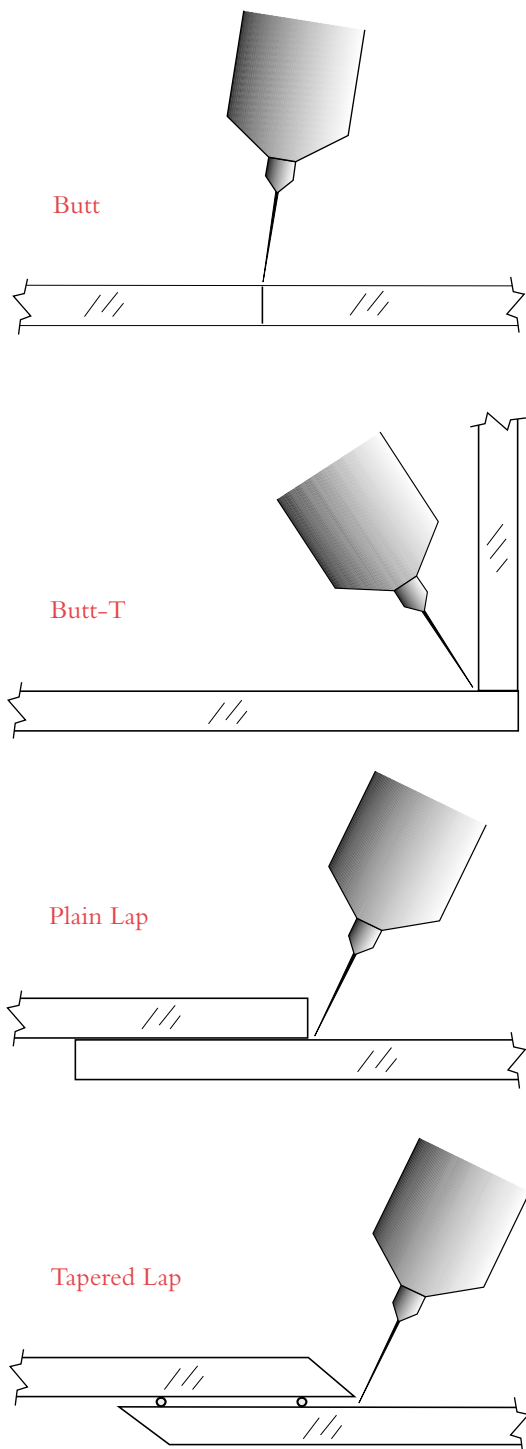
Print on the same side of the sheet (top or bottom). Always use the sag method when thermoforming decorated sheet so the design will register with the shape of the part. See “Heating Methods” section (page 1) of this manual.

TABLE 3: Overall Comparison of Joining Methods

Method of Joining	Solvent Cementing	Adhesive Bonding	Self-Tapping Screws	Medium Screws	Rivets	Hot Gas Welding	Hot Blade or Plate Welding	Ultrasonic Welding	Vibration Welding	Spin Welding	Ratings Legends	
											10=	1=
Tensile Strength	8	4	10	10	10	10	10	10	10	10	parent material strengths	poor
Speed	3	2	2	1	3	2	7	10	6	6	fast	slow
Tooling	–	1	1	1	3	5	7	8	8	5	costly	inexpensive
Labor	1	2	2	1	3	2	9	10	9	10	high	low
Capital Investment	1	1	2	2	2	4	6	9	8	5	highest	lowest
Cosmetic Appearance	10	3	5	5	5	2	8	9	9	8	best	worst
Setup Preparation	1	2	3	3	3	6	8	8	7	5	long	short
Part Size	10	10	10	10	10	8	6	2	4	6	unlimited	small
Dissimilar Materials	yes	yes	yes	yes	yes	perhaps	no	no	OK	no		
Part Design	9	10	10	10	10	5	6	1	8	3	simple	limited complex
Cost of Materials	9	6	4	1	3	10	10	10	10	10	most expensive	least expensive

FIGURE 6

Joint Design for Solvent Cement



Paint and ink removal

Care must be taken in choosing a solvent for removing paint and ink from the surface. Lacquer thinner, toluene, xylene, and Solvesso™ 100 will craze Tuffak sheet. Use Cerbire™ CPC 400 isopropyl alcohol, Grip-Flex T-4000 or Lacryl 206-T. They should be removed with fresh water as soon as the paint loosens.

JOINING TUFFAK COMPONENTS

Ideally, a one-piece thermoformed part will give the best performance. However, size limitation and other factors will call for fabrication of a Tuffak polycarbonate part from several components. Joining these components can be done by several methods, including solvent cementing, adhesive bonding and mechanical fastening. The choice of method will depend on strength requirements, and whether or not components must be disassembled periodically for repair or replacement. (See Table 3.)

