



Application booklet
Thermoforming

Thermoforming is one of the oldest and most common methods of processing plastic materials. Thermoformed plastic products are all around us and play a major part in our daily lives. It is a very versatile process used to manufacture a wide range of products from simple packaging trays to high impact aircraft cockpit covers. It is also used extensively to make design prototypes of products to be produced by other processes. The process, however, is basically the same in each case. In its simplest form thermoforming is the heating of a plastic sheet which is then draped over a mould whilst a vacuum is applied. The moulding is then allowed to cool before it is ejected from the mould using a reverse pressure facility.

Generally speaking amorphous materials, e.g. Polycarbonate and ABS are easier to thermoform than semicrystallines (like PE, PP) as they do not have such a critical forming temperature. When heat is applied amorphous materials becomes soft and pliable – when it reaches this state it is known as its Glass Transition Temperature (T_g). If heated to a higher temperature it reaches a Viscous state. The changes occur over a range of temperatures and enable the operator to have a fairly wide forming range.

Thermoforming is possible on our whole solid sheet range, except for POLYCARBONATE SAPHIR® HC hard coated range. Its hard and scratch resistant surface does not allow for any forming techniques. It is however possible to apply the hard coating after thermoforming. Contact us for more information. Thermoforming is not strictly limited to solid sheet: also our MULTICLEAR® Multiwall range can be – albeit limited – thermoformed, but forming procedures for MULTICLEAR® are not described in this booklet.

All techniques mentioned in this booklet are applicable to all ARLA PLAST AB polycarbonate sheet (with exception of POLYCARBONATE SAPHIR® HC hard coated range), GRIPHEN® sheet and ABS sheet grades. Where GRIPHEN® is indicated, it is also valid for the GRIPHEN® Frost range, unless otherwise specified.

Protective maskings are not meant for thermoforming, unless otherwise stated. Therefore it is recommended to remove the masking prior to the application of heat for the forming process. GRIPHEN® clear masking is thermoformable.

Surface textures normally decrease due to a thermoforming process. Only in case of GRIPHEN® FROST, the surface properties are maintained.

In order to determine the right product for the right application, it is important to understand the technical basics of the process.

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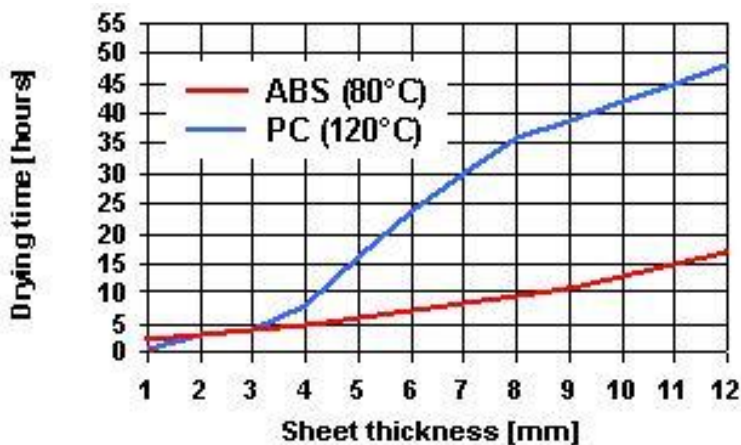
1. PRE-DRYING
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Our solid sheet can be cold curved with a minimum radius of 175 times the gauge thickness for outdoor applications, and 125 times the thickness for indoor applications. When smaller radii are needed thermoforming or drape forming is the way to go.

1. PRE-DRYING

In spite of the very low moisture absorption which contributes to the good dimensional stability of our polycarbonate sheet range, thorough pre-drying of sheet stock is essential for all thermoforming techniques in which the sheet temperature will rise above 160°C. Failure to do so will probably result in moisture blisters. GRIPHEN® sheet do NOT require predrying, as its forming temperatures remain low enough.

