TENOPEX
The Plastic Films Specialist

Tenopex® Graphics GS Series Processing Guide

Performance for Diverse Processing

Tenopex® GS Series films offers an excellent profile to meet the diverse yet demanding performance needs of both fabricators and end users.

1. Introduction

The Tenopex® Processing Guide provides detailed instructions and recommendations for the correct handling, preparation, forming, finishing, and post-processing of Tenopex® polycarbonate films and sheets. It serves as a technical reference for converters, fabricators, and design engineers who use Tenopex® materials in applications such as printed overlays, membrane switches, packaging windows, labels, safety visors, and thermoformed components.

This guide consolidates industry-recognized processing standards and Tenopex®'s in-house technical expertise to ensure consistent performance across applications.

2. Handling and Storage

Proper handling and storage are critical to maintaining film and sheet quality prior to processing.

Storage conditions: Keep materials in a clean, dry environment room temperature 23°C ± 2 °C and relative humidity < 50 %

Packaging: Store materials flat in their original packaging until use. If storage racks are used, ensure the film stacks are well-supported to prevent warping.

Masking: For specific grades of Tenopex® PC films and sheets like GS11, which are protected by a PE masking film on both sides. Avoid exposing the masked film to direct sunlight or elevated temperatures for extended periods to prevent adhesion of the masking.

Handling: Always lift with both hands or by 2 operators as shown in Fig.1 to prevent bending or surface stress. Wear clean cotton gloves to avoid fingerprints, oil, or static contamination. Avoid dragging sheets across sharp edges to prevent surface scratching.

Static control: Always handle in grounded environments with ionized air where possible to minimize static charge accumulation.

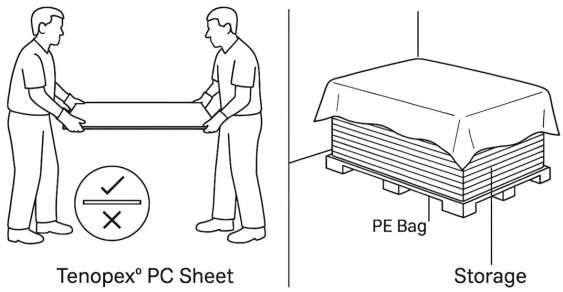

Fig. 1 Handling and Storage

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3. Printing

Tenopex® polycarbonate film can be first (front) surface printed and, due to its excellent clarity (GS11) at any gauge, it is also ideal for second-surface printing. Amongst the diverse compatible printing techniques, screen printing is the most common. Most inks adhere well to Tenopex® polycarbonate films (sheets) without pre-treating with a "printing coat".

Many inks contain aggressive organic solvents that promote adhesion to the film (sheet) surface, but may contribute to film (sheet) failure if not removed before further fabrication. Therefore it is suggested to dry thoroughly all inks after printing, to remove all solvents.

Tenopex® polycarbonate film (sheet) can be used in In Mold Decoration (IMD) process. For 1st surface printing, standard ink systems listed below may be suitable if they meet durability requirements for the applications. If the part will be a 2nd surface IMD application, the ink will be sandwiches between the injection moulded resin and the film (sheet) that the ink is printed on. In this instance, the inks must be able to withstand the high thermal and mechanical shear of the injection resin ; please consult your Tenopex® sales representative for compatible inks for 2nd surface IMD.

Tenopex® is compatible with digital printing and in many instances can be directly printed with digital printing machine without print receptive pre-treatment. Tenopex® polycarbonate film (sheet) works well with UV ink jet or solvent ink jet printing equipment from flat bed and/or roll fed options. Conditions for direct printing onto Tenopex® polycarbonate film (sheet) may vary from one printer to another so please consult with your Tenopex® sales representative with print equipment printing conditions for sampling printing trials.

Compatible ink systems :

- Physical solvent drying systems,
- Offset printing inks,
- UV Curing Systems,
- Flexographic/Letterpress/Gravure inks,
- Sublimation Inks,
- Conductive inks,
- (Acrylic or polysiloxane) Coatings and Clear Varnish for abrasion or chemical resistance which can be applied on by dip, spray or flow techniques,
- *Inks compatible with 2nd surface IMD, *please consult with your Tenopex sales representative*
- *Digital printing, *please consult with your Tenopex sales representative*

In all cases, it is recommended to check the suitability of all products supplied for it own particular purpose including finished product testing in its appropriate environment.

