



**Thermoforming Lucite XL Continuous Cast Sheet**

## Technical Service Report

### Thermoforming of Lucite XL sheet

#### Introduction

LUCITE XL continuous cast cross linked acrylic is specially formulated for superior thermoforming and chemical and stain resistance properties compared to general purpose acrylic sheet products. LUCITE XL is an alternative to SWG and ESG cell cast 'PERSPEX'® and is useful for the production of large spa's where cell cast sheets are of insufficient size. Note that if processing conditions are used, Lucite XL continuous cast sheet may, due to its lower molecular mass, it will however pull into thinner sections than cell cast acrylic sheet, and is very easy shaping.

LUCITE XL is used primarily for production of bath ware and spa's in which the thermoformed acrylic sheet is reinforced with fiberglass and polyester resins (GRP). In these end uses, LUCITE XL exhibits the excellent processing characteristics and surface quality needed to complex parts which are attractive and durable. This advisory note provides supplemental information which will help manufacturers consistently produce the best quality parts with LUCITE XL.

#### Cleaning

Carefully cleaned sheets and moulds will minimize irregularities and blemishes, and ensure production of a smooth, glossy part. However, acrylic sheet usually carries a static charge and this attracts airborne dust, saw chips, and dirt. The best way to control this is to maintain a very clean thermoforming area and try to isolate dirt and dust from the spray-up area. Once the LUCITE XL sheet is unmasked\* it may be cleaned with an aqueous solution of soap or washing up liquid. That method has the advantage of reducing static and removal of small particles and fibres, which can sometimes sublimate coloured dye onto the sheet at thermoforming temperatures. A possibly faster, and common method of cleaning, is to use an ionized air gun which tends to reduce static charges build-up somewhat vs. non-ionized air, as it blows contaminants off the sheet. Numerous other static eliminating cleaning agents exist, but none of these methods is more effective than a scrupulously clean thermoforming area.

\*In some cases, manufacturers may choose to thermoform the sheet with the film masking intact, in which case certain precautions are necessary. For details, see the "Temporary Protective Film Masking" section towards the end of this advisory note.

#### Cleaning with Solvents

The use of solvents, of any type, to clean Lucite XL, is neither necessary nor recommended, as it can induce subsequent stress cracking of the acrylic, and may depassivate the acrylic surface, resulting in staining in service.

#### Thermoforming Cycle

LUCITE XL acrylic sheet should be thermoformed with two important objectives in mind. These are: (1) to heat the sheet to appropriate forming temperatures, and (2) to draw the sheet uniformly into the mould at a rate and manner which balances accurate mould reproduction, adequate part thickness, and minimized stress in the thermo-formed parts. If the sheet is insufficiently heated or if it loses too much heat during forming, it will draw unevenly and yield parts containing high residual stress. This stress can cause cracking and warping during the reinforcing process or over a longer period of time, after the part has been produced and sold. For optimum thermoforming performance, the sheet core temperature should be between 160°C and 182°C. However, if, in the case of certain types of Lucite XL, such as Lustre or Marble grades, subsequent crazing is encountered, thermoforming temperatures of up to a maximum of 200°C may be used to obviate the problem. Temperatures can be verified using thermo labels or a non-contact IR pyrometer.

Notes:

\* pattern heating involves non-uniform heating of the sheet to improve material distribution, i.e. part thickness

- perimeter location = approximately 15 – 20 cm in from clamping frame, either on top or bottom sheet surface.

- "thinning" location = sheet area which corresponds to the location in final part of lowest thickness, e.g. footwells, drain end corners, etc.

\*\* Sheet temperatures on warm end, coupled with stretching, provide the highest level of texture

\*\*\* Temperatures in the table are based on our understanding of typical manufacturer's conditions. Each thermo-forming process has its own unique characteristics, and those parameters, together with variables in a manufacturer's reinforcement process, will determine the suitability of the thermoforming conditions. Each user must establish suitability of their own process conditions to insure the quality of their finished product.

(1) for properly stored sheet -- moisture absorption reduces the peak temperature of the sheet at which blistering may occur.

(2) Variables include 1 vs. 2-sided heating; heating rate; sheet thickness; mould design, material of construction and if heated; pattern heating; evacuation flow, controls and vacuum level.

Above these temperatures, blistering due to vaporization of absorbed moisture or at higher temperatures, polymer degradation may occur. Insufficiently heated sheet or excessive cooling prior to, or during part formation may lead to problems caused by induced stress in the sheet. The optimum heating cycle required to reach forming temperatures depends upon the sheet thickness as well as the type and settings of equipment used and the ambient conditions of the forming area. Such variables make process controls vital in thermoforming. A quick-response pyrometer effectively measures sheet surface temperature and should be used to establish cycle times. Once a heating cycle is established, temperature-sensitive tapes can be used to confirm that the process is in control and sheet surface temperatures are being reproduced consistently. A pyrometer should be used occasionally to check sheet surface temperature and can indicate potential stress problems due to insufficient heating below the surface of the sheet.