SOLVENT CEMENTING

This is the simplest method of joining Tuffak sheet to itself. The solvent type can be (a) pure solvent, (b) a polymerizable monomer/solvent or (c) a thickened solvent. Cemented joints have low impact and are not recommended if high impact resistance is necessary.

Solvents

Pure solvents are commonly used to bond two polycarbonate surfaces together. These solvents are water-thin. The most common methods for application of pure solvents are by needle applicator capillary action and edge dipping. The benefit of pure solvents is that they dry quickly and reach handling strength in a relatively short amount of time.

Polymerizable monomer cements will give a better-looking joint than the solvent cement since voids can be eliminated. However, these joints are more brittle, and they will blush more than a solvent-cemented joint.

Thickened cements, with 10–15% of the parent material dissolved in a solvent, can be used when mating joint parts that do not fit together. The polymer will fill some voids. The strength is not as high as a solvent joint.

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Use extreme caution when working with solvents and cements. Adequate ventilation is essential. Control exposure levels according to American Conference of Governmental Industrial Hygienists (ACGIH) guidelines. Before using any solvent or cement, the user should become familiar with the properties of the product and the precautions necessary for its safe usage. Material Safety Data Sheets should be obtained from the suppliers of these materials. See the Appendix for a listing of Adhesive Suppliers.

Joint design

Close-fitting and mating surfaces are required for solvent joints. Thicker cements require open access to the joint; they cannot enter the joint by capillary attraction as water-thin solvent does.

Processing

Solvent cements are easily needled along the edge of a joint through a fine hypodermic syringe, allowing capillary attraction to penetrate the joint (see Figure 6). Soaking mating edges in solvent, then pressing them together, creates a weaker joint because of the excess solvent. A good solvent joint should have a tensile strength of 2,500 psi. Force drying should be done in an oven on parts requiring service at elevated temperatures. The clearest joint is obtained by putting pressure on the joint, using a press while the solvent is drying.

ADHESIVE BONDING

Adhesive bonding creates the weakest type of joints. It must be used when other methods are not applicable, such as joining two different materials (e.g., Tuffak polycarbonate to metal). The prime requirement of the adhesive is its flexibility over a wide temperature range, since dissimilar materials have different coefficients of thermal expansion.

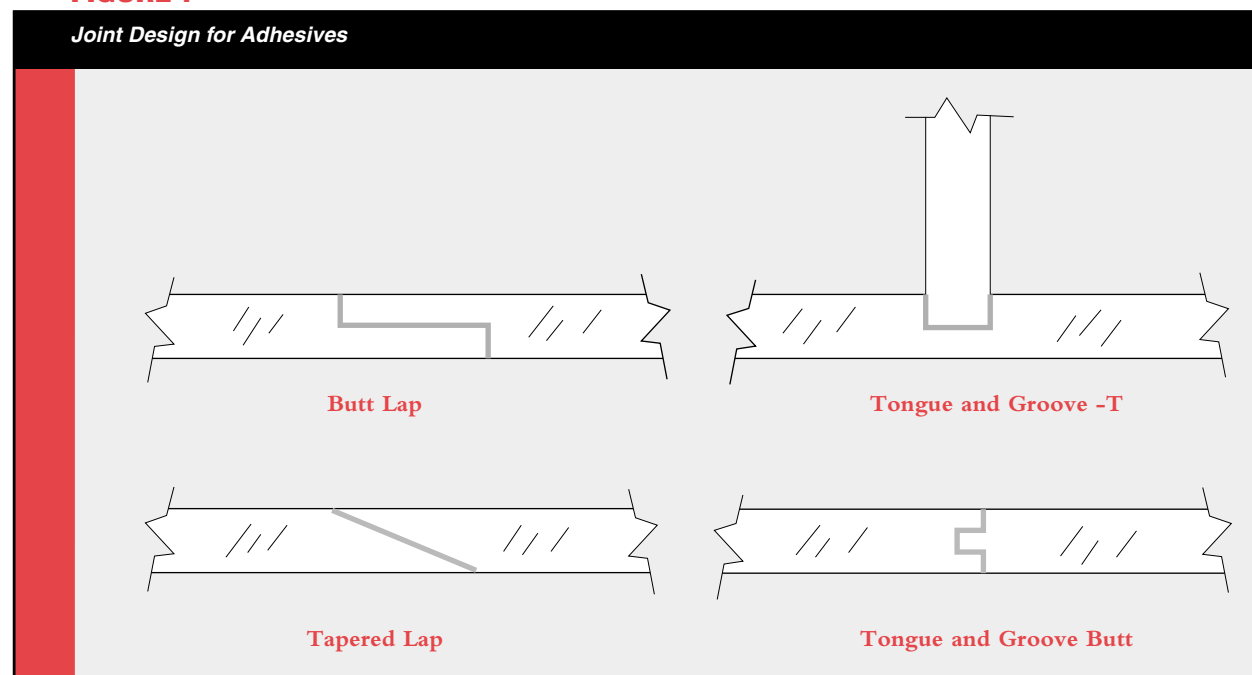
Types

■ **Thermoset Adhesives**—In comparison to thermoplastic adhesives, thermosets have superior strength, better heat and chemical resistance and no creep. Epoxies, urethanes, crosslinked acrylic and silicone rubber are all two-component systems that fit into this category and cure at or near room temperature. The flexibility of these systems allows absorption of impact and thermal movement during temperature cycling. See Table 4 for a list of Thermosetting Adhesives and Suppliers.