The recommended procedure for polycarbonate is to use an air circulating oven set at 120-125°C for PC and 70-80°C for ABS. After removal of the protective masking the sheet should be suspended (on drilled holes), put upright or laid flat on racks in the oven. Make sure that the sheets are arranged 20-30 mm apart so that the air can circulate freely between them.



Note that it is also possible to pre-dry with the masking on. In that case it is recommended that temperature should not exceed 90°C in order to avoid masking related problems. In that case drying temperature is much longer.

When it is required that forming should be done with the masking on the sheet, please contact us for latest information regarding thermoformable masking.

The minimum drying time depends not only on the sheet thickness, but mainly on the moist content. A simple test can be done to obtain optimum drying time: place a part of the dried sheet into an oven at 180°C for 10 minutes. If bubbles appear, the sheet is not fully dried, and process needs to be maintained. As soon as no bubbles appear no more, optimum drying time is set.

Pre-dried sheet should, if possible, be left in the oven until immediately before forming to save heating power and heating time on the thermoforming machine. Fully dried sheets taken out of the oven and cooled down to room-temperature may be used within a period of 1 hour up to a maximum of 10 hours (depending on the relative humidity and temperature of the work-shop) without the necessity of pre-drying them again. When preparing a blank for a thermoformed polycarbonate part, remember that the sheet shrinks the first time it is heated above its glass transition temperature. Shrinkage up to a maximum of 10% (for thin sheet) can be expected, unless the sheet is clamped in a frame.

Before starting the heating and thermoforming operation, the sheet should be cleaned by means of an antistatic cleaning agent or an ionized air gun. This is necessary to avoid marks on, or even imbedding of dirt or dust particles in the final article.

Take care while heating the sheet. Heating too fast will result in heat accumulating at the sheet surface and degrading it. The most appropriate heaters are infra red heaters. Contact heating and high-frequency heating are not suitable. Halogen heaters are mainly suitable for coloured sheet.

2. HOT LINE BENDING

The Hot Line Bending equipment is a simple IR- or electrical resistance heater, bending-calliper coated with fabric and a clamping device.

It is preferred to remove the masking, as forming occurs at 10-15 °C over glass transition temperatures, but in order to keep the finished part protected, remove the masking locally but avoid cutting the sheet surface. In some cases the masking can stay on the sheet during the entire process. Perform a preliminary test to find out the correct heating time.

For polycarbonate sheet up to 2 mm pre-drying normally is not needed. If bubbles occur on the edges, place some insulating material against the edges in order to avoid overheating them. If bubbles still occur, it might be needed to pre-dry.

If inner angles are smaller than 45° the masking should be removed on the inner side.

The heating time depends on the power of the IR heaters. With one side heating, it takes about 2 min to make a 3 mm sheet weak enough to bend. Thicker sheet need to be heated from both sides. If not available, turn periodically during the heating cycle. Always bend the sheet with the last heated side forming the outside radius.

When the sheet softens, remove from heating source, bend, place into calliper and clamp.

Cool slowly to prevent distortion. Keep the part close to the heating device to make it cool down evenly and reduce tensions. Once the part is below its T_g, it can be placed in a fixing device and cool down in the air.

Glass transition temperatures (T_g):

GRIPHEN®	81°C
ABS	min. 88°C, depending on the grade.
Polycarbonate	148°C



3. DRAPE FORMING

Uni-axial or slightly curved 3D bent parts can be achieved by drape forming. The mould, preferably preheated to 55-70% of the T_g to avoid cooling problems - can be made out of wood, aluminium or resin covered with felt. Slight pressure (with soft gloves or cloth, e.g. linen) is sufficient to drape the sheet over a positive mould. An alternative method is to place the flat sheet on the mould, foreseen with a load to push the sheet in place when getting soft. Then place mould and sheet in an oven.

