



Processing Guide

- **Forming**
- **Fabricating**
- **Finishing and Decorating**

Lexan

Introduction

This booklet is intended as a guide for the processing of Lexan® polycarbonate sheet.

Forming, fabricating, finishing and decorating methods are discussed. For more detailed information or advice please contact GE Structured Products.

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1.0 Forming

From high speed trains to street furniture, and from snowmobiles to motorway signs, Lexan® sheet products are designed and manufactured in a diverse range of shapes and sizes. One of the most economical methods of producing these parts is thermoforming.

Thermoforming Lexan® polycarbonate sheet is an established process that offers the designer the freedom to develop complex shapes and forms with cost/performance characteristics that have significant advantages over more traditional methods of production. Low cost tooling, large part production and reduced lead times all contribute to the advantages of producing sheet products in this way. With the introduction of Lexan® Exell® D and Lexan® Margard FMR, thermoformed applications can now be produced in both added value surface treated products, providing the engineer with enhanced design opportunities.

Whilst the thermoforming process is basically very simple, the number of different processing, production, design and finishing steps are quite varied. To assist the designer and the converter in the selection of a suitable production method, the following section outlines some of the techniques used in the design and manufacture of thermoformed products in Lexan® polycarbonate sheet.

Table 1.0: Formability

Material	Vacuum forming*	Drape forming	Twin sheet forming*	Pressure forming*	Hot/Cold line bending**	Cold curving	Flat lamination	Curved lamination
Lexan® 9030	x	x	x	x	x	x	x	x
Margard® MR5E					x			
Margard® MRA3					x			
Margard® HLG5					x		x	
Margard® HLG A3					x		x	
Margard® FMR		x			x	x		
Margard® FLG5		x			x		x	x
Exell® D	x	x	x	x	x	x		
Exell® D ST	x	x	x	x	x	x		
Sign grades	x	x	x	x	x	x		
CTG	x				x			
FR grades	x	x	x	x	x	x		
Gepax®	x	x	x	x	x	x		
Ultem®	x		x	x	x	x		

* Transparent sheet in contact with mould surface can cause haze and an optically distorted surface.

** The mar resistant or U.V. protected surfaces can be damaged around the bent area during the bending process.

1.1 Pre-Drying

The majority of thermoplastic resins, including sheet products, are hygroscopic, which means that they absorb moisture. Moisture builds up in the polymer sheet during manufacture, transportation and storage. In the 'as extruded' condition it presents no problem. However, during forming, excess moisture can cause bubbling and other surface appearance problems as well as a reduction in property performance.

Whilst the amount of water absorbed is not significant compared to other hygroscopic materials, it is essential that it is removed prior to forming. A hot-air circulating oven at $125^{\circ}\text{C} \pm 3^{\circ}\text{C}$ is recommended. To avoid warpage, drying temperatures should not exceed 125°C and the air volume in the oven should be changed six times per hour to allow for the removal of water vapour. After removing the protective masking, the sheets should be hung vertically in the drying oven and pre-dried according to the recommendations outlined in Table 1.1. Alternatively, the sheets can be placed in racks with a separation of approximately 1.0 to 2.5 cm between the sheets. Following pre-drying the sheet should be processed within a few hours. The time limit depends upon the wall thickness and local environmental conditions.

Table 1.1: Recommended Drying Times

Sheet Thickness (mm)	Drying Time (hrs)
0.375	0.15
0.50	0.25
0.75	0.50
1.00	1.00
1.50	1.50
2.00	3.00
3.00	4.00
4.00	10.00
5.00	16.00
6.00	24.00
8.00	36.00
9.50	40.00
12.00	48.00

1.2 Thermoforming Techniques

Lexan® polycarbonate sheet products are easily thermoformed and a wide variety of applications can be produced using the process. The basic steps involve the heating, shaping and cooling of a thermoplastic sheet product. There are a number of different forming techniques, some of which only require heating to allow the sheet to conform to a simple positive or negative mould as in drape forming. Others, such as vacuum and pressure forming require that, after heating, the sheet is made to conform to a mould by applying pressure or a vacuum.

Whilst each process is slightly different, as illustrated in Figures 1.1-1.4, the basic steps are very similar. The sheet is firstly clamped along all edges inside a clamping frame. A heat source is moved over the sheet raising its temperature until it is elastic. The heat source is removed and the mould table raised. The air in the space between the sheet and the mould is evacuated and the sheet is drawn towards the mould and takes its form. Pressure can also be applied to the positive side of the mould to reproduce detailed mould features. The sheet is cooled, the mould moved downwards, and the product taken out of the machine. The clamping edges are removed from the product and, if necessary, additional machining is carried out to finish the product.

As a manufacturing process the technique offers significant advantages and is widely used for its simplicity and low production costs. However, in order to preserve its protective coatings, Lexan® Margard® cannot be thermoformed.

The major benefits of thermoforming are listed below:

- Small to large part production
- Short lead times
- Small to medium size series
- Flexibility

Fig. 1.1: Positive Forming Fig.1.2: Negative Forming

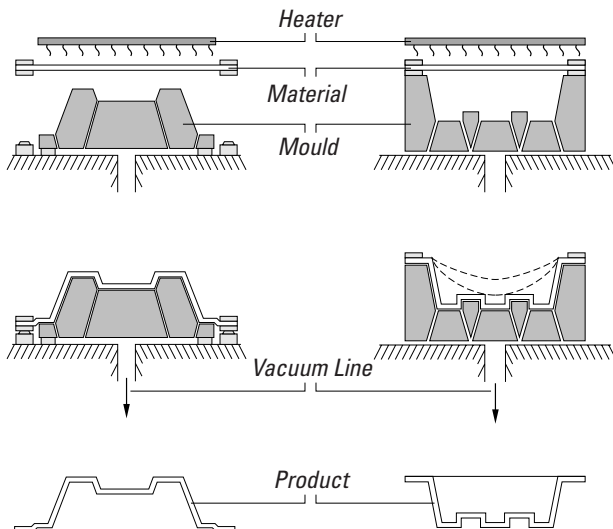
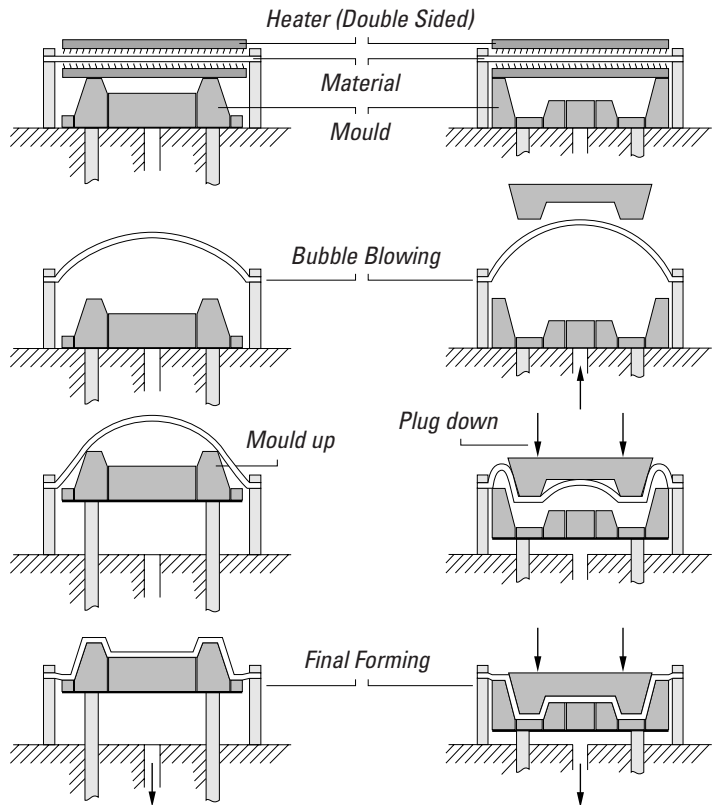


Figure 1.3 Bubble Forming Figure 1.4 Plug-Assisted Forming



1.3 Heating and Cooling

Heating

Controlled and uniform heating of Lexan® polycarbonate

sheet is the critical factor in the production of good quality thermoformed parts. Sandwich type heaters are recommended as they provide slow even heat on both sides of the sheet. These may be of the ceramic or quartz infra-red type. Proportional timers, together with a controlled heating rate are recommended, and due care and attention should be paid to the influence of power variations and air draughts. Slow heating rates will balance out hot spots and allow the sheet edges to reach the required forming temperature. Pre-heating of the clamping frame to 120°C-130°C is recommended. Since Lexan® polycarbonate sheet cools rapidly, it is essential that final control and heating is carried out on the forming machine itself. Normal sheet temperatures are in the range of 170°C-225°C for mechanical and vacuum forming.

Optimum forming conditions depend upon part design, draw ratio, sheet thickness and the forming technique employed. However, the following basic rules still apply:

- Forming at low temperatures gives the best hot strength, minimum spot thinning, and generally shorter cycle time.
- Forming at high temperatures gives the lowest internal stress levels but it increases mould shrinkage and material thickness may not be uniform.

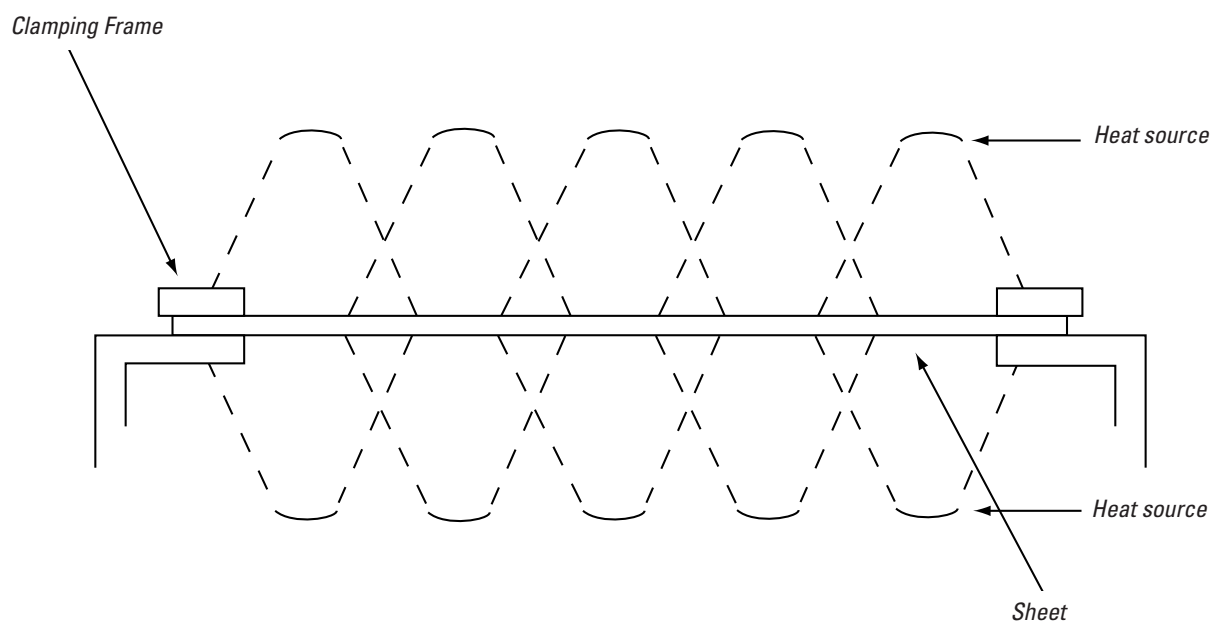
A compromise between the two will usually produce parts with acceptable properties within a satisfactory cycle time.

