

FUNCTIONAL FORMS

LEXAN™ SHEET PROCESSING GUIDE

FORMING, FABRICATING, FINISHING AND DECORATING
SOLID UN-COATED AND COATED SHEET



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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 common methods of producing these parts is thermoforming. Thermoforming LEXAN sheet, a polycarbonate material, is a manufacturing process where a plastic sheet is heated to its softening temperature, formed to a specific shape in or over a mold by using vacuum, and trimmed to create a usable product. Today, thermoforming can offer many benefits over other thermoplastics processes as well as other traditional materials like steel and glass reinforced plastics. The thermoforming process requires a relatively low level of forming pressure, so tooling can be constructed less expensively than tooling used in other processes. Depending on the part size, shape, and quantity, thermoforming can be an efficient and very cost-effective production process for many plastic parts. Tooling can be produced in a very short timeframe relative to other plastic processes and may provide faster production for large volume runs compared to rotationally molded or fiberglass reinforced plastic processes; resulting in quicker time to market.

Next to providing an excellent part volume/quality ratio, thermoforming process enables freedom of design and addition of small details in the part. Also pre-colored thermoplastic sheet can give the final part a good surface finish, which can eliminate the need for painting.

By using LEXAN EXELL™ D and LEXAN XL grades, you can enhance your design opportunities with a UV-resistant surface while thermoforming your product.

There are various steps involved in thermoforming including design, processing, production, and finishing. We recommend designers to contact us before tooling. To assist designers and converters with the selection of a production method, in the following section, we have outlined some of the design and manufacturing techniques that are used for thermoforming of LEXAN sheet.



Forming

TABLE 1
FORMABILITY

Sheet Materials	Vacuum forming#	Drape forming	Twin sheet forming#	Pressure forming*	Hot line bending**	Cold line bending**	Cold curving	Flat lamination	Curved lamination
LEXAN™ 9030 / 9030 TG	●	●	●	●	●	●	●	●	●
LEXAN ULG1003	●	●	●	●	●	●	●	●	●
MARGARD™ MR5E						●			
MARGARD HLG5						●		●	
MARGARD HLGA2						●		●	
MARGARD MR5 IR						●			
MARGARD FMR		●			●	●	●		
MARGARD FLG5 XT		●			●	●		●	●
LEXAN EXELL™ D	●	●	●	●	●	●	●		
LEXAN EXELL D SC IR	●	●	●	●	●	●	●		
LEXAN EXELL D ST	●	●	●	●	●	●	●		
Sign grades	●	●	●	●	●	●	●		
MARGARD CTGXT / CTGXT AF		●							
FR grades	●	●	●	●	●	●	●		
GEPAX™	●	●	●	●	●	●	●		
ULTEM™	●		●	●	●	●	●		

Transparent sheet in contact with mold 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.



Forming

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 manufacturing, transportation and storage. When sheet material comes out of the extrusion, 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.

Trapped moisture forms vapor above 120 °C and the vapor expansion creates bubbles in the sheet. It is essential that moisture in the sheet is removed prior to forming. Standard PC sheets should be placed in a dehumidifying air circulating oven for pre-drying, with approximately 10-25 mm. separation between sheets. Oven temperature should be at 120°C and monitored with controls. Polycarbonate sheet begins absorbing moisture immediately upon removal from the pre-drying oven. The rate of absorption is dependent upon the ambient dew point. For this reason, it is crucial to transfer the sheet directly to the forming machine as quickly as possible. 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. For specific PC sheet grades, please check the product datasheet for drying temperature advice.

Before starting the drying process, masking on the sheet materials should be removed. After removing the protective masking, the sheets should be hung vertically in the air-circulating drying oven or placed in a circulation oven and pre-dried according to the recommendations outlined in Table 2. 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. Generally, 2 hours drying time per mm. thickness of the sheet at 120 °C is recommended.

Do not expose the sheet to prolonged drying times at elevated temperature. Continuous exposure beyond 24-30 hours can reduce the physical performance of the LEXAN sheet and cause discoloration.

TABLE 2

RECOMMENDED DRYING TIMES

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

THERMOFORMING TECHNIQUES

LEXAN™ sheet, a polycarbonate product, can be thermoformed into a wide variety of applications. 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 mold as in drape forming. Others, such as vacuum and pressure forming require that, after heating, the sheet is formed to conform to a mold by applying pressure or a vacuum.

While each thermoforming process is slightly different, as illustrated in Figures 1 and 2, the basic steps are very similar. Vacuum forming, pressure forming, and line bending are the mostly used processes.

Pressure forming is a type of thermoforming process and pressure is applied to the positive side of the mold to reproduce detailed mold features. The sheet is cooled, the mold moved downwards, and the product taken out of the machine. The clamping edges are removed from the product and it's ready for trimming to finish the product.

As a manufacturing process, the technique offers significant advantages and is widely used for its simplicity and low production costs. Note, however, that LEXAN™ MARGARD™ sheet cannot be thermoformed because of its protective coatings.

The major benefits of thermoforming are listed below:

- Medium to large part production
- Short lead times
- Low tooling cost versus injection molding