Where applicable, remove standard masking before putting into an IR oven to be heated. Preferably the sheet should be clamped in a frame or hung, as placing it on a bed might mark the sheet. The sheet temperature should be about 20°C over its T_g to achieve easy forming. Place sheet on the mould immediately after heating; therefore minimise distance between mould and oven. Cool in surrounding air, but take care for drafts which could cause distortion of, and stress in the finished parts.

In most cases it is not needed to pre-dry the sheet for the drape forming process. Note that, as the sheet is not framed during the process, it will shrink during the heating process (sheet up to 5 mm can shrink up to 10% in extrusion direction; above 5 mm shrinkage is less)

4. VACUUM FORMING

Because of their good flow properties, all our sheet, allow you to make complex finished parts. Higher draw ratios can be achieved:

Polycarbonate:	up to 3:1
ABS:	up to 4:1
GRIPHEN®:	up to 5:1

Standard available vacuum forming machines, preferably with a sandwich heating system can be used to form our sheet.

All plastic sheet from Arla Plast require a minimum vacuum of 500 mm Hg (=0,66 atm = 0,066 MPa), but higher vacuum is preferred.

4.1 Temperatures

Ideal forming temperatures should be high enough to limit internal stress build up, but low enough to ensure a fast cycle time. In any case maximum temperatures should not be exceeded, in order not to 'burn' the material. Temperatures listed are sheet temperatures.

GRIPHEN®:	max 160 °C
ABS:	max 185 °C
Polycarbonate:	max 210 °C

4.2 Moulds

For long production runs and/or when optical quality is required, use temperature controlled aluminium or steel tools. For prototypes or limited production work, tools made of plaster, hardwood, reinforced epoxy or polyester resins may be used. Be aware that the mould material affects both cooling time and finish of the formed parts. It is also preferred that the mould roughness (Ra value) is situated between 1.0 to 1.4.

Allow for moulding shrinkage of 0.8 to 1% for polycarbonate and 0.5 to 0.6% for GRIPHEN®

For good evacuation of air, it is important to make an optimum number of holes in the right locations. If that is not the case, optical defects like little pores or craters could be formed. This may occur especially on parts with large flat surfaces. To avoid venting marks on the final moulding, these vent holes should not have diameters larger than 0.5 - 0.8 mm. Back drilling with larger drills is suggested to speed up air evacuation. Design moulds with such roundings (minimum equal to sheet thickness) that the plastic sheet can slip over without risk for thinning and webbing. A good release of the moulding can be obtained by providing a draft angle of minimum 4 to 6°.

4.3 Negative and positive mouldings

Negative moulds result in finished parts with a thin bottom and thick walls, whilst positive moulds result in parts with a thick bottom and thin walls. Depending on the application, either a positive or a negative mould should be built. For better external finish use negative moulds which show more detail.

Understand that hot thermoformable sheet reproduces every detail, badly finished moulds included. This can be reduced by either refinishing the mould or by reducing the mould temperature and/or the sheet surface temperature.



4.4 Heating

Remove standard protection masking prior to thermoforming, and blow off the sheet with ionised pressurised air.

When clamped on 2 sides only (in automatic feeders) be informed that the free side might shrink (see drape forming). Therefore four side clamping is preferred. If a heating profile is available, it is recommended to adjust it as such that when pre-blown, the sheet forms the same shape as the mould. That way the best thickness spread is obtained. It is also recommended that the systems used to support and clamp the edges of the sheet should also be heated, to avoid significant heat losses during heating as well as uneven cooling which could result in internal stresses or edge warping.

To improve the thickness gradient the sheet can be blown or mechanically pre-formed by means of a plug.

Heating range:

GRIPHEN®	100-160°C
ABS	150-180°C
Polycarbonate	175-210°C

It is recommended to supply minimum 30 kW/m² as heating power, but if present power is not sufficient, it might help to insulate the process with heat-reflecting material. One side heating is not recommended for sheets of 3 mm and above. To prevent surface degradation, avoid fast heating. The sheet can only absorb part of the IR radiation and accumulation of heat will damage the sheet and embrittle the formed part. The necessary heating time, proportional to the sheet thickness, has to be determined during preliminary tests on the thermoforming machine.