Cooling

Cooling times are dependent upon a number of factors.

These include ambient, forming and mould temperatures, mould material, cooling system, part thickness and design geometry. However, since Lexan® polycarbonate has a relatively high heat distortion temperature, formed parts can be removed from the mould at around 125°C. Forced cooling air or water cooling is not recommended.

Fig. 1.5: Sandwich Heating



1.4 Drape Forming

Drape forming is the simplest of all the thermoforming techniques. Using either a male or a female mould, the sheet is heated and allowed to conform to the shape of the mould under its own weight or with slight mechanical pressure.

The process involves placing the sheet (without the masking) and mould in a hot-air circulating oven. The temperature is raised to the point where the sheet sags (between 140°C-155°C) and conforms to the shape of the mould. Both items can then be removed from the oven and allowed to cool.

Figures 1.6 and 1.7 illustrate the basic steps.

Exceeding the glass transition point of Lexan materials will result in a decreased optical quality. Pre-drying is not necessary due to the low processing temperatures.

The drape forming process can be a combination of different methods. These include:

- Shaping under its own weight at a temperature of 155°C.
- Shaping under its own weight with a slight mechanical pressure. (Temp. 155°C)
- Cold curving into a jig and placing in an oven at temperatures between 140°C-155°C.
- Cold curving the sheet over a mould, exposure to a temperature of 150°C and application of vacuum to obtain a 3D shape.

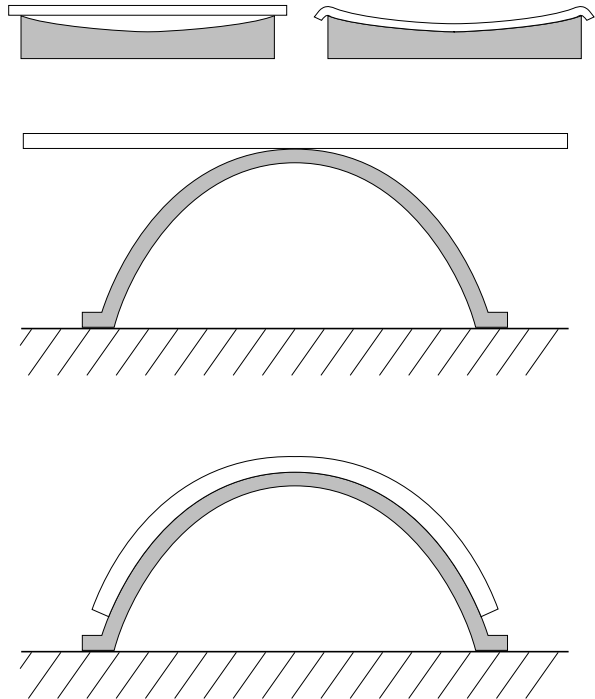
Cold curving guide-lines must be strictly followed, to avoid surface cracking of coated products.

Always allow for slow and unforced cooling. When shaping is carried out under the sheet's own weight, use oversized sheets in order to avoid material shrinkage problems. Alternatively, the sheets can be placed in the oven with the mould directly outside.

Once the sheet has reached the required temperature, it should be quickly removed and allowed to drape itself over the mould. The transition between the oven and the mould should be handled very fast since the Lexan® sheet sets-up rapidly once it has been removed from the oven.

Typical applications include visors and automotive safety glazing where the Lexan® sheet products easily meet the demanding quality requirements. In these types of application the mould needs to be made from a high gloss material such as steel, aluminium, or even glass in order to achieve the necessary optical quality.

Fig. 1.6 / 1.7: Typical Drape Forming Set-up

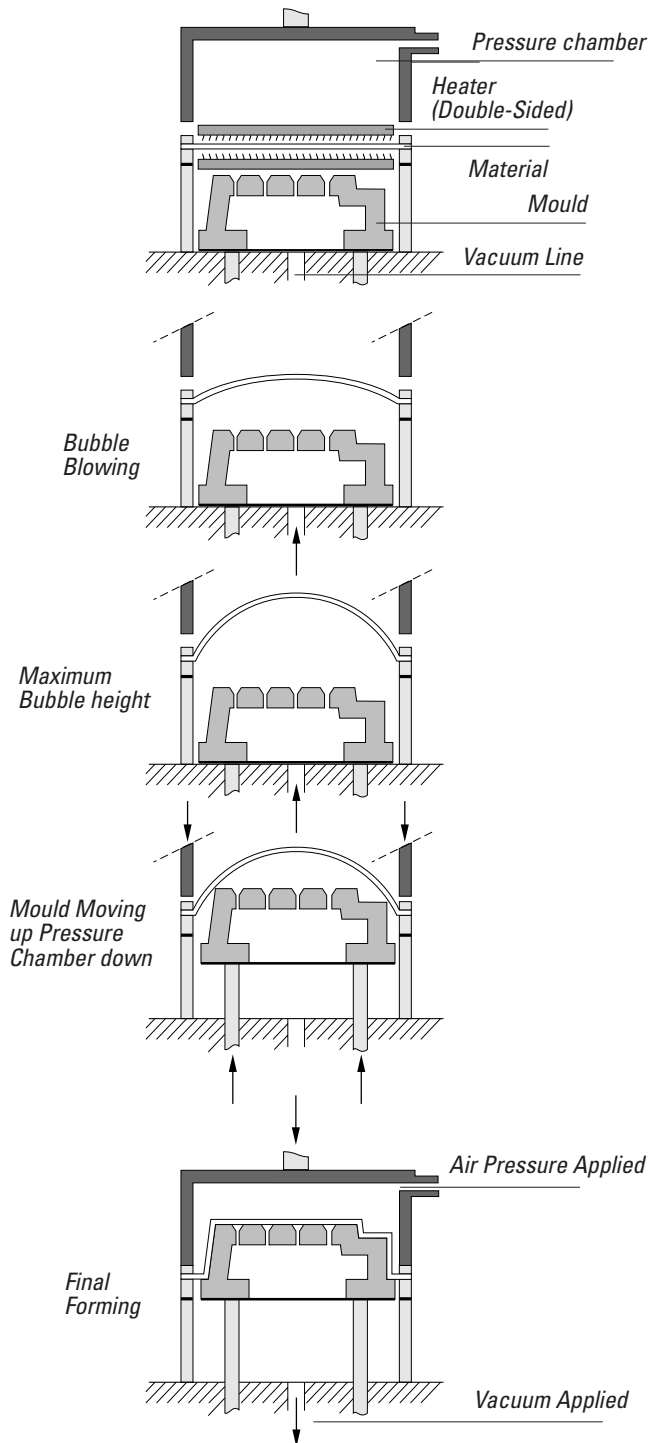


1.5 Pressure Forming

Pressure forming is basically the same as vacuum forming. However, during the final forming stage, compressed air is applied to the positive side of the mould to force the sheet to conform more closely to the mould. The result is a component with sharp features and detailed geometry.

The basic steps are illustrated in Figure 1.8, showing the pressure chamber mounted above the mould. Textured surfaces and small radii are typical of the fine detail which can be achieved with this process.

Fig.1.8: Pressure Forming



1.6 Twin Sheet Forming

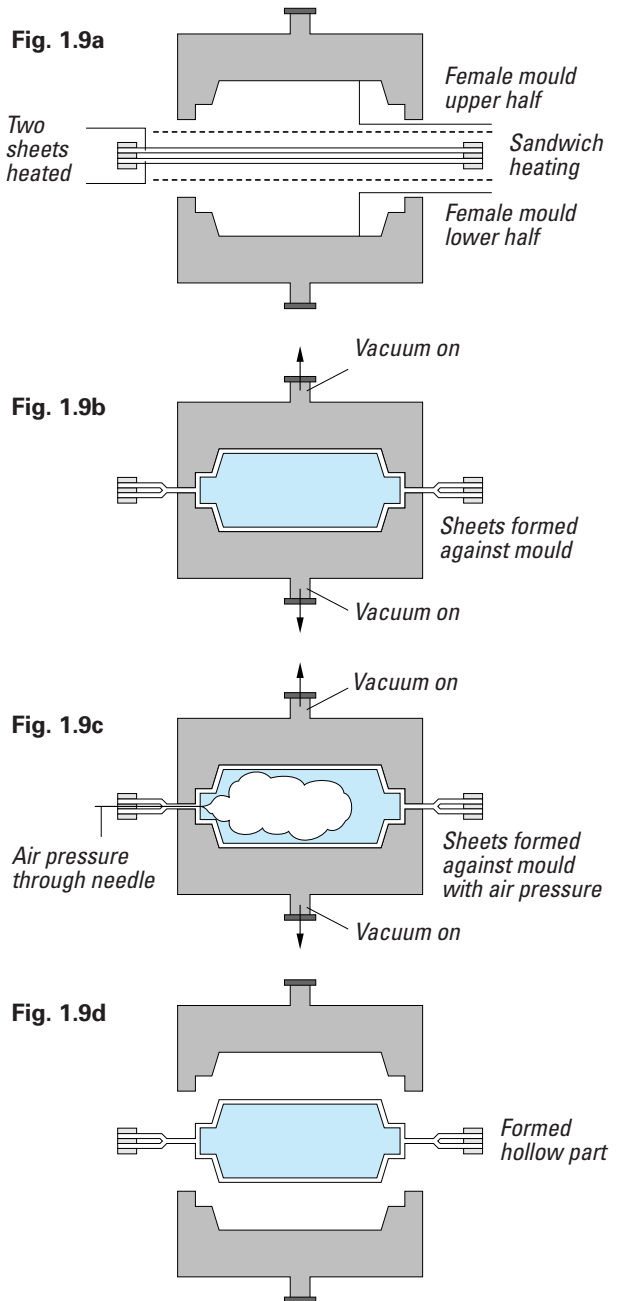
Twin sheet forming is a development of vacuum forming technology whereby two sheets are formed at the same time producing an application with a hollow sealed section. The basic steps in the process are outlined in Figures 1.9a-d.

Accurate temperature control is an essential element when using this technique since only one side of the sheet is heated. The ability to control heating in individual areas of the sheet is vital. Photocells also need to be installed to control sagging and hot-air is often used to keep the two sheets from touching each other.