Forming

FIGURE 1
POSITIVE FORMING AND NEGATIVE FORMING

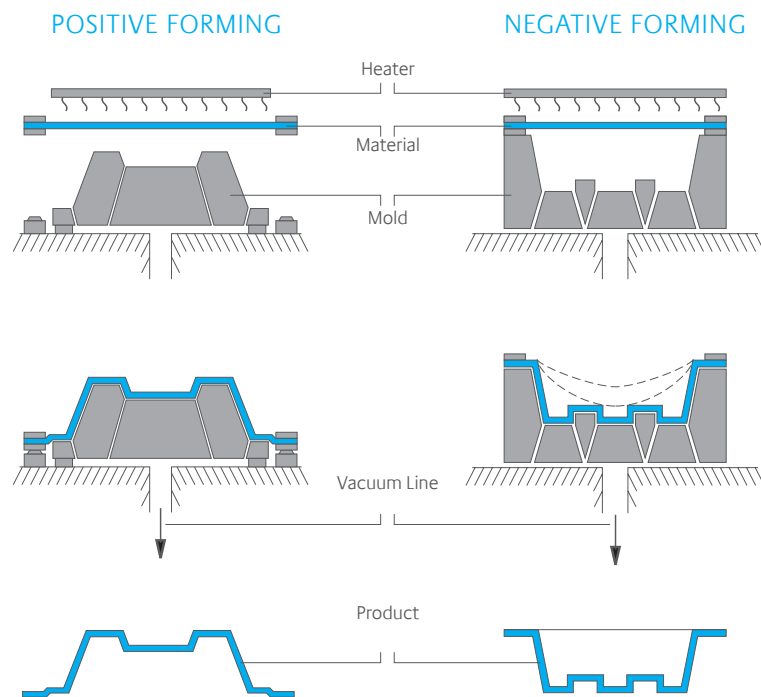
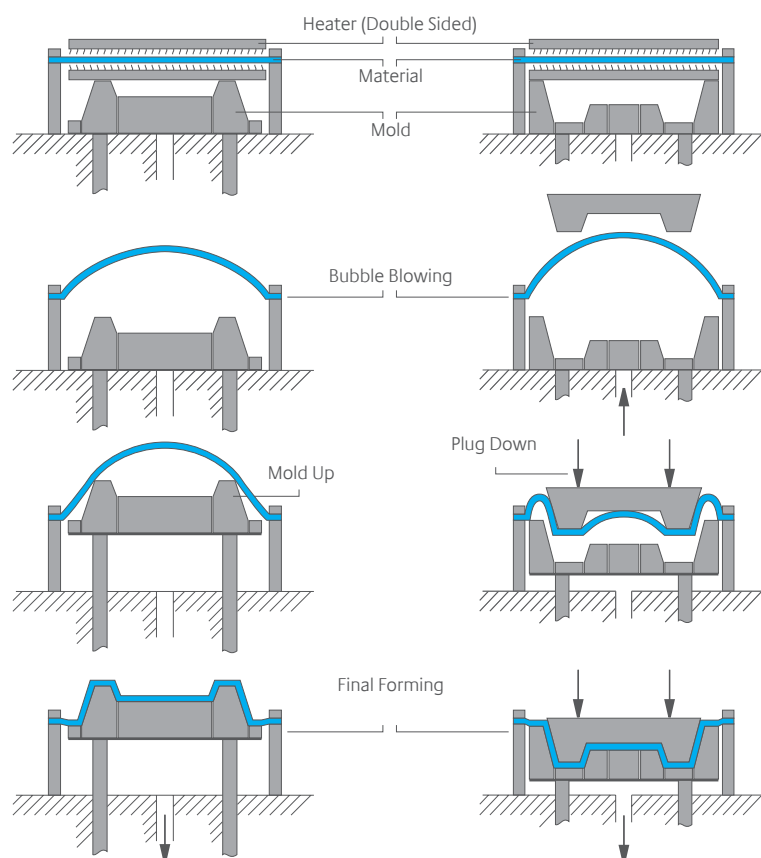


FIGURE 2
BUBBLE FORMING AND PLUG-ASSISTED FORMING



Forming

HEATING AND COOLING

HEATING

Controlled and uniform heating of LEXAN™ sheet, a polycarbonate material, is a 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, halogen heating or quartz infra-red type. Proportional timers, together with a controlled heating rate are recommended, and attention should be paid to the influence of power variations and air draughts.

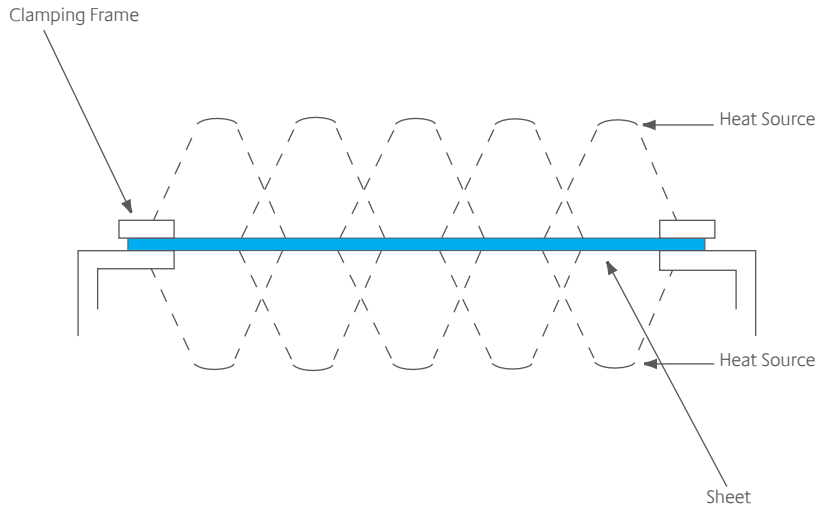
Slow heating rates will balance out hot spots and allow the sheet edges to reach the required forming temperature. Pre-heating of the clamping frame to 120 °C-130 °C is recommended. Since LEXAN sheet cools rapidly, it is essential that final control and heating is carried out on the forming machine itself. Normal sheet temperatures are in the process window of 170 °C-225 °C for vacuum forming.

Optimum forming conditions depend upon part design, draw ratio, sheet thickness and the forming technique employed.

COOLING

Cooling times are dependent upon a number of factors. These include ambient, forming and mold temperatures, mold material, cooling system, part thickness and design geometry. However, since LEXAN sheet materials have a relatively high heat distortion temperature, formed parts can be removed from the mold at around 125 °C. Forced water cooling is not recommended because of the risk of building and increasing stress level in the material.

FIGURE 3
SANDWICH HEATING



Forming

DRAPE FORMING

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

The process involves placing the sheet (without the masking) and mold 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 mold. Both items can then be removed from the oven and allowed to cool. Figure 4 illustrates the basic steps. Exceeding the glass transition point of LEXAN™ sheet materials will result in a decreased optical quality.

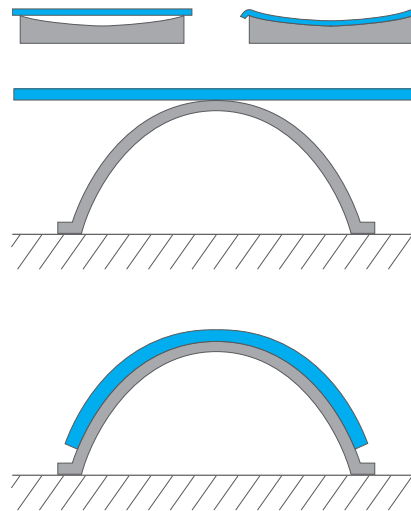
The drape forming process can be a combination of different methods. These include:

- 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 150 °C-165 °C.
- Cold curving the sheet over a mold, 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 help 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 mold directly outside. Once the sheet has reached the required temperature, it should be quickly removed and allowed to drape itself over the mold. The transition between the oven and the mold 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 can meet demanding quality requirements. In these types of applications the mold should be made from a high gloss material such as steel, aluminium, or even glass in order to achieve the necessary optical quality.