As soon as the sheet becomes plastic enough it will start the tension relaxation process while also expanding thermally, making it move up and down. Air pressure should be applied to keep the sheet as flat as possible, failing to do so will cause local uneven heating patterns. Once the heating process is finished, the forming can commence.

Note that different colours and different surface textures require different heating procedures.

Coefficient of dilatation (x 10⁻⁶ m/m °C)

Polycarbonate	Glass	Steel	Aluminium
67	7-9	12-15	21-23

4.5 Forming

As soon as the heaters are withdrawn, the sheet will be pre-blown to the required height, the mould moves up, and vacuum is applied to firmly form the sheet over the mould.



4.6 Cooling the formed part

Cool with compressed air; possibly with water mist (avoid droplets as they might cause marking). Let the part stiffen sufficiently and take it from the mould. Sheet which are formed at higher temperatures cool more rapidly, and because of this it requires more rapid forming. At the same time, however, its high heat deflection temperature under load enables short cooling cycles to be achieved. The mouldings can be removed from the mould with little risk of deformation as soon as they have cooled down to about 10-15°C below the T_g.

Using positive moulds, mould shrinkage might cause removal problems. Take care to remove before the part shrinks on the mould. Do not cool too fast, because the generated stresses may result in cracking. If necessary, annealing can be done.

Mould shrinkage:

GRIPHEN®	0.4-0.5%
ABS	0.3-0.7%
Polycarbonate	0.8-1.0%

(Mould shrinkage is mainly caused by the thermal contraction when cooling from demoulding temperature to room temperature)

4.7 Free forming

These techniques are utilized in forming dome shapes. Free blown billow forming uses air pressure while free drawing uses a vacuum.

The sheet is heated until a sag is formed. An optical switch and/or a micro-switch are coupled with the pressure (vacuum). The initial pressure (vacuum) is high (2,8 MPa or more) and is lowered towards the end of the forming cycle. The pressure (vacuum) is held until the sheet temperature cools down to 15-20°C below the T_g and the forming is able to be removed. Here will be no mark-off as no moulds are used, but dirt or oil in compressed air may cause marks on the sheet.

4.8 Plug-assist vacuum forming

Corner or periphery thinning of box-shaped articles can be prevented by use of a plug-assist to mechanically stretch and pull additional plastic material into the female cavity. Plug-assist vacuum forming and plug-assist pressure allow deep drawing and permit shorter cooling cycles and good wall thickness control. Both processes require close temperature control and are more complex than straight vacuum forming. The plug should be 10 to 20 % smaller than the mould and should be heated to ca 20-30°C over the T_g. Once the plug has forced the hot sheet into the mould cavity, air is drawn from the mould to form the part onto the mould.

Plug assist is an essential feature when forming multiple impression male moulds as they can be placed very close together without the fear of the material webbing between the formed parts.

4.9 Other methods

Other thermoforming methods are combinations of above mentioned ones.

High pressure forming (HPF) and Twin sheet forming (TSF) are two advanced methods which for small to average series can compete with injection moulding and blow moulding.

4.9.1 High Pressure Forming

Using a negative mould, the atmospheric air pressure that spreads the softened sheet over the mould, is increased by pressurised air up to 1 MPa.

This makes it possible to create sharp corners and very fine details like part textures.

4.9.2 Twin Sheet Forming

Two heated sheets are brought between two negative moulds. Air pressure in between these sheets is applied while the circumference of the sheet is clamped. An alternative technique forms the upper and lower part separately, and both parts are brought together, the circumference is reheated to obtain fusion of both parts. This technique creates hollow shapes, to obtain light parts with high structural stiffness.

4.10 Annealing

Whenever possible, use the optimum processing conditions to minimise the creation of internal stresses. Parts with too high internal stress levels should be annealed to avoid failure in service. This can be done by heating the parts evenly in an air circulating oven up to 10-20°C below their T_g, at which temperature they should be kept for 1 hour for every 3 mm of the part thickness. Then the part should be cooled slowly to room temperature, preferably in the oven with its doors closed.