As a highly competitive process for producing hollow sectioned parts, it is particularly suited to the production of large applications. These typically include luggage boxes, air ducts, roof domes and roof hatches.

The connection joint between the two parts is obtained by a combination of melting of the two materials and the exposed pressure of the moulds. No additional glue or other adhesive is therefore necessary. This method can be used to produce parts consisting of two different materials, colours and gauges. Fully automatic controlled equipment is manufactured by Geiss-Germany and Shelley-U.K.

Fig. 1.9a-d: Twin Sheet Forming



1.7 Product Design

The major factors that affect thermoforming product design fall into four main categories: function, economics, aesthetics and manufacturing. The first three of these are largely dependent upon the actual product. However, within the manufacturing area, certain limitations are imposed by the nature of the process. To assist the designer and the producer in the design process, the main factors affecting manufacturing are as follows.

Product Geometry

The component's geometry determines the degree of sheet stretching which, in turn, is a function of the draw ratio. The draw ratio is the relationship between the surface area of the thermoformed product (S) and the available sheet surface inside the clamping frame (s). (See Figure 1.10.a-b)

$$\text{Draw ratio } (Q_s) = S / s$$

$$= \frac{LW + 2LH + 2WH}{LW}$$

A similar relationship also exists between the sheet thickness and the average product thickness.

$$Q_T = T / T'$$

The above recommendations assume an even thickness distribution throughout the part, with a more or less symmetrical part geometry. If the component is long and slender, stretching may be unidirectional causing excessive thinning in certain areas. In these cases it is recommended that the depth of drawing be limited to a value equal to the smallest width of the product. For vacuum formed products, a draw ratio of 3:1 is commonly accepted as a maximum.

Product Radii

In all cases, whether positive or negative forming, all geometry changes should be accompanied by a generous radii. The basic criterion is that all radii should be at least equal to the wall thickness. General guidelines are illustrated in Figure 1.12.

Draft Angles

Lexan® polycarbonate sheet products, in common with all thermoplastic materials, shrink upon cooling. It is therefore essential that all surfaces should be given adequate draft angles to ensure easy release of the part from the mould. For positive moulds a minimum of 2° to 3° is recommended. However, 5° to 7° is preferable when part geometry allows. For negative forming 0.5° to 1° is a recommended minimum. If, however, the mould is textured, a minimum of 2° to 3° is advised. To avoid stress build-up and difficult removal through post mould shrinkage (0.8-1%), removal of the Lexan® part should take place at a part temperature of 120°C.

Fig. 1.10a-b: Blank Size Determination

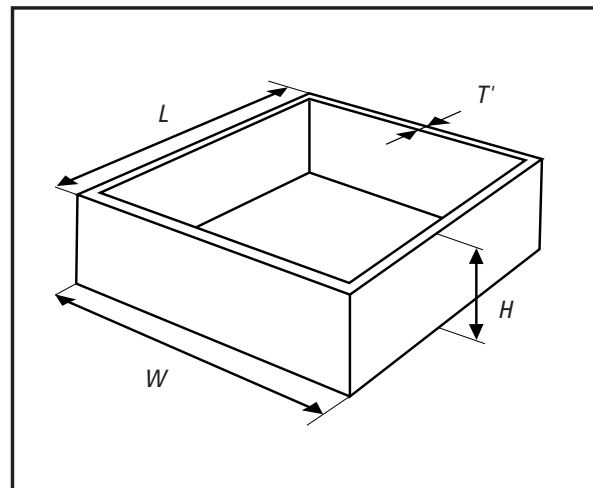
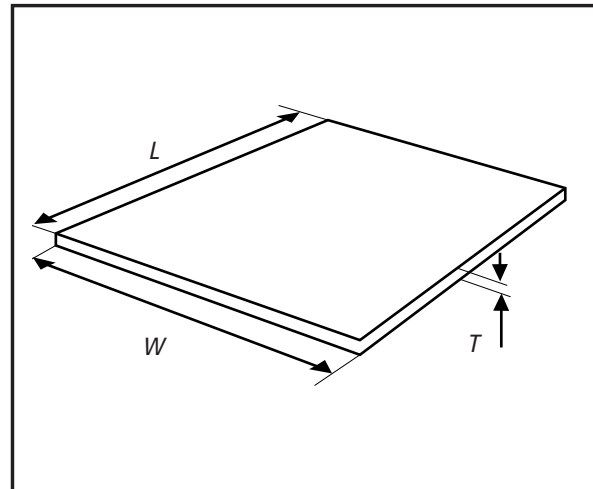
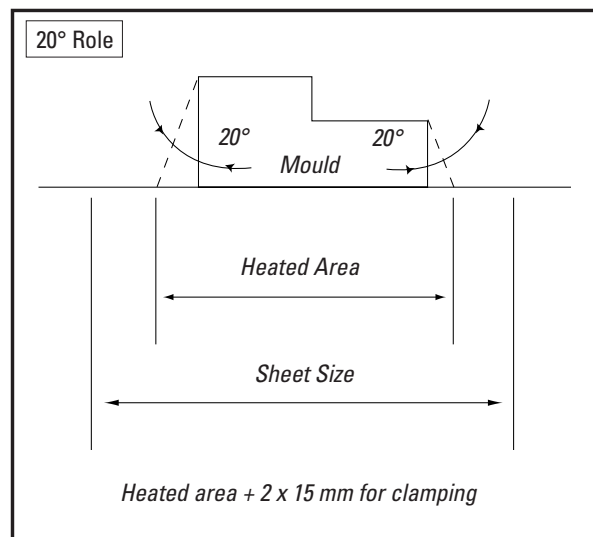


Fig. 1.11: Blank size required for forming



1.7 Product Design

Undercuts

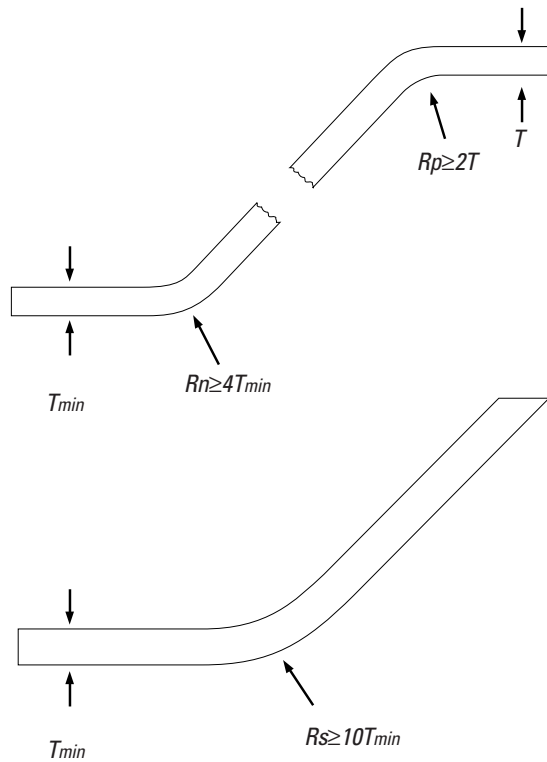
Undercuts are possible with vacuum forming. However, this often

makes the moulds more complex and the processing more critical. Undercuts are more common in negative forming and the simplest method is to use a loose, removable part in the mould.

A typical example is that of a rim around the circumference of the part as shown in Figure 1.13. The loose part can be a ring in two or more pieces that is removed from the part once it is formed.

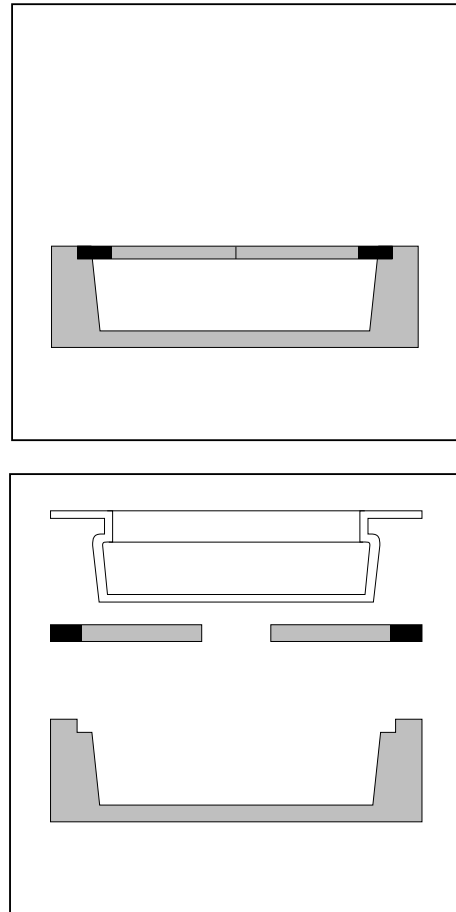
This method of producing an undercut is labour intensive and will obviously increase the cycle time. For large series, moving parts can be installed into the mould activated by both pneumatic and hydraulic cylinders.

Fig. 1.12: Minimum Radii Recommendations



- T - Initial sheet thickness
- T_{min} - Minimum formed thickness
- R_p - Radius on positive mould
- R_n - Radius on negative mould
- R_s - Radius at or near area of high stress

Fig. 1.13: Typical Undercut Design



1.8 Moulds and Mould Design

Moulds used for forming Lexan® polycarbonate sheet products are relatively inexpensive and can be made from a variety of different materials. Depending upon the number of production parts required and their quality, moulds can be made from wood, plaster of Paris, epoxy resins, metal-filled polyester or metals. Since they only need to withstand atmospheric pressure there is little wear and the flow of the plastic against the mould surface is minimal.

For prototypes and small series production, wood can be used. Whilst it has significant advantages in terms of availability and ease of processing, it does have disadvantages. Wooden moulds are not dimensionally stable, particularly at high forming temperatures, and often with large mouldings the release pressure can damage the mould surface. For medium to large production runs, cold curing epoxies or acrylics, or mould materials filled with aluminium are recommended. In these cases it may be necessary to provide cooling channels in the mould to conduct away the heat build-up. It is essential for part consistency that the mould temperature is kept constant during forming.

Shrinkage To allow for post forming shrinkage, 0.8%-1% should be added to all dimensions.

Vacuum Holes The evacuation of air from the mould needs to be achieved as quickly as possible. However, the vacuum holes should not be so large as to leave witness marks on the product after forming. To avoid marks on the moulding, 0.5-0.75 mm diameter holes are recommended. The holes can be recessed on the underside of the mould to improve evacuation, as illustrated in Figure 1.15a. Figure 1.15b illustrates the spacer and slot design.