FIGURE 4

TYPICAL DRAPE FORMING SET-UP



PRESSURE FORMING

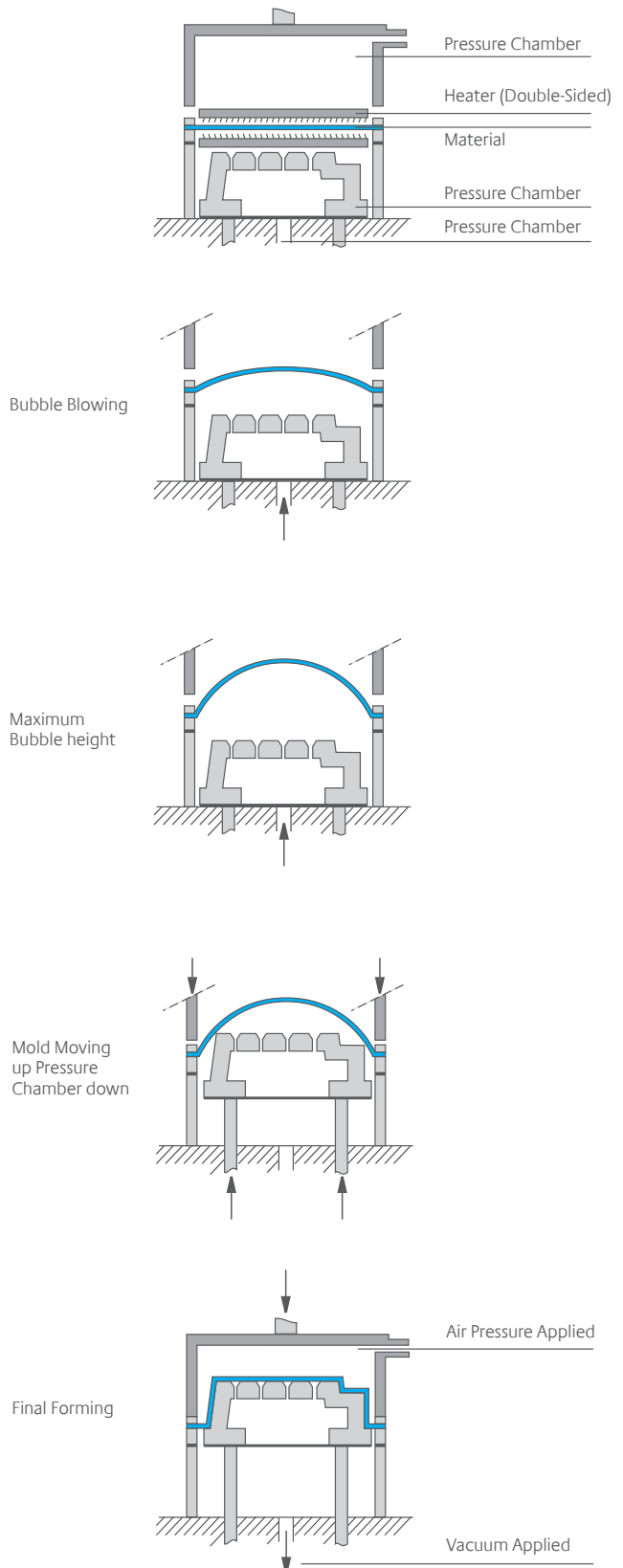
Pressure forming is similar to vacuum forming. However, during the final forming stage, compressed air is applied to the positive side of the mold to force the sheet to conform more closely to the mold. The result is a component with sharp features and detailed geometry.

The basic steps are illustrated in Figure 5, showing the pressure chamber mounted above the mold. High detailed, textured surfaces and small radii are typical of the fine detail which can be achieved with this process.



FIGURE 5

PRESSURE FORMING



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 Figure 6. 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, this method is useful for 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 molds. No additional glue or other adhesive is therefore necessary. This method can be used to produce parts consisting of two materials, colours and gauges.



FIGURE 6

TWIN SHEET FORMING

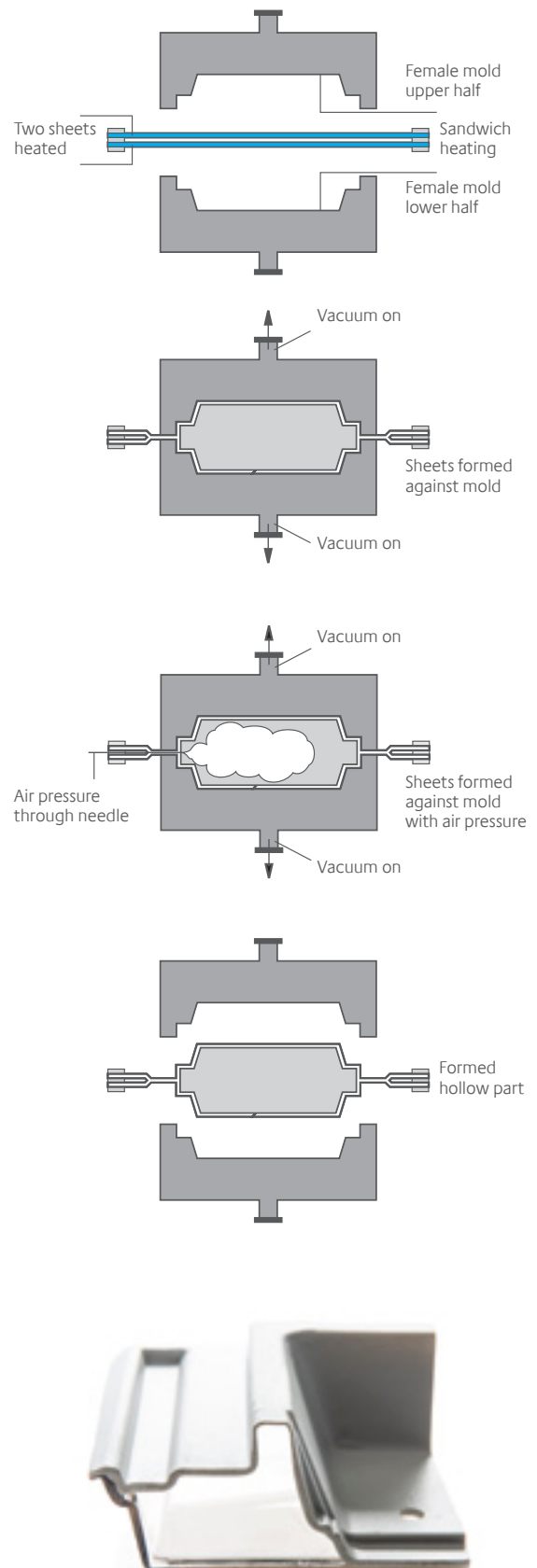


FIGURE 7
BLANK SIZE DETERMINATION

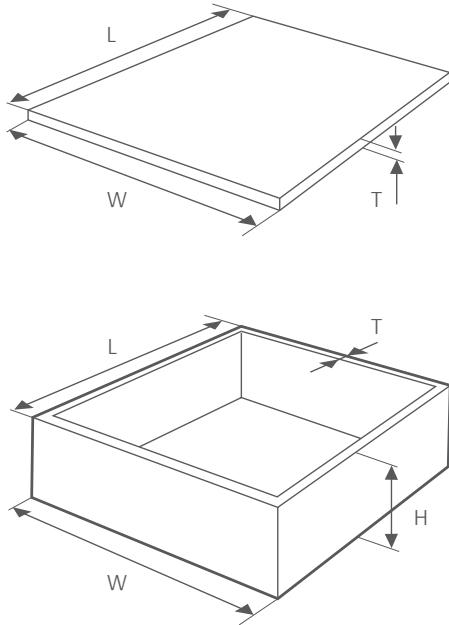
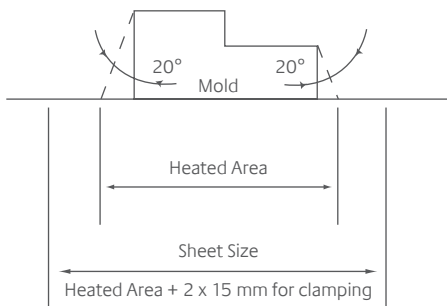


FIGURE 8
BLANK SIZE REQUIRED FOR FORMING



PRODUCT DESIGN

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, some key 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 difference between the surface area of the thermoformed product (S) and the available sheet surface inside the clamping frame (s). (See Figure 7)

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

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

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

$$QT = T / T'$$

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 used as a maximum. In some situation, higher draw ratio can be obtained based on the part geometry. The above recommendations assume an even thickness distribution throughout the part, with a more or less symmetrical part geometry.