5 TROUBLE SHOOTING

This comprehensive table is a summary of the most common causes and remedies thereto.

PROBLEM	POSSIBLE CAUSE	SOLUTION	Hot line bending	Drape forming	Vacuum forming	Free forming
Crazed or weak parts	sheet too hot	reduce heating			x	x
	mould too cold	increase mould temperature			x	
	part removed too late	shorten cooling cycle			x	
	vacuum rate too fast	restrict vacuum			x	
	sharp edges	round corners			x	
	sheet surface too small	use bigger sheet			x	
Webbing	uneven heating	check for hot spots or shade spots			x	
	mould spacing too small	min. spacing = 2 x depth			x	
	vacuum rate too fast	restrict vacuum			x	
	sheet surface too big	clamp-mould spacing < 50 mm			x	
Reduced or incomplete details	too small vacuum	check for leaks add vacuum holes			x	
	sheet temperature too low	increase heating			x	
Part sticks on to mould	mould too hot	reduce mould temperature			x	
	part removed too late	remove earlier			x	
	draft angle too small	draft angle should be > 6°			x	
Mark-off	mould surface too smooth	Sand surfaces			x	
	sheet temperature too high	reduce heating time	x	x		
	edges: masking came off	cut sheet with unprinted masking up		x		
	vacuum holes at the wrong place	redesign vacuum holes			x	
Surface defects	vacuum holes at the wrong place	redesign vacuum holes			x	
	dust on mould or sheet	clean with compressed air		x	x	
Unequal parts	mould/clamp too cold	increase pre-heating			x	
	uneven heating/cooling	check for drafts, check heater	x			
	part removed too late	remove part sooner			x	
Brittle parts	overheated parts	decrease heating power	x	x	x	x
Cracks or breakage	stresses too high	heat slower on wider area	x			
Bubbles in the sheet	too much heat	reduce heating	x		x	x
	moisture	pre-dry	x	x	x	x

6 ADDITIONAL INFORMATION

Delivery programme for thermoforming applications:

- ! We offer sheet from 0.75 to 15 mm, up to 2,1 m wide
- ! In a vast range of standard colours and any custom colour, including metallics and specialties
- ! In Polycarbonate, ABS, and Copolyester (PETG)
- ! With or without UV layer
- ! Also recycled products available
- ! Contact us for more information

COLOURS

Matching and sampling:

Arla Plast offers a comprehensive range of transparent colours, opal white diffusive tints and opaque colours. Most colours can also be colour-matched.

For a colour match in an opaque colour, a sample or RAL code or NCS code is required.

Transparent colours either only can be matched to a sample, or to light transmission requirements. Due to the specificity of the sheet extrusion process is it not possible to extrude one sheet in normal circumstances.

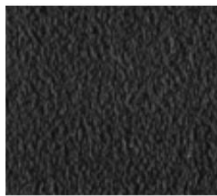
In order to see the thermoforming possibility of a coloured sheet for sampling reasons, it can be useful to paint a transparent sheet with formable paint prior to forming. Alternatively, any coloured sheet can be thermoformed and spray painted into the desired colour.

TEXTURES

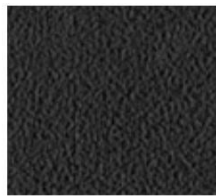
Arla plast offers its extensive range of textures:



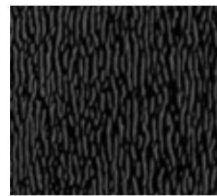
00 (smooth)



30



35



38



40



45



50



57



60

Additionally, the frosty matt surface of GRIPHEN® Frost also retains its properties when thermoformed.