An effective method for experimentally establishing and checking heating and draw uniformity is to mark the sheet in 15cm squares and measure variations in temperature and in draw uniformity across the sheet. This information is very useful in determining how to adjust the heating controls or strategically "screen" the heating elements with wire mesh (window screen) to prevent overheating and control part thickness in deep-draw areas. Plating or painting of the clamp frame and oven interior to produce reflective surfaces should be considered. This action results in increased oven efficiency and improved temperature uniformity within the sheet. Once the heating controls and cycle have been established, various control mechanisms can be used to reproduce the cycle, for instance, a photoelectric cell which monitors sheet sag during heating, a top-mounted pyrometer to monitor sheet temperature while linked to heater controls, or a timing mechanism may be used.

After the sheet is heated, the vacuum draw should proceed in a smooth and timely fashion. Because the thickness of LUCITE XL is consistent throughout the sheet, proper control of the heating and forming of parts will lead to reproducibility in part thickness on similar points in each part, and on a part-to-part basis. Variations in heating or draw rate, resulting in forming at lower temperatures, could create structural weaknesses caused by induced stress.

## Equipment

**Ovens** - The best way to ensure uniform heating is to heat the sheet from both sides. Ideally, this would be done in a closed air-circulating oven. A semi-automated thermoforming machine usually provides top and bottom radiant heating for sheet held in a movable metal clamp frame. Ovens which heat sheet from the top only run the risk of blistering the top surface of the sheet with too much heat or inducing stress through uneven or inadequate heating.

Several heating techniques are currently in use for production of spas or sanitary ware:

(1) Ceramic or Quartz Panels: This is the best type of unit for uniform heating and longevity. The heating element is completely embedded in a ceramic or quartz panel. Such elements show little deterioration or loss of efficiency with age, and the individual panels offer a good method for individual or zone controlled heating.

(2) Metal-sheathed Tubular Rods containing heating elements also are common. The rod surface gradually oxidizes, reducing thermal efficiency which may be partially restored by cleaning with steel wool or emery cloth.

(3) Coiled nickel/chrome wire is frequently used and has a quick response time. It also loses thermal efficiency, and it has the shortest life expectancy of all types of heating elements. The loss of efficiency may lead to inconsistent or inadequate performance and, in the long run, higher energy costs.

(4) Quartz tube: Similar to the metal sheathed tubes, these elements have a quartz tube surface. Due to brittleness, they are better suited for upper heating surfaces than on the bottom. They have medium heat-up response time.

(5) Quartz bulbs (sealed): These have a quick heating response time, leading to advantages in feed-back control and pattern heating and allowing rapid heating times.

**Moulds** - Moulds may be constructed inexpensively with simple materials, such as wood, plaster, epoxy, or reinforced polyester. The life expectancy of such moulds is short, however, and the low heat-transfer coefficient of the construction materials, coupled with the lack of mould temperature control, reduce thermoforming efficiency. Cast aluminium moulds with moulded-in heat control channels are more efficient and last longer, but require greater initial investment and are costly to modify. Uniform mould temperature is essential to the production of minimally stressed parts. Typically, this temperature should be in the range of 60°C -70°C. The mould interior must be channelled, and should have enough vacuum holes to allow fast, uniform evacuation during thermoforming. The vacuum holes, usually 0,635 mm in diameter, may be slotted to improve air evacuation and minimize mark-off on the acrylic sheet. In female moulds, the acrylic tends to shrink away from the mould as it cools so that partremoval is enhanced. It is good practice, however, to use a 2°-3° draft angle in mould designs to supplement this natural occurrence. Uniform cooling is desirable so that design integrity is maintained, warpage is minimized, and residual stress content is minimal and uniform. In some instances, a male plug assist is used to push sheet into the deepest parts of the mould, although the chances of marring the surface of the part are heightened by such use. If a plug assist is used, the plug temperature should be maintained within 25°C of the sheet temperature, or be made from a low thermal conductivity material, in order to assure minimal stress or chill marks in the part. The finished acrylic part can usually be removed safely from the mould at a temperature of 80 °C. The actual temperature is dependent upon the part geometry and mould complexity; if the design has an undercut, a cam-actuated mould which opens to release the part may allow removal at a higher part temperature.

**Vacuum** - The basic requirements of vacuum pump, surge tank and required lines are very critical. The application of the vacuum during the cycle should be consistent. The sheet being drawn must contact the mould (and thus begin cooling) uniformly and quickly so that highly stressed thin sections in the part do not occur. Normally, a vacuum of 736 mm of mercury is used, and the reading on the gauge should not drop below 508 mm during forming. The size of the surge tank and the number and size of holes in the mould must be designed with those conditions in mind. Optimal tank dimensions can be calculated by use of the formula:

$$V_{ss} P_{ss} + V_{mm} P_{mm} = V_{tt} P_{tt}$$

Where  $V_{ss}$  = volume in surge tank and piping

$V_{mm}$  = volume in mould (including channelling)

$V_t$  = total volume ( $V_s + V_{mm}$ )

$P_{mm}$  = pressure in mould\*

$P_{ss}$  = pressure in surge tank\*\*

$P_t$  = desired working pressure

\* At sea level = Atmospheric 101 kPa.

\*\* Equivalent to 736 mm mercury.