Forming

PRODUCT RADII

With positive forming, geometry changes should be accompanied by a generous radii. With negative forming, small radii can be achieved. The basic criterion is that all radii should be at least equal to the wall thickness. General guidelines are illustrated in Figure 9.

DRAFT ANGLES

LEXAN™ sheet products, in common with other 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 mold. For positive molds 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 mold is textured, a minimum of 2° to 3° is advised. To avoid stress build-up and difficult removal through post mold shrinkage, removal of the part made from LEXAN sheet should take place at a part temperature of 120°C .

UNDERCUTS

Undercuts are possible with vacuum forming. However, this often makes the molds 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 mold. A typical example is that of a rim around the circumference of the part as shown in Figure 10. 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 increase the cycle time. For large series, moving parts can be installed into the mold activated by both pneumatic and hydraulic cylinders.



FIGURE 9

MINIMUM RADII RECOMMENDATIONS

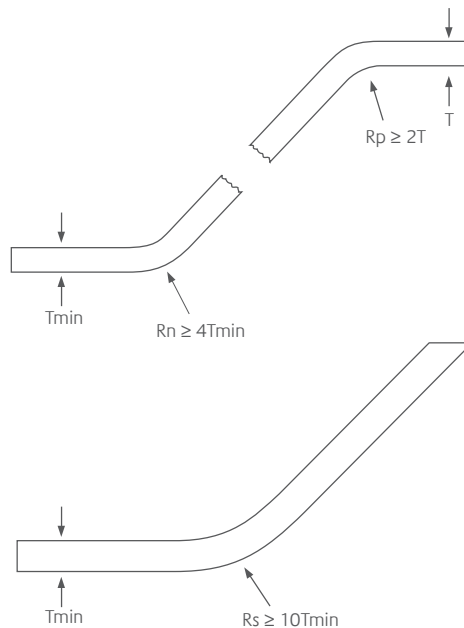


FIGURE 10

TYPICAL UNDERCUT DESIGN

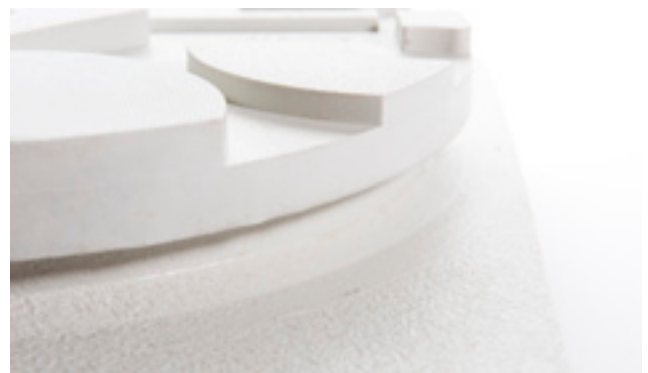
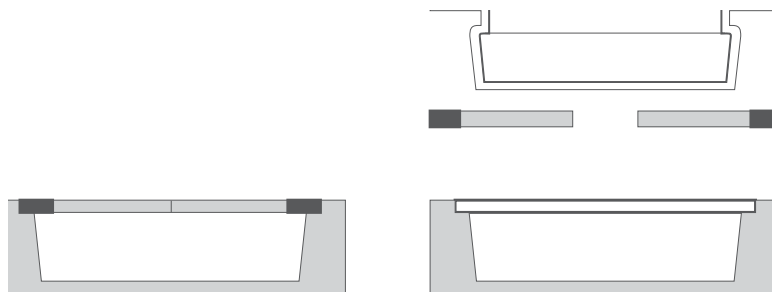


FIGURE 11
VACUUM HOLE RECOMMENDATIONS

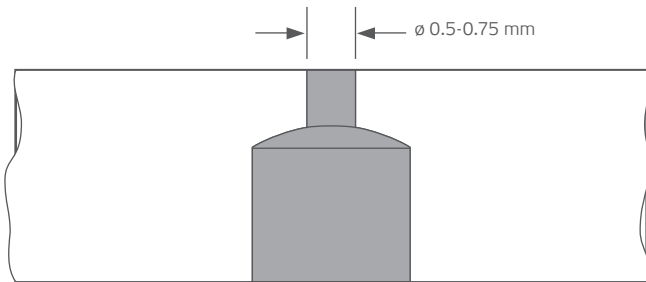
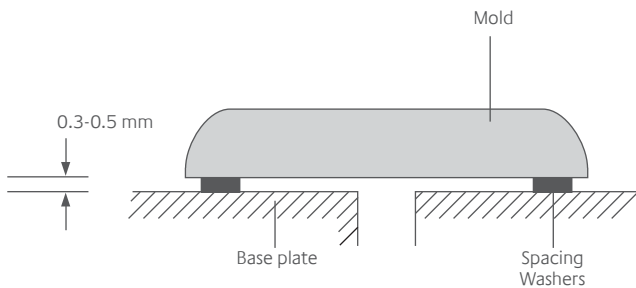


FIGURE 12
SLOT DESIGN RECOMMENDATIONS



MOLDS AND MOLD DESIGN

Molds used for forming LEXAN™ 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, molds can be made from wood, polyurethane foam, epoxy resins, metal-filled polyester, metals or 3D printed molds.. Since they only need to withstand atmospheric pressure, there is little wear and the flow of the plastic against the mold surface is minimal.

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

SHRINKAGE

The mold shrinkage should be a design consideration when constructing the mold. The heating/cooling cycle and the type of forming equipment will also influence results. To allow for post forming shrinkage, for standard polycarbonate grades, 0.6-0.7% should be added to all dimensions with a heated mold of 120 °C. For specific products, please check the product data sheet for the possible shrinkage information about that material.

VACUUM HOLES

The evacuation of air pressure from the mold 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 significant marks on the molding, 0.5-0.75 mm diameter holes are recommended. The holes can be recessed on the underside of the mold to improve evacuation, as illustrated in Figure 11. Figure 12 illustrates the spacer and slot design.

DOMES AND PYRAMIDS

Domes are among 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 13. Taking the process one step further, pyramids can be produced, as shown in Figure 14. A simple wooden skeleton acts as a mold and, after applying the pressure, the mold is raised and the sheet allowed to cool on the mold. Contact with the mold is limited to the edges of the pyramid and optical quality parts can be produced. Recommended processing temperatures are between 170 °C-180 °C.