Fig.1.15a: Vacuum Hole Recommendations

Vacuum holes

Diameter holes 0.5-0.75 mm
back drilling recommended

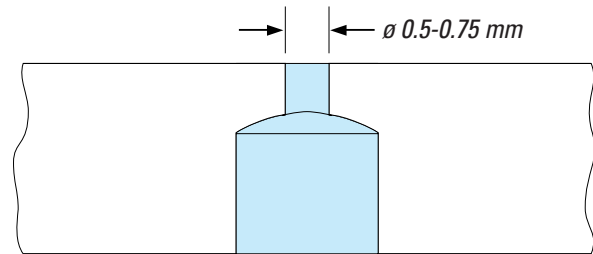


Fig.1.15b: Slot Design Recommendations

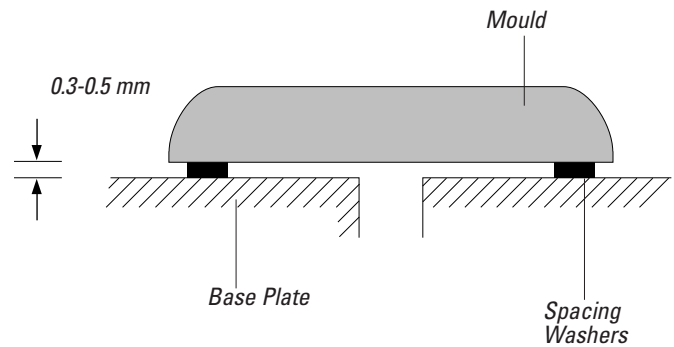


Fig.1.14: Typical Vacuum Forming Mould



1.9 Domes and Pyramids

Domes are probably the simplest applications made by the thermoforming process. The technique involves clamping the edges of the sheet and, after heating, applying gentle pressure to the underside. The sheet then stretches like an elastic membrane to form the dome. With accurate pressure control, the shape is maintained until the sheet has cooled. The basic steps in the process are illustrated in Figure 1.16.

Taking the process one step further, pyramids can be produced, as shown in Figure 1.17. A simple wooden skeleton acts as a mould and, after applying the pressure, the mould is raised and the sheet allowed to cool on the mould. Contact with the mould is limited to the edges of the pyramid and optical quality parts can easily be produced. Recommended processing temperatures are between 170°C-180°C.

Fig. 1.16: Free-blown Domes

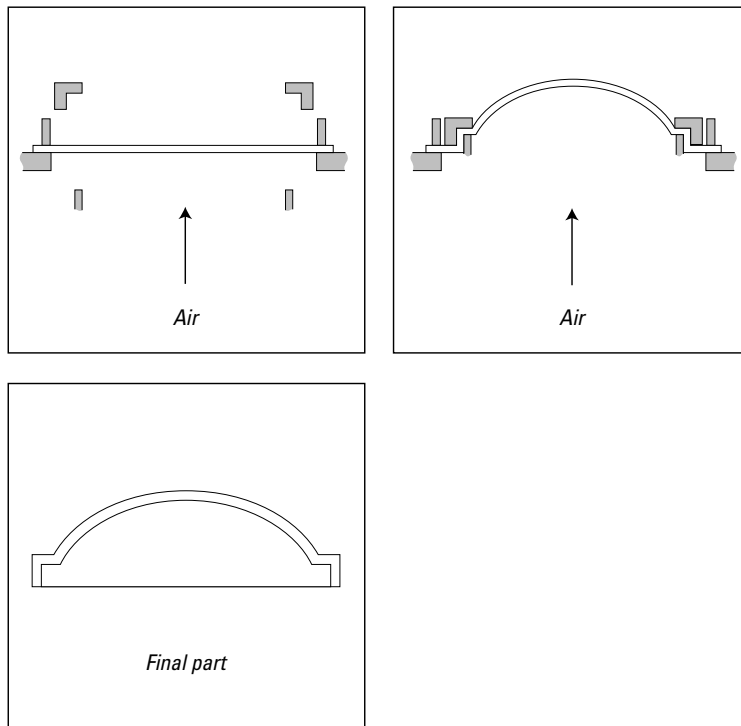
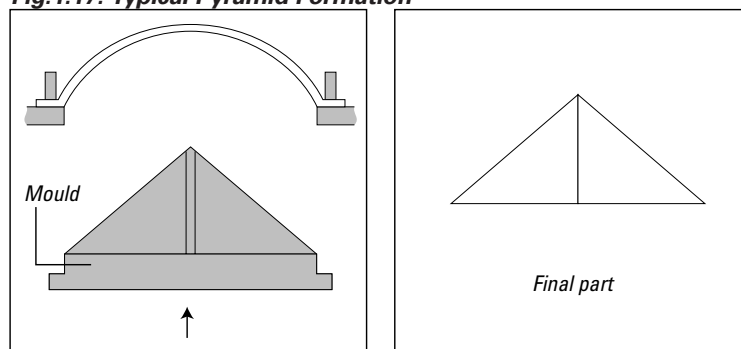


Fig.1.17: Typical Pyramid Formation



1.10 Hot Line Bending

Hot line bending is a process involving the application of heat to the bending zone to enable thicker sheets and more acute angles to be formed. The sheet is heated locally along the line of the bend using a radiation heater, typically an electrical resistance heater. Depending upon the set-up, the sheet can be heated from one or two sides. In the case of single side heating, the sheet needs to be turned several times to achieve optimum heating. The protective masking can be left on the sheet during the hot line bending process.

When the sheet has reached a temperature 155°C-165°C, the heaters are switched off and the sheet bent to the required angle. For close tolerances and/or high volume production, the use of a bending machine equipped with temperature controlled heaters on both sides is recommended. A typical set-up is illustrated in Figure 1.18.

Since the process involves localised heating, the expansion characteristics of the sheet are not entirely predictable. For sheet widths of up to 1m, the bend line is usually straight. For sheet widths greater than 1m however, the line of the bend is often concave with the outer edges lifting, as shown in Figure 1.19.

Simple jigs can be constructed to allow the sheet to cool in position which reduces the degree of distortion. In all cases it is recommended that prototype parts are produced to determine the feasibility of the bending operation.

Fig.1.18: Typical Set-up for Hot Line Bending

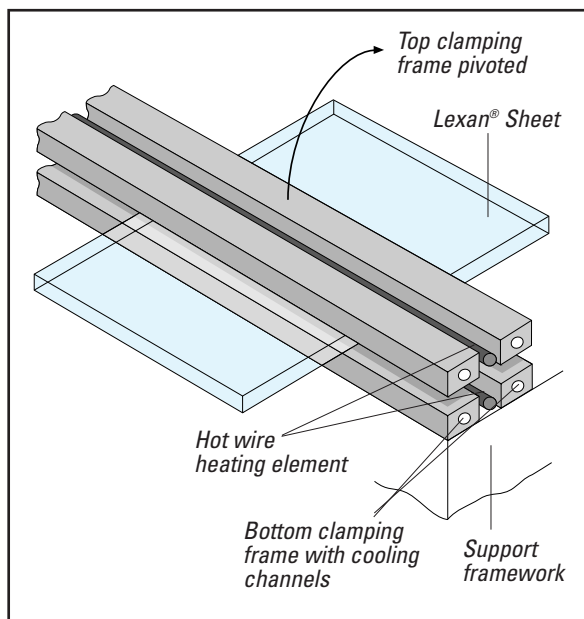
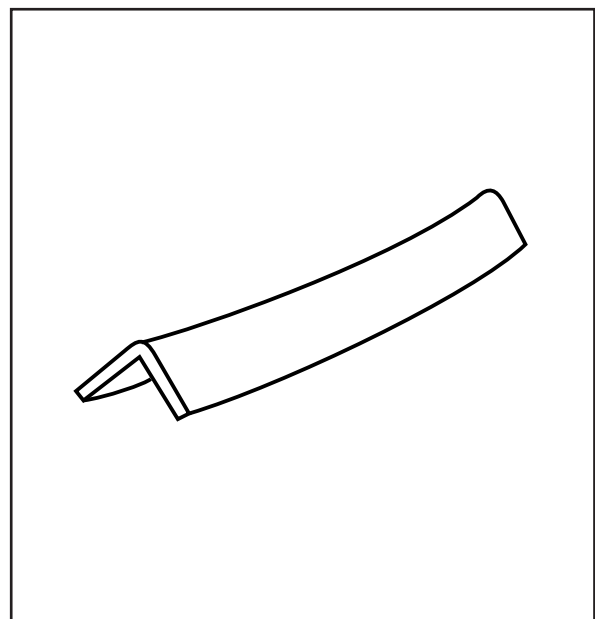


Fig.1.19: Concave Edge Effect on Wide Sheets



1.11 Cold Curving

This technique involve placing the sheet under stress. However, provided certain precautions are taken, the performance characteristics of the sheet are not substantially changed.

Cold Curving

This technique simply involves installing a curved sheet, thereby placing a slight bending stress across the sheet. The stress levels in the curve are a function of sheet thickness and radii, and, provided they do not exceed a recommended maximum, the stress will have no influence upon the property performance. The basic criteria for the minimum radii is 100 times sheet thickness for uncoated Lexan® sheet products, 175 times sheet thickness for Lexan® Exell® D and 300 times the sheet thickness for Lexan® Margard® FMR. Table 1.2a outlines the recommended radii for a range of sheet thicknesses. This technique is not recommended for Lexan® Margard® MR5E. As combinations of high stress and unfavourable chemical conditions can lead to environmental stress-cracking in the contact areas, it is essential that all materials are checked for chemical compatibility prior to installation. Curving Lexan® CTG or uncoated Lexan® sheet, prior to the drape forming process, may be done at radii 100 times to the sheet thickness.

Table 1.2a: Minimum Cold Curving Radii

Sheet Thickness (mm)	Lexan® Exell® D Min. Radius (mm)	Uncoated Lexan® Products Min. Rad. (mm)
1.0	-	100
1.5	-	150
2.0	350	200
3.0	525	300
4.0	700	400
5.0	875	500
6.0	1050	600
8.0	1400	800

Table 1.2b: Minimum Cold Curving Radii

Sheet Thickness (mm)	Lexan® Margard® FMR5E/FLG5*
2	600
3	900
4	1200
5	1500
6	1800
8	2400

* One side coated FMR5E

Cold Line Bending

Cold line bending is possible, since Lexan sheet products are very ductile, even at low temperatures. However, the process does involve some degree of permanent plastic deformation and the results are dependent upon sheet thickness, tooling and the angle of strain bending. A typical cold line bending operation is illustrated in Figures 1.20 and 1.21.

Recommendations for Cold Line Bending

- Use sharp tool edges.
- Allow sufficient time for sheet relaxation after bending (\pm 1-2 days).
- Do not reduce bending angle during installation or force the sheet into the desired position.
- Bending operation should be performed quickly for optimum results.
- Textured sheets should only be bent so that the textured surface is in compression.
- Due to stress relaxation immediately following bending, overbending is usually required to achieve the desired angle.
- Coloured sheets can show tint variations along the bend following bending.