Thermoforming simulation programmes

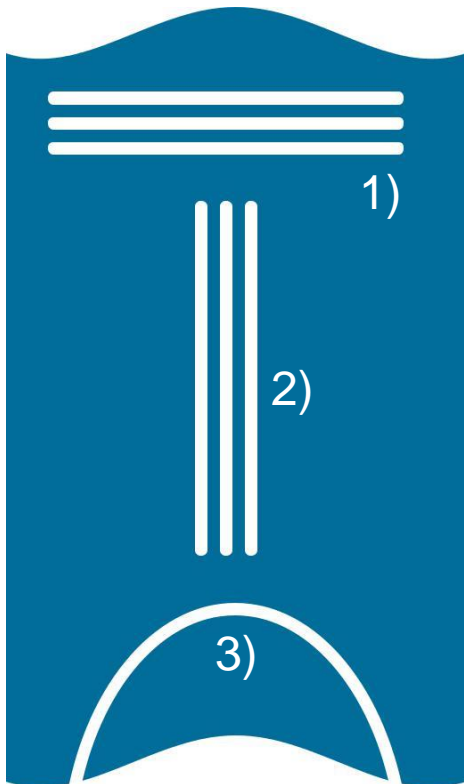
Relative new are the thermoforming simulation programmes.

However, due to the complexity of both the sheet extrusion process and the thermoforming process, will it probably never be possible to fully simulate the whole process for obtaining all processing parameters. These simulations therefore are more suitable to get a general idea but not the details.

Extrusion related common issues

The sheet extrusion process has a typical build up with a die and calendering roll stack.

Extrusion related issues can be:



Orange arrow indicates extrusion direction

Due to the specificity of the sheet extrusion process, extrusion defects most commonly are either:

- 1) perpendicular to extrusion direction
- 2) parallel to extrusion direction
- 3) following the material flow

On small scale, separate defects are present at random. Extrusion defects often are more visible when the sheet has been exposed over its glass transition temperature T_g .

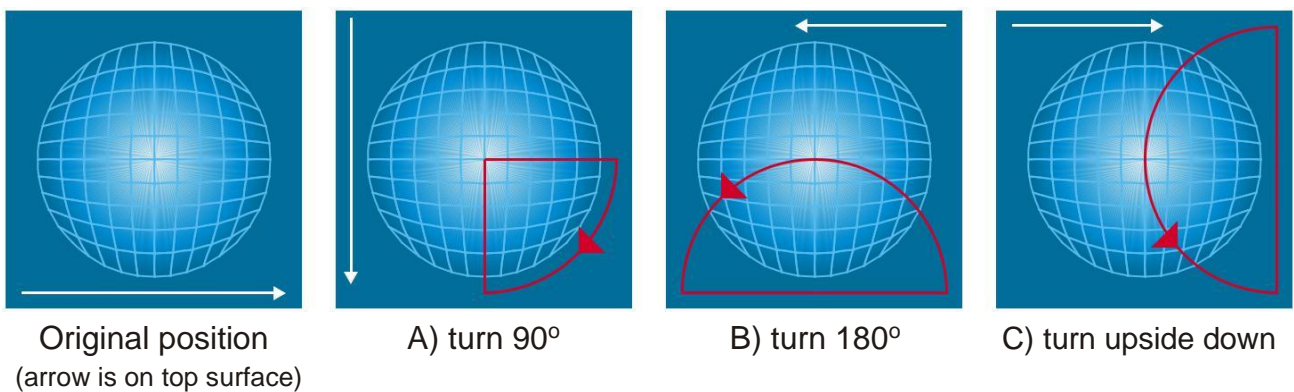
This is typically the case in thermoforming techniques. But of course thermoforming itself creates its own defects as well.

In order to distinguish between defects caused by thermoforming and extrusion related defects:

Test if the defect still occurs/ is on the same spot:

- A) when the sheet is turned 90° (if possible)
- B) when the sheet is turned 180°
- C) when the sheet is turned upside down

If the defect does not follow the rotational movement, it is probably not extrusion related.



For more information contact your local agent or contact Arla Plast directly