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, sheet can be 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 15. 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 1 m however, the line of the bend is often concave with the outer edges lifting, as shown in Figure 16. 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.

This technique involves placing the sheet under stress. However, provided certain precautions are taken, the performance characteristics of the sheet will likely remain unchanged.

FIGURE 13
FREE-BLOWN DOMES

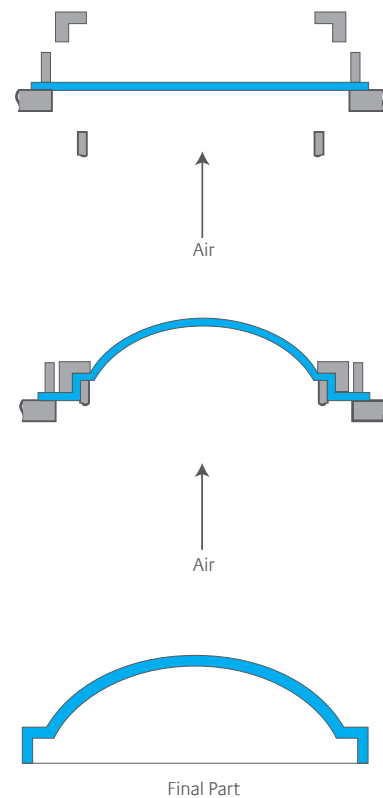
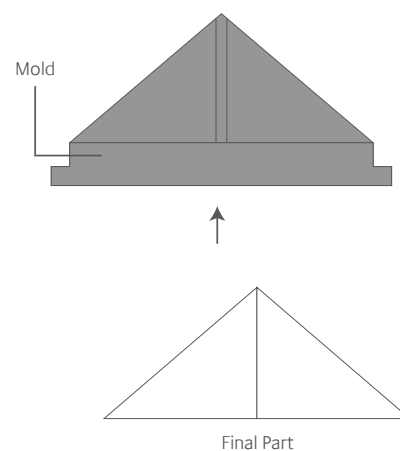


FIGURE 14
TYPICAL PYRAMID FORMATION



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. It is recommended not to exceed maximum sheet thickness and radii, to prevent any influence of stress on the product 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 sheet and 300 times the sheet thickness for LEXAN™ MARGARD™ FMR sheet. Table 3a outlines the recommended radii for a range of sheet thicknesses.

This technique is not recommended for mar-resistant, hard coated sheets such as LEXAN MARGARD MR5E sheet. 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 formable hard coated products such as LEXAN MARGARD CTG, FMR5XT sheet series and uncoated LEXAN sheet materials prior to the drape forming process, may be done at radii 100 times to the sheet thickness.

FIGURE 15

TYPICAL SET-UP FOR A BENDING MACHINE EQUIPPED WITH TEMPERATURE CONTROLLED HEATERS ON BOTH SIDES

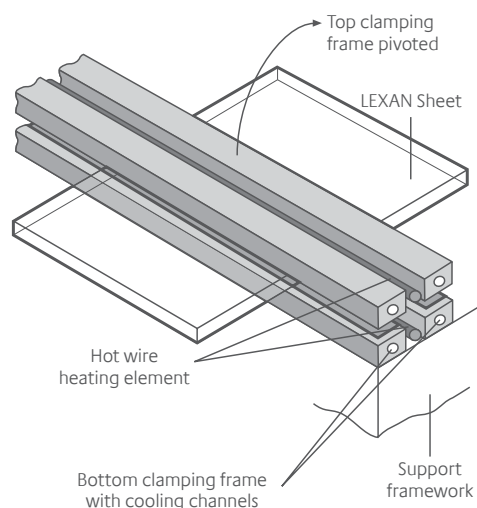


TABLE 3A

MINIMUM COLD CURVING RADII

Sheet Thickness (mm)	LEXAN EXELL D Sheet Min. Radius (mm)	Uncoated LEXAN Sheet 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
9.5		
12		
15		

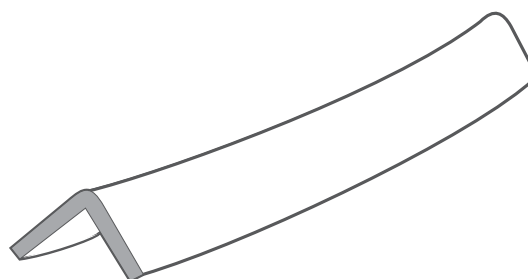
TABLE 3B

MINIMUM COLD CURVING RADII

Sheet Thickness (mm)	LEXAN MARGARD Sheet CTG/FMR5XT Min. Radii (mm)
2	600
3	900
4	1200
5	1500
6	1800
8	2400

FIGURE 16

EXAMPLE OF CONCAVE (BANANA) EFFECT AFTER HOT LINE BENDING



COLD LINE BENDING

Cold line bending is another forming technique for LEXAN™ sheet products. Due to ductile nature of polycarbonate material, this forming technique can be performed even at room temperatures. However, the process does involve some degree of permanent plastic deformation and the results can be influenced by sheet thickness, tooling and the angle of strain bending.

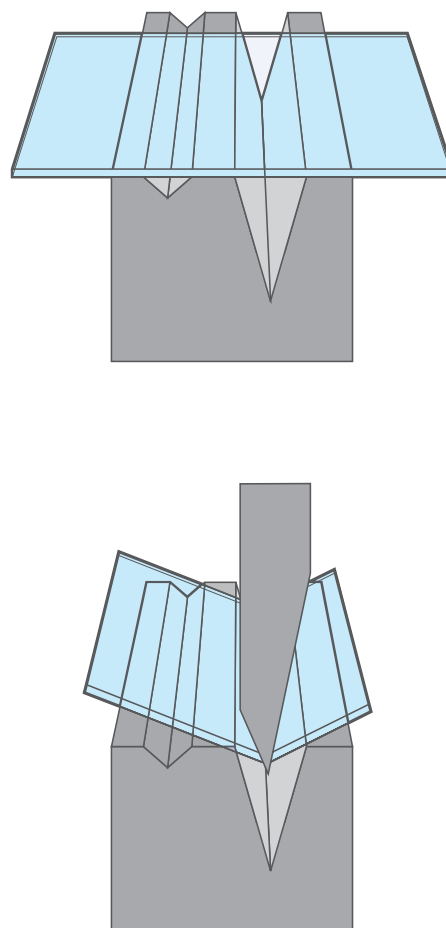
A typical cold line bending operation is illustrated in Figure 17.

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.
- 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°. Cold line bending of LEXAN sheet FR grades is limited because of the decreased notched impact of these materials. 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 impact strength demanding applications. We recommend not to use hard coated materials such as LEXAN™ MARGARD™ MR5E and FMR sheet and UV resistant sheet grades such as LEXAN EXELL™ D sheet due to the fact that the mar resistant coating or UV protected surface can be damaged around the bent area during the bending process. For more information on any of the forming techniques please contact your local service team of SABIC. Cold line bending of FR sheet grades should be considered carefully because of the decreased notch impact effect of the process on the material.