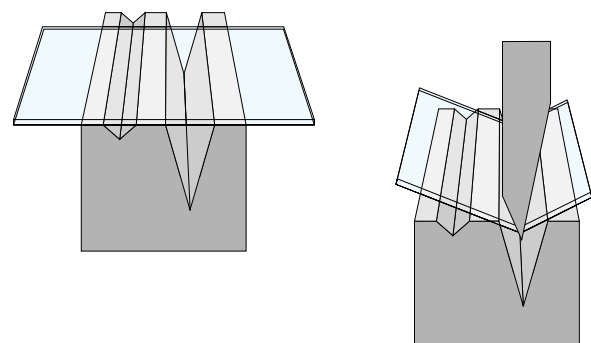
Smooth and notch-free edges (rounded and/or 45° tapered edges) of the Lexan® sheet are necessary to avoid-side cracking during bending. In order to limit the critical elastic strain, cold line bending is usually restricted to an angle of 90° or higher, for sheet thicknesses up to 6 mm.

Thicker Lexan® sheet of 8, 9.5 and 12 mm, can be cold line bent up to an angle of 135°.

Following bending, residual stresses will remain in the sheet and will reduce the impact strength of the material in the area along the bend. This technique should therefore be limited to less demanding applications.

The mar resistant coating of Lexan® Margard® MR5E and FMR sheet and the U.V. protected surface of Lexan® Exell® D sheet may be damaged around the bent area during the bending process. For more information on any of the forming techniques please contact your local GE Plastics Structured Technical Service Centre.

Fig.1.20 and 1.21: Cold Line Bending



2.0 Fabricating Techniques

Fabrication can be defined as the construction, manufacture or assembly of a number of related component parts. For Lexan® polycarbonate sheet products, that could involve the construction of window panels, the manufacture of a large motorway sign or the assembly of a safety shield around a piece of machinery. In one way or another each of these applications requires fabrication. The following section discusses the techniques and processes used to fabricate finished products from Lexan® polycarbonate sheet and provides recommendations and advice on how to achieve the best results.

2.1 Cutting and Sawing

Lexan® polycarbonate sheet products can be cut and sawn easily and accurately using standard workshop equipment. Circular saws, band saws, jig saws and common hacksaws can all be used successfully. However, certain important guide-lines should be followed. General guide-lines are listed below with specific recommendations outlined in each cutting section.

- The sheet must always be securely clamped to avoid undesirable vibration and rough cut edges.
- All tools should be set for cutting plastics with fine toothed panel blades.
- The protective masking should be left on the sheet to prevent scratching and other surface damage.
- When finishing the edges of all Lexan sheet products should be clean and free of notches.
- If possible swarf and dust build-up should be blown away with a compressed air supply.

Circular Saws

This type of cutting operation is the most common and, whilst cutting speeds and feeds are not so critical as with other thermoplastics, it is important to follow the recommended guide-lines.

- Tungsten carbide tipped saw blades are preferred with alternative teeth bevelled at 45° on both sides to improve cutting and reduce side pressure.
- Always use a low feed to get a clean cut.
- Always start cutting with the blade at full speed.
- For single sheets less than 3 mm thick, bandsaws or jig saws are preferred to circular saws.

Bandsaws

These can be of the conventional vertical type or the specially developed horizontal type suitable for plastic sheet materials. In both cases it is vital that the sheet is adequately supported and clamped during the cutting operation. The saw guides should be as close to the sheet as possible to reduce blade twist and off-line cutting.

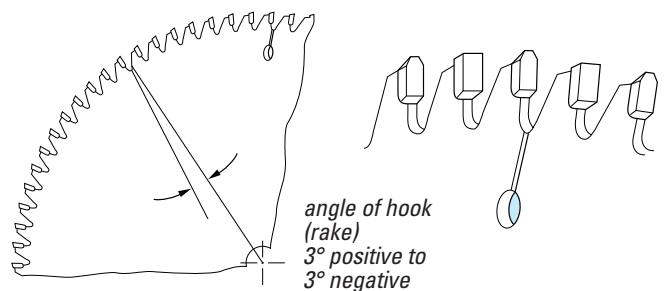
Jig Saws and Hacksaws

The most important consideration with this type of cutting is support and clamping, particularly with the use of a jig saw. Blades having a tooth spacing of 2-2.5 mm are ideal with the emphasis upon low cutting feeds.

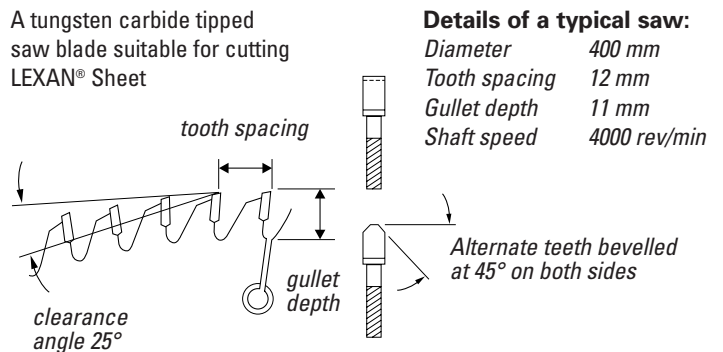
Table 2.1: Cutting and Sawing Recommendations

	Circular Saw	Bandsaw
Clearance Angle	20°-30°	20°-30°
Rake Angle	5-15°	0-5°
Rotation Speed	1800-2400 m/min	600-1000 m/min
Tooth Spacing	9-15 mm	1.5-4 mm

Fig. 2.2: Typical Tungsten Carbide Tipped Circular Saw suitable for Lexan® sheet products



A tungsten carbide tipped saw blade suitable for cutting LEXAN® Sheet



Details of a typical saw:

Diameter	400 mm
Tooth spacing	12 mm
Gullet depth	11 mm
Shaft speed	4000 rev/min

2.2 Drilling

Standard high speed steel twist drills or drills with an angular wedged bit can be used for drilling Lexan® sheet products. Carbide-tipped drills can also be used since they retain their sharp cutting edge. The most important factor to consider when drilling Lexan® sheet products is the heat generated during the actual process. In order to produce a clean, well-finished hole that is stress-free, the heat generated must be kept to an absolute minimum. By following a few basic guide-lines, clean, stress-free holes can easily be produced.

- The drill hole must be cleared frequently to prevent swarf build-up and excessive frictional heat.
- The drill must be raised from the hole frequently and cooled with compressed air.
- The sheet or product must be adequately clamped and supported to reduce vibration and ensure a correctly sized hole.
- Holes should not be drilled closer to the edge of the sheet than 1-1.5 times the diameter of the hole.
- All holes must be larger than the bolt, screw or fixing to allow for thermal expansion and contraction.
- For long production runs the use of carbide-tipped twist drills is recommended.

Drilling feeds and speeds are outlined in Table 2.2 with the various drill configurations in Figures 2.3 to 2.6.

Table 2.2: Drilling Recommendations

Hole Diameter	Speed (rev/min)	Feed (mm/min)
3	1750	125
6	1500	100
9	1000	75
12	650	50
18	350	25

Recommended drill angles:

Clearance Angle	α	15°
Rake Angle	λ	0°-5°
Included Tip Angle	ϕ	120°-160°
Helix Angle	β	30°

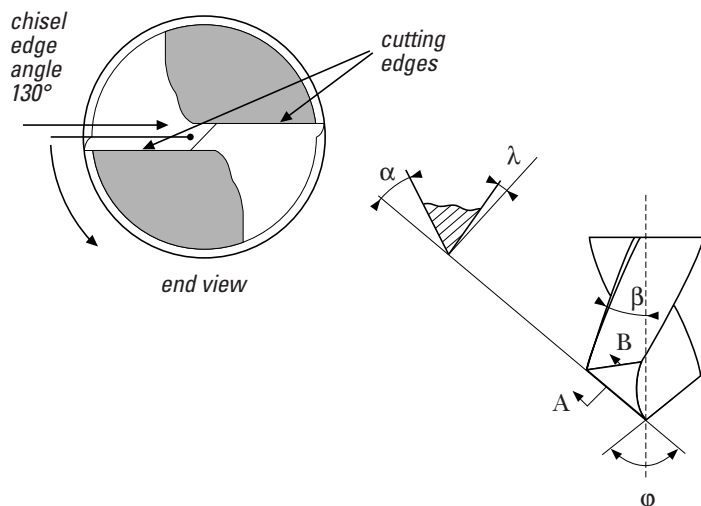


Fig. 2.3 and 2.4: Typical Drill Configuration

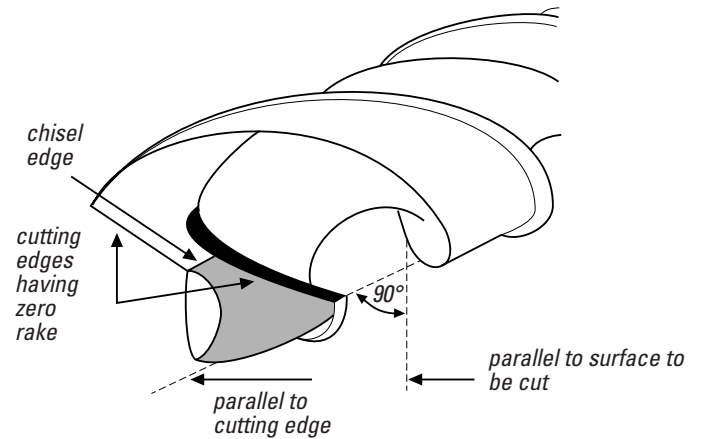


Fig. 2.5: Drill suitable for large holes

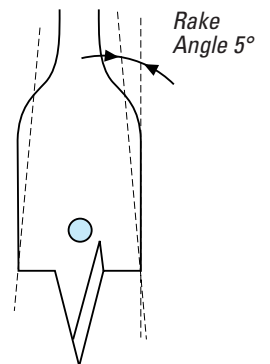
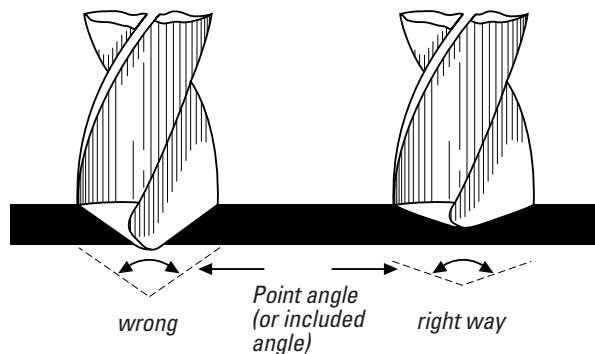


Fig. 2.6: Drill suitable for thin sheet



2.3 Milling

Lexan® sheet products can be machined using conventional milling machines fitted with standard high speed knife cutting tools.

Once again the importance of suitable clamping cannot be over-emphasised. Mechanical jigs and fixtures, or vacuum chucks provide a suitable clamping medium.