■ **Thermoplastic**—We do not recommend any thermoplastic adhesives for Tuffak polycarbonate. Typical thermoplastic adhesives are acrylics, acrylonitrile, cellulose, vinyls, acetates and butadiene/styrene. They can be hot melts, contact cement, or pressure sensitive. All of them lack strength, have poor heat and solvent resistance and can only be used for light duty.

FIGURE 7

Joint Design for Adhesives





Joint design

Since the tensile and adhesive strengths of these adhesives are low, joints should be designed with plenty of surface area to carry a shear load (rather than peel or tensile). Tongue and groove, double scarf and tapered joints are all satisfactory for adhesives (see Figure 7).

Application of adhesive

Preparation of mating surfaces is important because of the mechanical nature of adhesive bonds (compared to cohesive solvent cement bonds).

Roughening the surface and cleaning away all loose dust and foreign material is necessary for a good bond. A .010" wire spacer can be used to ensure even spacing of parts. High pressure is not needed to ensure good penetration of the adhesive into the surfaces.

MECHANICAL FASTENING

Mechanical fastening is the slowest and most costly joining method. It is also the strongest and most positive method, particularly to a dissimilar material like metal. Less preparation of mating surfaces is needed, and there is no degradation of Tuffak polycarbonate at the joint. This joining method is best for all high-impact situations. It allows disassembly of the fabrication should parts need to be replaced, cleaned or repaired. Fasteners are categorized as threaded, including those that use predrilled holes such as bolts, self-threading screws or inserts and some permanent fasteners such as rivets, pin or clinching-type. All fasteners must be clean of any cutting oil which could cause crazing after assembly in a hole.

Threaded

Threaded fasteners can use a predrilled hole, and the fastener cuts its own threads or has a nut, such as through bolts. The hole may be prethreaded for machine screws or a threaded insert may be press-fitted or welded into a predrilled hole. Predrilled holes for self-tapping screws would have a diameter half-way between the root and outside diameter of the screw. Use a coarse thread, Type 25, for both screws and inserts. Inserts are chosen when frequent disassembly is anticipated, and cross-threading is likely.

The material thickness must be great enough to allow at least four threads to be engaged. Vibrational service may rule out self-tapping screws because high stresses can lead to cracks emanating from the hole.

Fasteners hold better in holes pretapped in Tuffak, compared to threaded inserts. The joint, however, is not as strong, since plastic threads are susceptible to breaking and chipping and can be cross-threaded more easily. Metal inserts give the strongest joint, and the press-fit type hold well. Expansion-type inserts are stronger than press-fit. When predrilling for bolts, drill oversize to allow for ample clearance, since the hole will shrink more than the fastener under thermal contraction. A tight fit might crack the hole.

Permanent

Tuffak polycarbonate permanent fasteners include some that cannot be used on other, more brittle materials and plastics. These include rivets, pins, staples, clinching fasteners, stitching, grommets and eyelets. Because Tuffak polycarbonate is a notch-sensitive material, fasteners should not have sharp edges.

TABLE 4: Thermosetting Adhesives

Type	Manufacturer	Use
Acrylic	Lord Corporation	When high strength is important, but cosmetics (clarity) is not (brown in color).
Urethane	CIBA Specialty Chemicals Corporation and Conap, Inc.	Useful with jewel trim on sign cans. Is clear, tough and has good strength; is fast-reacting, so special applicator may be necessary.
Clear Silicone Rubber	GE Silicones	Useful for sign tie-back; not as strong as urethane, but affects paint less. Used with a primer.
Epoxy	Epoxy formulators (many)	Do not use amine-hardened or other rigid systems.

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Speed rivets have two heads which fit inside each other to provide a longer-lasting joint. One-sided, blind rivets must have a washer on one side to prevent digging into the Tuffak polycarbonate surface. Rivets should be aluminum or use a soft washer to protect the soft Tuffak sheet surface. Spring clips and V & J fasteners, used for holding two parts lightly together, can be used successfully.

Snap fits, if designed properly, can work well with Tuffak polycarbonate. They have low creep characteristics compared to other plastics and maintain the required interference over a long time.