FIGURE 17
COLD LINE BENDING



Fabricating

FABRICATING TECHNIQUES

Fabrication can be defined as the construction, manufacture or assembly of a number of related component parts. Examples of fabricating LEXAN™ sheet products include 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 sheet and provides recommendations and advice to help maximize results.

CUTTING AND SAWING

LEXAN sheet products can be cut and sawn 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.

CAUTION should be taken and required safety equipment should be worn when cutting and sawing. When working with thermoplastics sheet, always consider safe and careful handling. Please keep in mind that plastics will lose heat more slowly than metals. Avoid localized overheating. The method and the purpose that you choose to utilize our products are beyond our control. Therefore, it is imperative that you test our products to determine to your own satisfaction whether our products, technical assistance and information are suitable for your intended use and application. This application-specific test must at least include analysis to determine suitability from a technical as well as health, safety, and environmental standpoint. Such testing has not necessarily been done by SABIC. For further assistance and recommendations, please contact SABIC's Functional Forms business that you can find the contact details on the back page of this brochure.

- 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 sheets, materials 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, it is important to follow the recommended guide-lines for speeds and feeds.

- 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 that are made for cutting 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

An 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 recommended with the emphasis upon low cutting feeds.

GUILLOTINE SAW

Can be used on non-FR type sheets.

TABLE 4

GENERAL 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

FIGURE 18
TUNGSTEN CARBIDE TIPPED SAW BLADES
USED FOR CIRCULAR SAWS

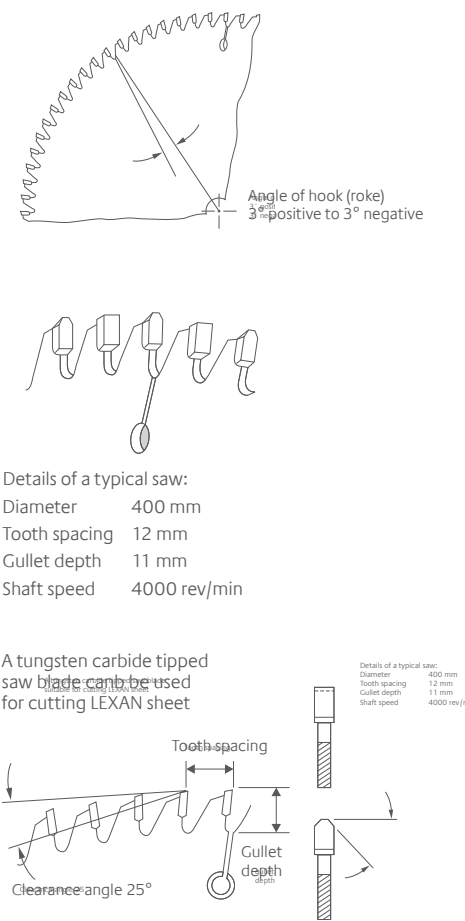
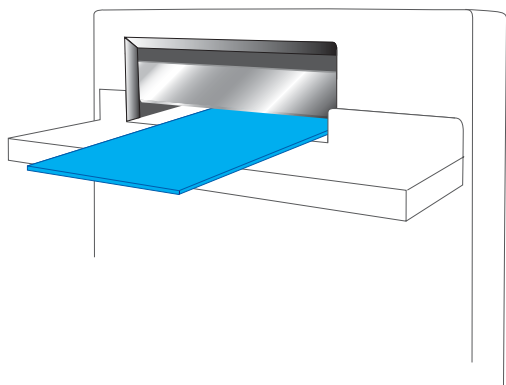


FIGURE 19
GUILLOTINE SAW



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. One of the most important factor to consider when drilling LEXAN sheet products is the heat generation during the actual process. In order to produce a clean, well-finished hole that is stress-free, the heat generation must be kept to an absolute minimum. By following a few basic guide-lines, clean, stress-free holes can 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.
- Select the drill bit that matches the size hole you want to drill.
- Adjust the drill press' speed according to your drill press operator's manual.
- Maintain drill feed pressure sufficient to form a continuous spiral-shaped chip. This chip forms as the drill advances through the polycarbonate sheet material. Use air or water for a coolant if the drill bit becomes hot enough to melt, rather than cut, the polycarbonate.
- Do not use oil or cooling fluid for drilling

Drilling feeds and speeds are outlined in Table 5 with the various drill configurations in Figures 20 to 11.

TABLE 5
FRONT VIEW DRILL BIT

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

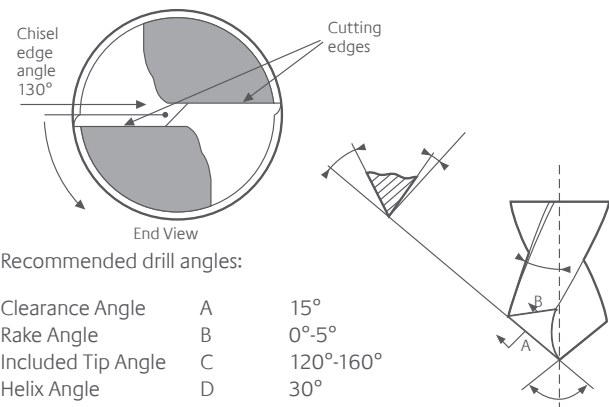


FIGURE 20
TYPICAL DRILL CONFIGURATION

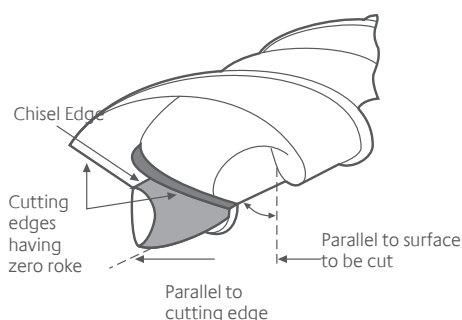
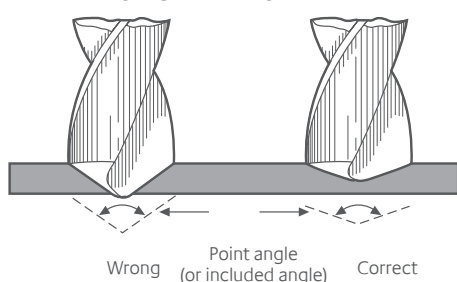


FIGURE 21
TWO OR FOUR DRILL FOR LARGE HOLES



FIGURE 22
DRILL BITS FOR THIN SHEET



REMARK:

Please consult equipment supplier for drilling, cutting, cooling fluids, which are recommended for polycarbonate

MILING

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 good clamping medium. Table 7 outlines cutting speeds and feeds with a typical cutting tool illustrated in Figure 23. 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.

Before starting trimming process, sheet should be secured well to avoid vibration and to eliminate risk of cracking. 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, which helps create 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 6
MILLING RECOMMENDATIONS

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

FIGURE 23
SINGLE FLUTE SPIRAL CUTTER



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. While 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 systems which can be used successfully to assemble plastic 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 7
COEFFICIENT OF THERMAL EXPANSION

Depending on the weathering conditions, thermal expansion of LEXAN sheet can be larger than aluminium or steel.