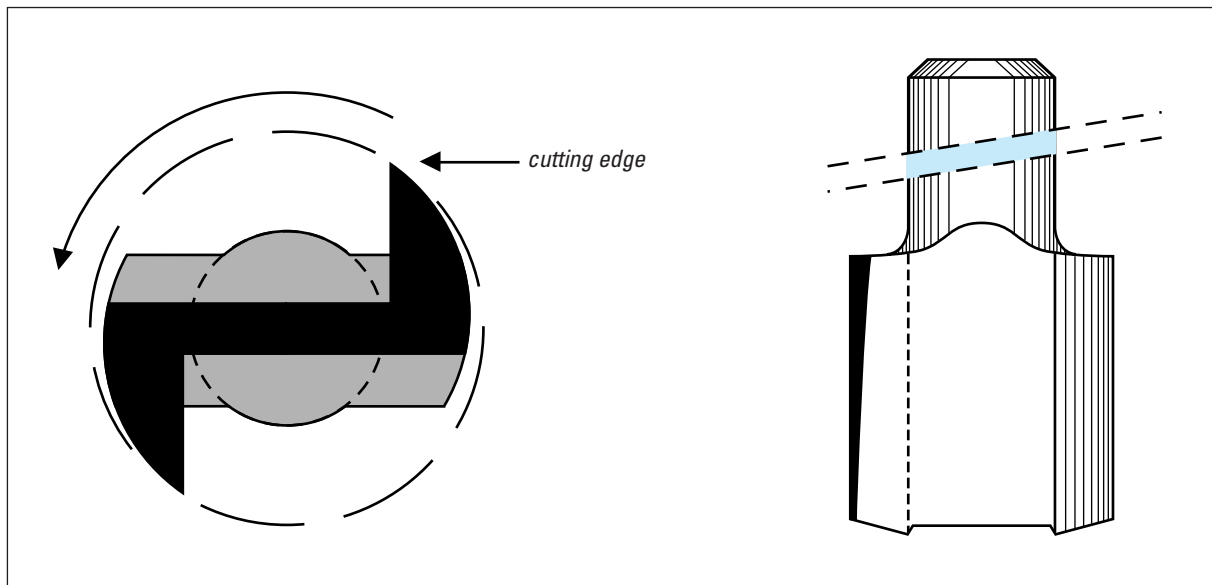
Table 2.3 outlines appropriate cutting speeds and feeds with a typical cutting tool illustrated in Figure 2.7. Forced-air cooling enables higher cutting rates. However, care should be taken not to over-heat the material. The use of cutting fluids to lubricate or cool the sheet is not recommended.

Computerised trimming is a fully automatic milling process. It is extremely accurate and operates horizontally as well as vertically. The use of a vacuum-operated jig avoids vibration of the part ensuring a smooth cut. Standard high speed, two-sided cutting routers with tungsten carbide tips are recommended, with a cutting speed of approximately 250 m/min at 25.000/30.000 RPM at a sheet thickness of 4 mm.

Table 2.3: Milling Recommendations

Clearance Angle	5°-10°
Rake Angle	0°-10°
Cutting Speed	100-500 m/min
Cutting Feed	0.1-0.5 mm/rev.

Fig. 2.7: Typical Milling Cutter



2.4 Mechanical Fastening Devices

With a few exceptions, all mechanical assembly techniques involve some form of additional fastening device. The choice of device is often dependent upon the nature of the fastening required. Whilst rivets tend to be permanent, screws and nuts can be made detachable and some of the spring clips types can be either permanent or separable.

There are many different types of mechanical fastening system which can be used successfully to assemble plastic sheet components.

Within the limitations of this publication only a small number can be discussed.

For simplicity they are divided into three groups:

- Screws, nuts and bolts
- Rivets
- Spring clips and other fastening devices

Two important factors need to be considered with all these fastening systems. Firstly, allowance needs to be made for thermal expansion and contraction. All holes, slots and cut-outs must be machined over-size to allow for the dimensional changes as a result of temperature changes. Secondly, the distribution of tightening torque should be equal. With the aid of compatible rubber washers and large screw and rivet heads, the tightening torque should be spread over as wide an area as possible and should not be excessive.

Table 2.4

Material	m/m°C x 10-5
Lexan sheet	6.7
Glass	0.7 - 0.9
Aluminium	21. - 2.3
Steel	1.2 - 1.5

2.4.1 Screws, Nuts and Bolts

Machine Screws

The majority of these screws are made from steel, but other metals and alloys are used for specialised applications. Several examples of this type of fastening system are shown on this page. Figures 2.9 and 2.10 illustrate sheet fastening devices known as 'blind screw' and 'blind nut' anchors.

Self-Tapping Screws

Self-tapping screws are widely used within the plastics industry.

Basically they produce their own thread as they are driven into a hole and may be considered whenever an assembly is likely to be dismantled and re-assembled. Whilst the majority of these screws are designed for plastic mouldings, with the aid of spring clips and washers they can be adapted for sheet applications. Figures 2.11 to 2.14 show some typical fastening systems.

Caution

If the application calls for a screwed assembly, it is vitally important that the following recommendations are considered.

- Do not use countersunk head screws as the 'wedging' action of the countersunk head causes excessive hoop stress on the sheet. This can lead to part failure.
- Be sure that all oil, grease and other coatings are removed from the screws before assembly. Certain oils and greases can cause environmental stress cracking.

Fig. 2.11-2.14: Other Typical Fastening Systems

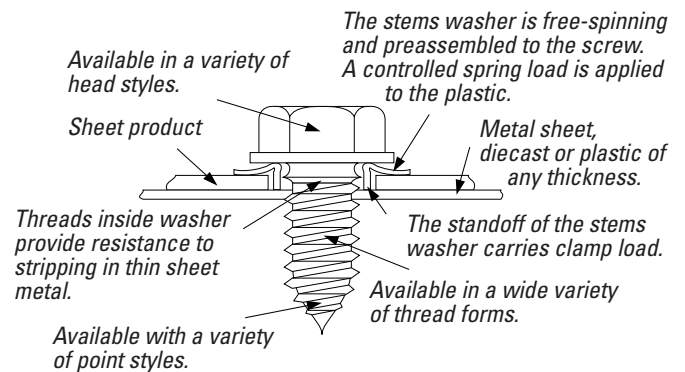
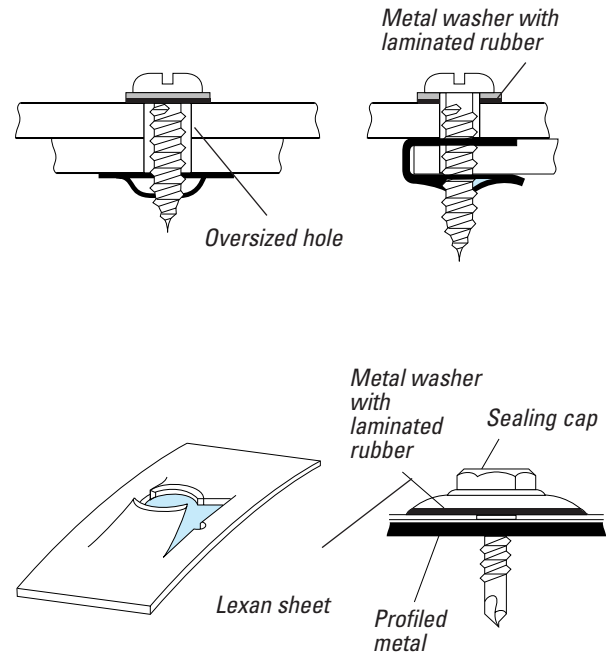
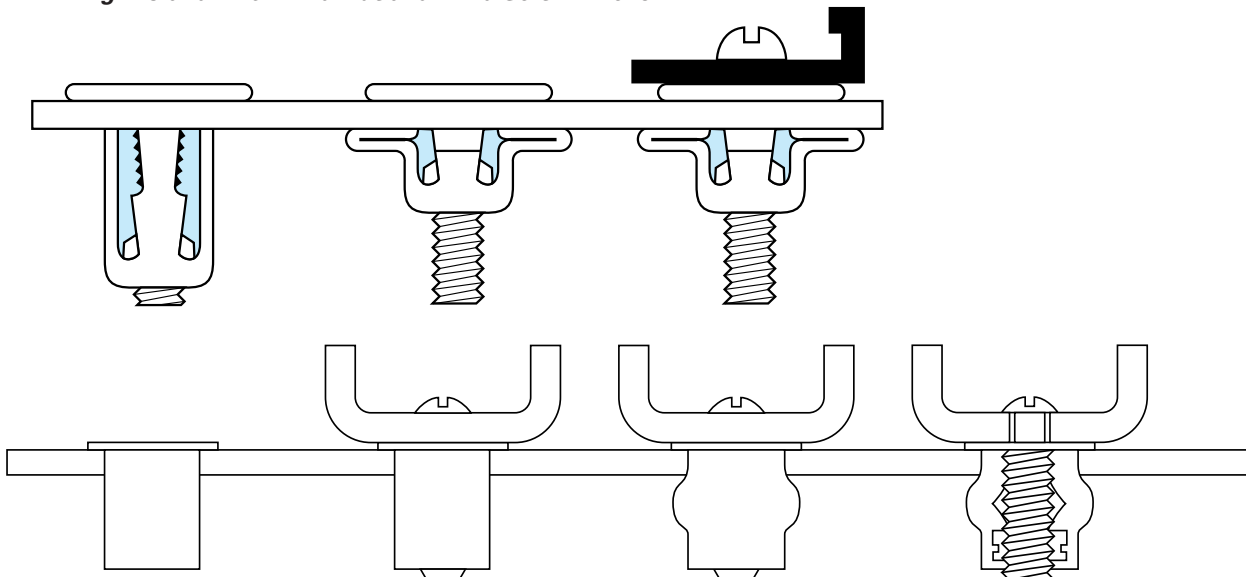


Fig. 2.9 and 2.10: Blind Nut and Blind Screw Anchor



2.4.2 Riveting Systems

Whilst riveting is a popular and effective assembly technique, certain guide-lines should always be followed when considering this type of assembly method. Riveting can induce both radial and compressive stresses in the plastic sheet and precautions should be taken to distribute these forces over as wide an area as possible.

In a plastic-to-plastic assembly a metal back-up washer with laminated rubber is recommended to reduce the compressive stresses. If the diameter of the rivet with a rubber washer is slightly bigger than the hole diameter, then the hoop stresses will be transmitted to the washer rather than the plastic sheet. For plastic-to-metal joints, the head of the rivet with a rubber washer should be against the plastic, and the hole in the sheet should be large enough to allow for thermal movement. Holesize is 1.5 x expanded rivet diameter.

Rivet diameters should be as large as possible and spacing should be between 5-10 times their diameter. GE Plastics Structured Products recommends the use of aluminium, brass and copper rivets.

There are several different types of riveting system, however, the most popular is the 'pop-rivet'. This type of rivet provides the means to assemble two components together with access restricted to one side only. Figures 2.15 and 2.16 illustrate typical rivet assemblies.