HEALTH AND SAFETY STATEMENTS

MACHINING AND HEATING

All thermoplastic materials produce some gases or vapors at high temperatures from either direct heating or machining. This will not result in harmful concentrations of gases or vapors if handled in areas with adequate ventilation.* It is always good practice to provide local exhaust ventilation as close to the point of possible generation of vapors as practical.

Any dust produced by the machining of Tuffak polycarbonate sheet is considered nuisance dust. The ACGIH recommended TWA for nuisance dust is 10 mg/m³ – total dust; 5 mg/m³ – respirable dust.

CEMENTS, ADHESIVES, AND CLEANERS

Some cements, adhesives, and cleaners contain volatile components that may be toxic if inhaled for extended periods or swallowed.

Employees should be protected from direct skin or eye contact with the materials by use of protective equipment, such as impervious gloves, aprons, and goggles where splashes are possible.

Some of the materials recommended herein are flammable. Most release noxious fumes during heating

and must be kept from flames or sources of high heat. There should be no smoking in any area in which the solvents, adhesives, or cleaners are stored or used. In case of fire, only dry powder or chemical fog fire extinguishers should be used.

Before using any chemical suggested in this bulletin (e.g., cement, solvent, adhesive, sealant, or cleaner, etc.), the user should become familiar with the properties of the product to be used and the precautions necessary for its safe usage. Material Safety Data Sheets should be obtained from the manufacturer for these purposes.

APPENDIX

SOURCES OF SUPPLY

Adhesives, thermosetting

- CIBA Specialty Chemicals Corporation
East Lansing, MI (800) 759-7165
- Conap, Inc.
Olean, NY (716) 372-9650
- GE Silicones
Waterford, NY (518) 233-3505
- Lord Corporation
Erie, PA (814) 868-3611

Air dryers

- Conair/Franklin
Pittsburgh, PA (412) 312-6000
- Universal Dynamics
Woodbridge, VA (703) 491-2191

Carbide saw blades

- Forrest Manufacturing Company, Inc.
Clifton, NJ (800) 733-7111
- General Saw Corporation
Secaucus, NJ (201) 867-5330
- Markay Cutting Tools
Elk Grove Village, IL (847) 364-5505
- West Coast Saws
Tacoma, WA (253) 272-3000

*Suggestions for the design of exhaust ventilation are provided in *Industrial Ventilation — A Manual of Recommended Practice*, published by the ACGIH (1988); and American National Standards Institute, *Fundamentals Governing the Design and Operation of Local Exhaust Systems*, Z9.2-1979.



(APPENDIX, CONT.)

Cements, polymerizable and solvent

- Caseway Industrial Products
Punta Gorda, FL (941) 639-5202
- Industrial Polychemical Science (IPS)
Gardena, CA (800) 421-2677 or
(310) 366-3300

Circulating air drying ovens

- Despatch Industries
Minneapolis, MN (612) 781-5363
- Gruenburg
Williamsport, PA (570) 326-1755
- New England Oven & Furnace Co., Inc.
Orange, CT (203) 799-2005
- Precision Quincy Corporation
Woodstock, IL (815) 338-2675
- The Grieve Corporation
Round Lake, IL (847) 546-8225

Die-cutting equipment and supplies

- Atlas Die, Inc.
Elkhart, IN (219) 295-0050
- National Steel Rule Die Co.
Vandalia, OH (937) 667-3515

Laser-cutting equipment and services

- Kerns Electronics
Wadena, MN (218) 631-2755
- Laser Machining, Inc.
Somerset, WI (715) 247-3285
- Raycon
Ann Arbor, MI (734) 677-2614

Paints

- AKZO Coatings Inc.
Norcross, GA (770) 662-8464
- Spraylat Corporation
Mount Vernon, NY (914) 699-3030

Panel saws

- Hermance Machine Company
Williamsport, PA (717) 326-9156
- Schelling America, Inc.
Charlotte, NC (704) 814-6072

Panel saws, CNC routers

- RWH Industries, Inc.
Littleton, MA (978) 741-3600

Router bits

- Onsrud Cutter Inc.
Libertyville, IL (847) 362-1560
- Robb Jack Corporation
Lincoln, CA (916) 645-6045

Temperature measurement, infra-red

- IRCON Inc.
Niles, IL (847) 697-5151
- Mikron Instrument Company
Wyckoff, NJ (201) 891-7330
- Raytek
Santa Cruz, CA (800) 866-5478

Thermoforming machines

- John Brown, Inc.
Beaverton, MI (517) 435-7741
- Central Automated Machinery, Inc.
Gladwin, MI (517) 462-1921
- MAAC Machinery Company, Inc.
Itasca, IL (630) 285-1500
- Plasti-Vac, Inc.
Charlotte, NC (704) 334-4728
- The Shuman Company
Charlotte, NC (704) 525-9980

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See MSDS for Health & Safety Considerations.

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