Material	m/m °C x 10 ⁻⁵
LEXAN sheet	6.7
Glass	0.7 - 0.9
Aluminium	2.1 - 2.3
Steel	1.2 - 1.5

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 24 and 25 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. While the majority of these screws are designed for plastic moldings, with the aid of spring clips and washers they can be adapted for sheet applications.

Figure 26 shows some typical fastening systems.

FIGURE 24
BLIND NUT AND BLIND SCREW ANCHOR

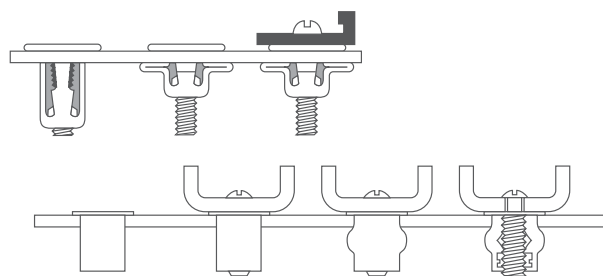
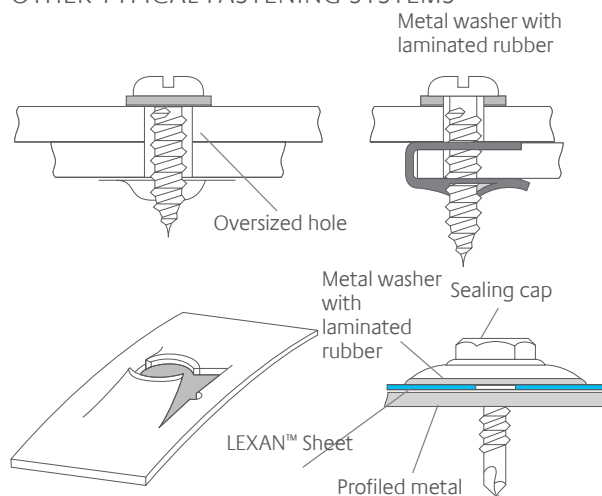


FIGURE 25
OTHER TYPICAL FASTENING SYSTEMS

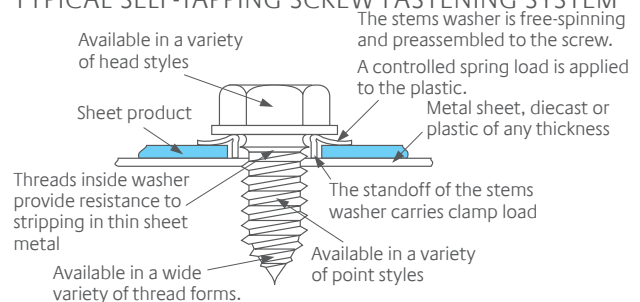


CAUTION

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.

FIGURE 26
TYPICAL SELF-TAPPING SCREW FASTENING SYSTEM



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. Hole size 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. SABIC recommends the use of aluminium, brass and copper rivets. There are several different types of riveting systems, 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 27 and 28 illustrate typical rivet assemblies.

FIGURE 27
RIVET ASSEMBLY

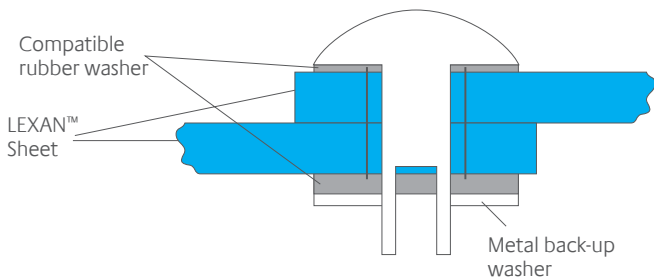
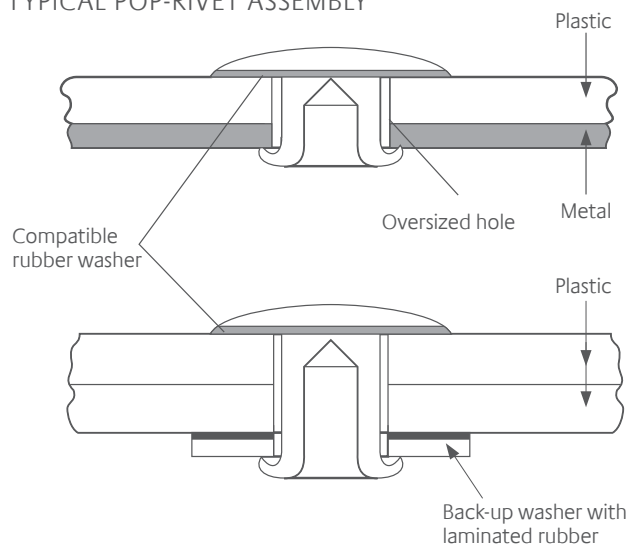


FIGURE 28
TYPICAL POP-RIVET ASSEMBLY



Fabricating

MISCELLANEOUS FABRICATION TECHNIQUES

Many different techniques are used to cut and fabricate polycarbonate LEXAN™ sheet products.

These techniques include:

- Shearing
- Punching
- Tapping

While 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 sheet. However, the process is usually restricted to molded 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 LEXAN sheet above 1mm products is not recommended due to the following disadvantages:

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

For further technical assistance and recommendations, please contact SABIC's Functional Forms business that you can find our contact details on the back page of this brochure. When working with LEXAN sheet, always consider safe and careful handling. The method and the purpose that you choose to utilize our products are beyond our control. Therefore, it is imperative that you test our products to determine to your own satisfaction whether our products, technical assistance and information are suitable for your intended use and application. This application-specific test must at least include analysis to determine suitability from a technical as well as health, safety, and environmental standpoint. Such testing has not necessarily been done by SABIC. Unless we otherwise agree in writing, all products are sold strictly pursuant to the terms of our standard conditions of sale, which are available upon request.

FIGURE 29

WATER JET CUTTING EXAMPLE



Finishing, Decorating and Cleaning

FINISHING, DECORATING AND CLEANING

The following section discusses the techniques and processes that can be used to finishing, decorating and cleaning of LEXAN™ sheet and provides recommendations and advice on how you can create the best finished products.

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 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 resin 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 resin 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, table 9, is an on-going process at SABIC's Functional Forms business and many standard products have already been tested.

A complete list of compatible 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 Table 8.

For further technical assistance and recommendations, please contact SABIC's Functional Forms business that you can find the contact details on the back page of this brochure.

When working with LEXAN sheet, always consider safe and careful handling. The method and the purpose that you choose to utilize our products are beyond our control. Therefore, it is imperative that you test our products to determine to your own satisfaction whether our products, technical assistance and information are suitable for your intended use and application. This application-specific test must at least include analysis to determine suitability from a technical as well as health, safety, and environmental standpoint. Such testing has not necessarily been done by SABIC. Unless we otherwise agree in writing, all products are sold strictly pursuant to the terms of our standard conditions of sale, which are available upon request.