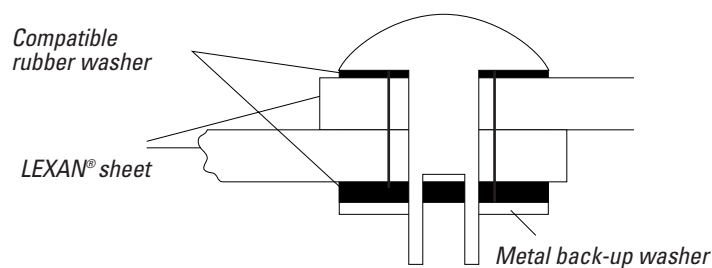
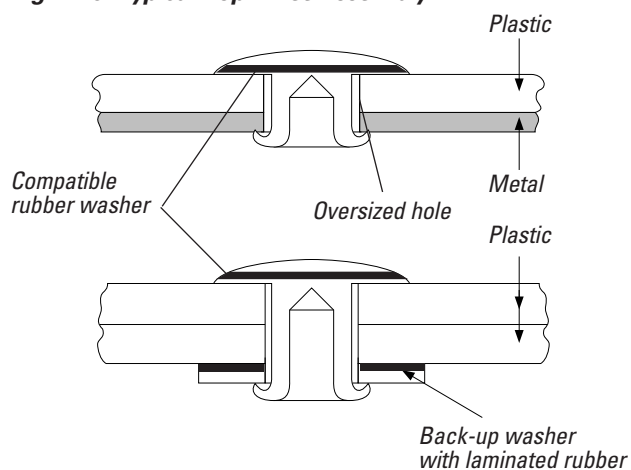


Fig. 2.16: Typical Pop-Rivet Assembly



2.5 Miscellaneous Fabricating Techniques

Many different techniques are used to cut and fabricate Lexan® polycarbonate sheet products.

These techniques include:

- Shearing
- Punching
- Tapping
- Laser Cutting
- Water Jet Cutting

Whilst these techniques are used, they are not recommended since they either induce unnecessary stress on the finished part or result in a poor surface finish.

With both shearing and punching the process involves a shearing action with a guillotine or a punch which tends to leave a roughly cut surface. This surface often contains micro-cracks which may lead to premature failure.

Tapping is possible in Lexan® polycarbonate. However, the process is usually restricted to moulded parts. Self-tapping screws or machine screws require a minimum depth to achieve the necessary holding power and sheet products do not have the necessary thickness.

Laser cutting of GE sheet products is not recommended due to the following disadvantages:

- Rough cutting edges
- Carbon deposition on cutting edges
- Stress level increase in thick sheets

With water jet cutting, the following considerations should be taken into account:

- No stress at any sheet thickness
- Cutting edge requires further finishing
- Limited cutting speed
- Expensive equipment

For more information regarding fabricating techniques or any assembly process please contact your nearest GE Structured Products Technical Service Centre.

3.0 Finishing, Decorating and Cleaning

As the final steps in an assembly process, finishing and decorating often takes up the most time and require the most significant input. The operations are usually performed on the surface appearance of the assembly. Attention to detail is essential if the components are to perform their required function. In this particular area, it is also vital that appropriate consideration is given to the chemicals coming into contact with the Lexan® polycarbonate sheet product. Whether the chemical is a paint system, an adhesive system or a cleaning agent, it is essential that it is compatible with the Lexan® sheet product. GE Structured Products has a comprehensive database listing compatible systems, and advice and support is always available from all GE Structured Products Technical Service Centres.

3.1 Chemical Resistance

The chemical resistance of a thermoplastic is dependent upon five major factors:

1. Stress level in the application
2. Temperature
3. Exposure time
4. Chemical concentration
5. Type of chemical involved

Lexan® polycarbonate resin has a good chemical resistance, at room temperature, to a variety of dilute organic and inorganic acids. Water, vegetable oils, solutions of neutral salts, aliphatic hydrocarbons and alcohols are also included in this category. When a thermoplastic is attacked by a chemical it usually takes one of three forms. In the first case the chemical is absorbed into the plastic, and plasticisation and/or crystallisation occurs. The visible signs of this type of attack are swelling or surface whitening. Lexan® polycarbonate is affected in this way by partial solvents such as low molecular weight aldehydes and ethers, ketones, esters, aromatic hydrocarbons and perchlorinated hydrocarbons.

In addition, chemical attack ranging from partial to complete destruction of Lexan® polycarbonate occurs in contact with alkalines, alkali salts, amines and high ozone concentrations.

The third type of attack is often the most difficult to predict since environmental conditions dictate whether or not the plastic will be affected.

Combinations of certain environments, coupled with stress and/or strain upon the material, cause stress cracking or crazing of the polycarbonate. Crazing can be induced at moderate to high stress levels by low molecular weight hydrocarbons. Products such as acetone and xylene may cause stress cracking even at very low stress levels and should therefore be avoided.

Taking into account the complexity of chemical compatibility, all chemicals which come into contact with polycarbonate should be tested. For sheet products the most common contact is with sealants, gaskets and the various cleaning media.

Chemical compatibility testing, Figure 3.1, is an on-going process at GE Structured Products and many standard products have already been tested. A complete list of recommended cleaners, gaskets and sealants is available upon request. However, a shortened list of some of the more common compounds is outlined in the respective sections in Tables 3.2-3.6

In case of doubt about any aspect of chemical compatibility of Lexan® polycarbonate sheet always consult your nearest GE Structured Products Technical Service Centre for further advice.

Chemical Resistance of Lexan® Margard® MR5E The 'mar' resistant coating of Lexan® Margard® provides an additional benefit in terms of chemical resistance. The proprietary

coating is resistant to a range of chemical agents that under normal circumstances are detrimental to Lexan® polycarbonate.

Table 3.1 outlines the results of a series of tests carried out on coated and uncoated Lexan® polycarbonate sheet.

The tests also included an evaluation of impact resistance and in each case the application of the chemical showed no significant effect upon the impact resistance of the Lexan® Margard®. The tests were conducted on 3 mm samples with an exposure time of 5 minutes, at room temperature and stress-free.

Fig. 3.1: Lexan® sheet chemical compatibility summary

Chemical class	Effects
Acids (Mineral)	No effect under most conditions of concentration and temperature.
Alcohols	Generally compatible.
Alkalis	Acceptable at low concentration and temperature. Higher concentrations and temperatures result in etching and attack as evidenced by decomposition.
Aliphatic Hydrocarbons	Generally compatible.
Amines	Surface crystallisation and chemical attack.
Aromatic Hydrocarbons	Solvents and severe stress-cracking agents.
Detergents and Cleaners	Mild soap solutions are compatible. Strongly alkaline ammonia materials should be avoided.
Esters	Cause severe crystallisation. Partial solvents.
Fruit Juices and Soft Drinks	Compatible at low stress levels. Some concentrates not recommended.
Gasoline	Not compatible at elevated temperatures and stress levels.
Greases and Oils	Pure petroleum types generally compatible. Many additives used with them are not, thus materials containing additives should be tested.
Halogenated Hydrocarbons	Solvents and severe stress-cracking agents.
Ketones	Cause severe crystallisation and stress-cracking. Solvents.
Silicone Oils and Greases	Generally compatible up to 80°C.

Table 3.1: Lexan® Margard® Chemical Resistance Tests

Chemicals	Uncoated PC	Lexan® Margard® MR5E
Toluene	W/S	ok
Acetone	S	ok
Methylethylketone	S	ok
Dichloromethane	W/S	ok
Sulphuric acid (95-97%)	ok	ok
Hydrochloric acid (32%)	ok	ok
Ammonia (25%)	ok	ok
Thinner (Sikkens 1-2-3)	W/S	ok
Super Gasoline (Esso)	W/S	ok
Diesel Fuel (Esso)	ok	ok
Fuel C	ok	ok
Hairspray	ok	ok

W = surface whitening

S = surface dissolution

3.2.1 Painting

Be it simple or complex, decorative or functional, hand-controlled or automatic, painting Lexan® sheet products offers the designer the freedom to create a dramatic effect in a sign or a simple colour code for instructions.

Provided certain basic recommendations are followed, most techniques used to apply paint to wood, metal, building materials and other plastics can be used for Lexan® sheet products. The important factor is once again one of compatibility. Only approved paint systems should be used. Some paint and thinner systems are not compatible with Lexan® sheet products and can cause stress cracking and a reduction in impact performance. Paint systems for Lexan sheet should be flexible. Combinations of flexible primers and hard top coats could also work. Any paint system should be flexible at subzero temperatures.

In view of adhesion problems, painting is not recommended for decorating the coated sides of either Lexan® Margard® MR5E or Lexan® Margard® FMR.

Painting Recommendations

- Clean the sheet and remove static with a damp chamois cloth or ionised air treatment.
- Avoid too high a delivery rate and too heavy a wet coat thickness.
- Allow adequate drying before applying spray mask to painted areas.
- Do not expose painted faces to a low temperature and high humidity environment during drying.
- Use dry air in all compressed air lines. Drain water taps frequently.
- Paint solvents should be evaporated from the paint surface as quickly as possible by providing appropriate air circulation.
- Follow recommended machining and trimming practices for finishing post-decorated faces.

Table 3.2: Painting Systems for Uncoated Lexan® sheet

Supplier	Paints	Thinner	Comments
AKZO Coatings	Autocryl 01-69004 Class 45	- 06-302007	2K Acrylic Primer/2K/PUR Top coat/2K/PUR
Diegel	PA 21	24896	1K Flex. acrylic
Schaepman	C1 F57 C1 W28 C4 P212	VOA 462 Water VOA421/H4P4	Acrylic Acrylic/water based 2K Acrylic
Herberts	R 47633 41605 R 4790 R 4780	- 11098 - -	2K Primer Basecoat BMW metallic 2K Clearcoat 2K One layer system
Becker	TH 130 DJ-331-5176 TC 132	NT19 ET-134 -	2K Top coat 1K Primer (flexible) 2K Clear coat
HSH	Interplan 1000		1K Water-based
Morton	L446	U987	1K Acrylic System

NB. For information regarding application techniques and property values please contact the relevant paint supplier.

3.2.2 Screen Printing

Silk-screen printing is a well-established process that offers a wide variety of options for a decorative finish. However, in most cases the printing must be accomplished prior to installation, since the process is basically a horizontal one and is generally restricted to small-to-medium part sizes.

The process involves forcing viscous inks through a very fine, thin screen that is treated in such a way as to allow the ink only through to the patterned area. Special inks are required that are formulated so that they will pass through the mesh, while being sufficiently viscous to prevent run-out.

This type of finishing operation is often used in the sign industry and a wide variety of screen printing inks and thinners are available.

Once again the importance of chemical compatibility cannot be over-emphasised and only paints and thinners recommended for use with Lexan® sheet products should be used.

This process is not suitable for decorating Lexan® Margard® MR5E, Lexan® Margard® FMR5E and Lexan® Margard® MRA3.