A proper vacuum pump and surge tank must be supported by appropriate piping. Flexible hose (38 mm) should be used; the tank should be located as close to the mould as possible; and tees and elbows or other restrictions in the lines should be eliminated. Valves should be the full-open type and the vacuum gauge should be placed in a location easily visible to the operator.

#### **Temporary Protective Film Masking –**

Polyethylene film is used as a temporary protective film on the top surface of the Lucite XL cast acrylic sheet. In most cases, it may be left on the sheet during thermoforming and subsequent fabrication to help avoid minor defects to the part surface\*. After fabricating the bath, it is recommended to remove the film prior to shipment for sale or prolonged storage. This helps to avoid degradation of the film by heat or sunlight, which can make the film hard to remove. In some cases, damage to the film may make it desirable to remove the film prior to thermoforming. For example, rough handling may scratch, tear or partially dislodge the film. Forming with the film damaged may leave subtle marks on the acrylic surface. If the film is laid back onto the sheet after it is dislodged, air is trapped under the film which then expands during heating and forming which can leave marks. The film can also absorb and transmit water vapour. At forming temperatures, the trapped moisture vaporizes and can result in blisters in or under the film which may leave an impression in the sheet surface. If the film is damaged, or the sheet and film have had exposure to high humidity or lengthy open storage, the user is advised to evaluate and compare effectiveness of removal of the film masking prior to forming. The following steps will help to avoid making marks on the sheet during thermoforming and subsequent handling:

#### **Suggested Actions:**

- Lower sheet forming temperature to reduce the mark-off impressions or,
- Remove the masking prior to forming the sheet.
- After forming the part, use a protective film with pressure-sensitive adhesive to cover all or part of the part's surface to avoid problems with scratching and fibreglass over-spray. In addition to the above suggestions, it is always advisable to keep sheet wrapped and to use proper sheet storage techniques to reduce moisture absorption.

## Barrier Coats

Composite materials such as glass fibre reinforced polyester (GRP) or thermoplastic sheets used in spa or boat manufacturing have occasionally exhibited problems in use such as delamination or blistering. These quality defects can be attributed to process problems during production. One accepted method to reduce susceptibility to delamination and blistering is to use a barrier coat applied as a primer ("tie coat") to the back side of the show surface of the product. The barrier coat can be a hybrid or vinyl ester material that is unaffected by moisture and has reduced water transmission rate compared to the surface layer or general purpose reinforcing layer. The cost of barrier coat material and labour is an insurance step to prevent much greater costs due to warranty replacements or customer dissatisfaction.

Blistering in reinforced thermoplastic spas can have many causes depending on materials, production application technique, and production equipment. Foam backed and co laminate spas can blister due to blowing agent problems, differential moisture absorption of different layers, or simple delamination due to an adhesion problem.

Fibreglass reinforced acrylic spas can blister from air pockets caused by poor rollout, catalyst droplets from incompletely mixed streams in the spray gun, poor operator spraying technique, or chemical decomposition of the polyester resin by hot water ("hydrolysis") over time.

The type of polyester backing and its formulation affect its susceptibility to hydrolysis. For example, isophthalic polyester is more resistant to hydrolysis than orthophthalic polyester. The hydrolysis can be worsened by too much or too little catalyst or poor mixing, so good process control and operator training are very important. Some of the above factors are discussed in more detail by resin and catalyst supplier literature on blisters. See the attached reference list for some of this literature.

To eliminate spa blisters caused by hydrolysis, many manufacturers in North America have applied a vinyl ester or hybrid polyester barrier coat before spraying the structural glass reinforcement on the unit. The vinyl ester compounds are vinyl esters of epoxy based polymers that are not affected by hot water and are highly impermeable to water diffusion. The hybrid compounds can be of several different chemical compositions. For example, polyester-polyurethane polymers are used which are much more resistant to hot water than standard polyesters. Use of water resistant hybrids for boat construction has been reported to be very effective in eliminating blistering and improving surface quality.

## Barrier Coat Recommendations

For Hot Tubs a barrier coat is recommended. Vinyl ester is best. This does not need to cover the entire spa, but the bottom 1/3 (or at least the footwell) should be covered with 1 to 2 mm. Without a barrier coat, water will permeate through the thin Lucite in time (6 months to 1 year). If the GRP is poor, this water can seep into the GRP by osmosis. In time the water breaks down the polyester resin giving hydrolysis decomposition products (a yellowish liquid). This causes blistering. This is very common in the boating industry if poor quality resin and techniques are used. Epoxy resins are also good barrier coats. Unfilled, Iso phthalic polyester resins without glass fibres are better than ortho phthalic resins. Filler and glass in the resin allows water to seep in. Worse still, is poor roll out (consolidation) of the GRP, especially if it leaves any air pockets.

Ideal gel times at 25 C are 12 to 20 minutes. Less than 12 minutes may not give a good bond (unless the resin is formulated with some MMA or MAA acrylic laminating resin). More than 20 minutes gel time runs the risk of solvent attack and crazing. Maximum exotherm of the filled resin should be less than 85C. A 100 g pot test with neat resin should give a maximum exotherm of 100 - 110 C.