TABLE 8
LEXAN SHEET CHEMICAL COMPATIBILITY SUMMARY

Chemical class	Effects
Acids (Mineral)	No effect under most conditions of concentration and temperature.
Alcohols	Generally compatible.
Alkalies	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 9
LEXAN MARGARD SHEET CHEMICAL RESISTANCE

Chemicals	Effects	
	Uncoated PC Sheet	LEXAN MARGARD MR5E Sheet
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	W/S	OK
Diesel Fuel	OK	OK
Fuel C	OK	OK
Hairspray	OK	OK

W = surface whitening
S = surface dissolution

LEXAN SHEET CLEANING RECOMMENDATIONS

These cleaning recommendations apply to all LEXAN polycarbonate sheet products, including, but not limited to, LEXAN solid sheet and signs, LEXAN coated MARGARD™ sheet and LEXAN multiwall sheet. Periodic cleaning using correct procedures can help to prolong service life. For cleaning, it is recommended that the following instructions be adhered to:

CLEANING PROCEDURE FOR SMALL AREAS – MANUAL

1. Gently wash sheet with a solution of mild soap and lukewarm water, using a soft, grid-free cloth or sponge to loosen any dirt or grime.
2. Fresh paint splashes, grease and smeared glazing compounds can be removed easily before drying by rubbing lightly with a soft cloth using petroleum ether (BP65), hexane or heptane. Afterwards, wash the sheet using mild soap and lukewarm water.
3. Scratches and minor abrasions can be minimized by using a mild automobile polish. We suggest that a test be made on a small area of LEXAN sheet with the polish selected and that the polish manufacturer's instructions be followed, prior to using the polish on the entire sheet.
4. Finally, thoroughly rinse with clean water to remove any cleaner residue and dry the surface with a soft cloth to prevent water spotting.

CLEANING PROCEDURE FOR LARGE AREAS - AUTOMATED

1. Clean the surface using a high-pressure water cleaner (max. 100bar or 1,450psi) and/or a steam cleaner. We suggest that a test be made on a small area, prior to cleaning the entire sheet.
2. Use of additives to the water and/or steam should be avoided.

OTHER IMPORTANT INSTRUCTIONS FOR CLEANING LEXAN SHEET:

- Never use abrasive or highly alkaline cleaner on LEXAN polycarbonate materials.
- Never use aromatic or halogenated solvents like toluene, benzene, gasoline, acetone or carbon tetrachloride on LEXAN polycarbonate materials.
- Use of incompatible cleaning materials with LEXAN sheet can cause structural and/or surface damage.
- Contact with harsh solvents such as methyl ethyl ketone (MEK) or hydrochloric acid can result in surface degradation and possible crazing of LEXAN sheet.
- Never scrub with brushes, steel wool or other abrasive materials.
- Never use squeegees, razorblades or other sharp instruments to remove deposits or spots.
- Do not clean LEXAN polycarbonate sheet in direct sunlight or at high temperatures as this can lead to staining.
- For all mentioned chemicals consult the manufacturer's Material Safety Data sheet (MSDS) for proper safety precautions.

ADDITIONAL IMPORTANT CONSIDERATIONS FOR MULTIWALL, CORRUGATED AND SIGN SHEET:

- Cleaners and solvents generally recommended for use on polycarbonate are not necessarily compatible with the UV-protected surfaces of LEXAN multiwall sheet, corrugated and sign polycarbonate materials.
- Do not use alcohols on the UV-protected surfaces of LEXAN sheet.
- Never clean the Dripgard surface of LEXAN multiwall sheet and corrugated sheets.

GRAFFITI REMOVAL FROM LEXAN MARGARD SHEET

- Butyl cellosolve can be used to remove paints, marking pen inks and lipstick stains. Afterwards, wash the sheet using mild soap and lukewarm water.
- Masking tape, adhesive tape or lint removal tools can be used to lift off old, weathered paints.
- To remove label stickers, the use of kerosene or petroleum ether (BP65°) can be generally effective. If solvent doesn't penetrate to sticker material, apply heat (hair dryer) to soften the adhesive and promote removal of the sticker. Afterwards please follow the cleaning procedure for small areas as outlined above.

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 compatible 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 sheet or LEXAN MARGARD FMR sheet.

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.

For painting systems please consult SABIC.

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 FMR5XT sheets. The one side coated grades of LEXAN MARGARD sheet such as LEXAN MARGARD HLG5, LEXAN MARGARD FLG5XT and LEXAN MARGARD HLGA2 sheets can be screenprinted at the uncoated side.

SCREENING RECOMMENDATIONS

- Use only compatible 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.
- If a digital printing process is used, only print on the sheet side which has the unprinted masking.

For screen printing inks please consult SABIC.

ANTI-STATIC TREATMENT

As common with all insulating materials, LEXAN™ 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. Typically, relative humidity above 60% is effective.

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. While some adhesives/sealants form a flexible bond, others form a rigid bond. Some are capable of filling gaps, while others are for close contact. Some can withstand high temperatures, while 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 SABIC Structured Products. A comprehensive data-base of compatible adhesives is available, and in all cases it is strongly recommended that all adhesives are checked for compatibility before use. Table 10 presents an overview of some of the initial criteria used to select an adhesive and Table 11 provides a list of compatible adhesives indicating generic types, trade names and application areas. Figure 30 outlines some typical joint configurations

TABLE 10

ADHESIVE SELECTION CHART FOR LEXAN SHEET PRODUCTS (POLYCARBONATE)

Adhesive Type	Joins LEXAN sheet to	Supplier
Epoxy	Metals, Plastics, rubbers	3M Company
Epoxy	Plastics	3M Company
Polyurethane	Plastics, Metals, wood	Henkel
Polyurethane	Plastics, Metals, wood	Henkel
Hot Melt	Plastics, Wood	3M Company
Hot Melt	Plastics, Wood Glass, Ceramics	Henkel
Silicone	LEXAN uncoated sheet, LEXAN EXELL D™ sheet, LEXAN™ MARGARD™ MR5E sheet and LEXAN MARGARD FMR sheet - Building Materials	Momentive Performance Materials
MS polymer	LEXAN uncoated sheet, LEXAN EXELL D sheet, LEXAN MARGARD MR5E sheet and LEXAN MARGARD FMR sheet - Building Materials	Bostik
Tapes	Plastics, Glass, Metals	3M Company
Tapes	Metals / Plastic	Fasson
Tapes	—	Velcro
Tapes	—	Multifoil
Tapes	—	Sellotape

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.

TABLE 11

ADHESIVE GROUPS AND PROPERTY PROFILE

	Impact Resistance	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	+

LAP JOINTS

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

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

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

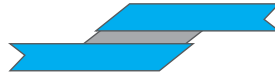
A simple lap joint could create cleavage and peel stress under loading, particularly in bonding thin sheets.

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

FIGURE 30
JOINT DESIGN CONFIGURATIONS



1. Joggle Lap Joint



2. Tapered Single Lap Joint



3. Double Lap Joint



4. Simple Lap Joint



5. Round Lap Joint

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