The one side coated Margard® grades such as Lexan® Margard® HLG5, Lexan® Margard® FLG5 and Lexan® Margard® HLGA3 can be screenprinted at the uncoated side

Screening Recommendations

- Use only approved paints and thinners.
- Do not mix different paints and inks.
- Do not substitute spray thinners for screen thinners.
- Do not add solvents such as toluene, xylene, cellulose acetate, methylethylketones or other related chemicals to the inks.
- Use water-moistened chamois or soft cloths to avoid abrasion or scratching during cleaning prior to printing.
- Use the correct colour of paint to achieve opacity required.
- Provide good air circulation and ventilation during drying.

Table 3.3: Silk Screen Inks for Uncoated Lexan® sheet

Supplier	Inks
Sericol	Seritec TH Polyplast PY Uvispeed UX
Diegel	HV/Z
Gibbon Inks & Coating Ltd.	Malercryl Polyvin/Marlerstyrene
Coates	Vynaglaze/Vynafresh /Touchkey/HG/PK/PK-Jet
Pröll	Jet 200/Thermo-Jet/ Noriprint PS
Marabu	Marastar SR/Maraplast D

3.2.3 Anti-static Treatment

As common with all insulating materials, Lexan® polycarbonate sheet tends to build up a static charge. It is often necessary to clean and discharge the surface prior to painting or screen printing.

Wiping the sheet with a damp chamois or applying de-ionised air to the surface is often all that is required. Another effective method in minimising static charge build-up is control of the relative humidity: the higher the relative humidity, the lower the static charge build-up will be. Relative humidity preferably should always be above 60%.

3.3 Adhesives and Sealants

The use of adhesives to bond dissimilar materials is now universal. Over the past twenty years polymer technologists have developed adhesives with a wide range of properties and application profiles. Adhesion technology has become a branch of the plastics industry in its own right, offering a technique that is one of the most efficient, effective and economical methods of joining plastic components to themselves and to other materials. However, it is a technology that often causes the most problems. Whilst some adhesives/sealants form a flexible bond, others form a rigid bond. Some are capable of filling gaps, whilst others are for close contact. Some can withstand high temperatures, whilst others cannot. The choice of adhesive types is vast, as are the applications areas. It is vitally important, therefore, to select the adhesive carefully, ensuring its compatibility with the materials being used and the working environment.

The importance of chemical compatibility was discussed in Section 3.1 and adhesive selection and testing is an ongoing process at GE Structured Products. A comprehensive data-base of suitable adhesives is available and in all cases it is strongly recommended that all adhesives are checked for compatibility before use.

Table 3.5 presents an overview of some of the initial criteria used to select an adhesive and Table 3.6 provides a list of compatible adhesives indicating generic types, trade names and application areas. Figures 3.2 and 3.3 outline some typical joint configurations and can be a guide in determining the right joint geometry for an application.

3.3 Adhesives and Sealants

Table 3.5: Adhesive Groups and Property Profile

	Impact Behaviour	Moisture Behaviour	Number of Components	Temperature Limits (°C)	Gap Filling
Epoxy	Bad	Very Good	1 or 2	200 +	+
Polyurethane	Very Good	Good	1 or 2	140	+
Hot Melt	Good	Good	1	60	+/-
Silicone	Excellent	Very good	1 or 2	250	+

Table 3.6: Adhesive Selection Chart for Lexan® polycarbonate sheet products

Adhesive Type	Product Name	Joins Lexan® sheet to:	1/2 Part System	Supplier	Comments
Epoxy	Scotch Weld DP 110	Metals, Plastics, Rubbers	2 part	3M Company	Fast curing, epoxy with high shear strength
Epoxy	Scotch Weld DP 190	Plastics	2 part	3M Company	Epoxy with high shear strength
Polyurethane	Bison PUR	Plastics, Metals, Wood	2 part	Perfecta	
Polyurethane	Plio-grip 6000	Plastics, Metals, Wood	2 part	Good Year	Flexible, very short pot life (10min.)
Hot Melt	Jet Melt 3736 Jet Melt 3764	Plastics, Wood Plastics, Wood	1 part	3M Company	Good heat resistance. Oil and water resistant
Hot Melt	Macromelt XS6335	Plastics, Metal, Glass, Ceramics	1 part	Henkel	Clear
Silicone	*Silpruf® SCS2000	Lexan® uncoated Lexan® Exell® D, Lexan® Margard® MR5E + FMR Building Materials	1 part	GE Bayer Silicones	Excellent adhesion, UV and weather resistant, flexible.
Silicone	*SEA 210	Plastics, Glass, Metal, Wood	2 part	GE Bayer Silicones	Fast Cure
Silicone	Multi Sil	Lexan® uncoated Lexan® Exell® D, Lexan® Margard® MR5E + FMR Building Materials	1 part	GE Bayer Silicones	Excellent adhesion, UV and weather resistant, flexible.
Tapes	Scotchtape VHB Range	Plastics, Glass, Metals	-	3M Company	Double sided Pressure sensitive
Tapes	Fas Tape	Metals/ Plastic	-	Fasson	Double coated
Tapes	PS-18	-	-	Velcro	Hook and loop tape
Tapes	SR 321 SW 321	-	-	Multifoil	PE Foam, 2 sides PE Foam, 2 sides
Tapes	5669	-	-	Sellotape	PE Foam, 2 sides

* These products are compatible with coated Lexan® sheet products, Lexan® Exell® D, Lexan® Margard®. Other silicone sealants may contain AMINO or BENZAMID curing agents which are not compatible with Lexan® sheet and may cause stress corrosion. Consult the manufacturer before using other silicone sealants.

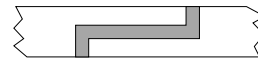
The listed adhesives, adhesive tapes and sealants have only been tested under normal atmospheric conditions to determine their compatibility and adhesion performance with Lexan® sheet products. The actual choice of adhesive will depend upon the design of the joint, the circumstances under which the joint will be used and the prevailing environmental conditions. In all cases the adhesive type should be fully tested under exact conditions to determine complete compatibility and performance.

3.3 Adhesives and Sealants

Lap Joints

The double butt lap joint provides maximum uniform stress distribution in the load bearing area.

Fig. 3.2: Joint Design Configurations



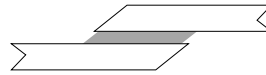
1. Double Butt Lap Joint

The joggle lap joint allows a more uniform stress distribution than a single tapered lap joint.



2. Joggle Lap Joint

A tapered single lap joint is more efficient than a single lap joint, allowing for bending of the joint edge under stress.



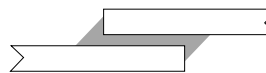
3. Tapered Single Lap Joint

A double lap joint allows for greater rigidity than a single lap joint.



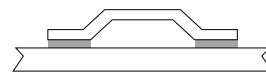
4. Double Lap Joint

A simple lap joint could create cleavage and peel stress under loading, particularly in bonding thin sheets.



5. Simple Lap Joint

A round lap joint can be used to add rigidity and strength to an assembly and minimise the deflection of flat sheets.



6. Round Lap Joint

Double scarf lap joints have better resistance to bending forces than double butt joints.

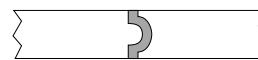


7. Double Scarf Lap Joint

Butt Joints

Rounded tongue and groove joints are self-aligning and can act as an overflow reservoir for adhesives.

Fig. 3.3: Joint Design Configurations



1. Rounded Tongue and Groove Joint

Landed scarf tongue and groove joints function as control stops for adhesive line thickness.



2. Landed Scarf Tongue and Groove

Recessed tongue and groove joints improve cleavage resistance of straight butt end joints.



3. Tongue and Groove Joint

Straight butt end joints are not usually recommended for most types of applications.



4. Butt Joint

3.4 Cleaning Recommendations

Periodic cleaning of all Lexan® polycarbonate sheet products can be accomplished easily and without the need for specialised cleaning agents. However, as is the case with all thermoplastic materials, certain chemicals can cause structural as well as surface damage and precautions need to be taken to avoid any aggressive cleaning agents.

The basic cleaning agent for all Lexan® polycarbonate products is a solution of lukewarm water with mild soap or household detergent, using a soft cloth or sponge to loosen any dirt and grime.

All surfaces are then rinsed with cold water and dried with a soft cloth to prevent water spotting. However, in some cases this may not be sufficient and certain solvent cleaners may be needed to remove stubborn stains, graffiti etc. In these cases the following list of cleaning agents are approved for use at room temperature:

- Methyl alcohol
- Ethyl alcohol
- Butyl alcohol
- Isopropyl alcohol
- White spirit
- Heptane
- Hexane
- Petroleum ether (BP 65°)

Cleaning prior to Forming

Should it be necessary prior to forming to clean Lexan® sheet,

it is recommended that the dust is blown off with an ionising air gun or the sheet is wiped with a soft cloth dipped in water or a mixture of isopropanol and water.

Recommendations for Cleaning Lexan® Margard®

The unique surface of Lexan® Margard® sheet provides superior protection against chemical attack. Even graffiti such as spray paint are easily and quickly removed. Although Lexan® Margard® has a mar resistant coating, the use of abrasive cleaners and/or sharp cleaning instruments that may damage or scratch the coating should be avoided.

The recommended cleaning procedure for the removal of graffiti etc. is as follows:

- Paints, marking pens, inks, lipstick, etc, use graffiti remover. (See Table 3.7).
- Labels, stickers, use kerosene or white spirit.
- Final wash with warm soap solution, followed by rinse with clean water.

Table 3.7: Recommended Graffiti Removers

Supplier	Product	Application
Chemalex	Vandalex	Spray/hand
Nucoat	AG 2	Hand/cloth
Prochemko	Graffitex III	Hand/cloth
Jumbo	J.T. Graffiti	Spray/hand/cloth

Recommended Cleaner Supplies

DiverseyLever Divizia
Odborárska 52
SK-831 02 Bratislava
Slovakia
Ph: 07 - 501 29 88/
Ph: 07 - 525 48 95

DiverseyLever
Haachtsteenweg 672
B-1910 Kampenhout
Belgium
Ph: 016 - 61 77 77

DiverseyLever AG
CH-9542 Münchwilen
Switzerland
Ph: 071 - 969 27 27

DiverseyLever
Wienerbergstrasse 7
A-1103 Vienne
Austria
Ph: 01 - 60 55 70

DiverseyLever SRO
Táborská 5/979
140 00 Praha 4
Czech Republic
Ph: 02 - 61 22 25 24

DiverseyLever A/S
Smedeholm 3-5
DK-2730 Herlev
Denmark
Ph: 044 - 85 61 00

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Recommended cleaners

SUMALIGHT D12

BRUCODECID
(heavy duty cleaner
i.e. Railwaystations)

Points to remember



- **Don't use abrasive or highly alkaline cleaners.**
- **Never scrape the sheet with squeegees, razor blades or other sharp instruments.**
- **Don't clean Lexan® sheet products in the hot sun or at elevated temperatures as this can lead to staining.**

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