Printing Tips :

a) Use static eliminators to facilitate film (sheet) handling and reduce dust attraction to the material surface.
b) Keep the printing press and area free of dust and smoke.
c) When printing from a web in tension, it is important to consider dimensional change resulting from the film (sheet) stretching and then returning to its original dimension, when tension is applied and the removed. This will ensure accurate print registration.
d) Drive off all solvents as soon as possible. Tenopex® film (sheet) can be safely dried at temperatures up to 120-125°C (depending on the thickness used).
e) Make sure UV inks are formulated to cure completely accordingly to your requirement.
f) Follow guide-lines for offset printing i.e : low solvent inks or thin ink film, increase / decrease alcohol content for dampening solution, use short lifts to prevent set-off, etc

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g) Avoid excessive ink deposit (thickness) to minimise dimensional and aesthetic irregularities in thermoforming.
h) Test ink adhesion after curing using cross-hatch or tape test.

4. Bonding

Tenopex® polycarbonate film (sheet) are compatible with a wide range of commercial adhesives and laminating systems, as well as heat sealing systems. The adhesive must remain thermally and chemically stable during forming and service ; the choice of adhesives will be dictated by the specific application.

Being an amorphous polymer, Tenopex® polycarbonate film (sheet) is easier to bond because of limited chemical resistance. The solvents in adhesives make the surface swell and dissolve, resulting in good adhesion. Nevertheless, a drawback of amorphous material is its sensitivity to environmental stress cracking and it takes time for the solvent to evaporate, or water in the case of water based adhesives. The adhesive type primarily determines the characteristics of an assembly. See below table.

Adhesives Types and Characteristics

Type - Function	Adhesive	Curing	Characteristics
Structural (gap filling)	Epoxies	A+B comp. chemical reaction	Chem./moist./heat/creep resist., stiffness, brittle, low impact
	Polyurethanes	A+B comp. chemical reaction	Ductile, flexible, impact, creep, high peel strength
Sealants (gap filling)	Polyurethanes	Chemical reaction moisture	Ductile, flexible, impact, creep, high peel strength
	Silicones	Chemical reaction moisture	Impact, flexible, heat resistance, low shear
Contact (not filling)	Polyurethanes Cyano acrylates	Chemical reaction chemical reaction humidity	See above to polyurethanes fast curing, high peel strength, chem, aggressive, moisture sensitive
Hot melts	EVA	Temperature chemical reaction	Fast adhesion, low temp. resistance
Solvents (not filling)	$MeC1_2$, M.E.K. Toluene	Physical evaporation	Easy application, high strength, stress cracking, polluting, toxic

Assembly Techniques for Tenopex's polycarbonate films (sheets)

Material	Welding	Adhesives	Mechanical Assembly
Tenopex®	Vibration, ultrasonic, induction possible	Generally easy, critical are Cyanoacrylate and Acrylic because of stress cracking	Avoid high stresses at point leadings, filled : prevent brittle rupture

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5. Heat Sealing

Heat impulse, jaw and ultrasonic sealing are 3 heat sealing methods that has good results for Tenopex® polycarbonate films (sheets). Preliminary testing indicates that ultrasonic technique is the most reliable, producing peel strengths of 1.5N per mm of width. Speeds of this method range from 150mm/s with 0.075mm film to 30mm/s for 0.5mm sheeting.

Impulse and jaw methods produce bonds ranging from 0.5-2.5N per mm of width. See below table, impulse method is more rapid, particular with the thinner gauges. It should be noted that these times were obtained on laboratory equipment with only single jaw heating. Times on actual production equipment running at normal operating temperatures would be much faster.

Sealing Time (seconds)

Method	Thickness (mm)		
	0.025	0.075	0.125
Impulse	2.5	3.5	4.5
Jaw	7	8	9

Jaw sealing requires temperatures of 205°C for 0.025 mm film and 220°C for the two thicker films. Dielectric sealing is not practical with common commercial equipment because of Tenopex films (sheets)' low dissipation factor.

6. Cleaning

General cleaners recommended for use with Tenopex polycarbonate films (sheets) include :

- Mild soap and water
- Isopropyl alcohol
- Freon TF
- Denatured alcohol (methyl, isobutyl, etc.)

7. Static Control

Air ionization, liquid treatments and special cleaners are used for static control with Tenopex® polycarbonate films (sheets).

8. Die Cutting

Tenopex® polycarbonate films (sheets) can be die cut with either steel rule, matched metal and to a lesser extent, rotary dies. Tenopex® shear strength of 70N/mm^2, relatively low in comparison to metals, simplifies and eases tool design and processing. In addition, parts may be cut from single or multiple sheets depending on press tonnage, working area and material thickness.

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The press tonnage required to die cut Tenopex® film (sheet) can be determined by the simple formula :

$$F = \frac{(P)\,(A)}{9830\ N\ (metric\ ton)}$$

F = press tonnage
P = shear strength of Tenopex® film (sheet)
A = cross sectional area

The cross sectional or shear area can be found by multiplying the total length of the cut by the film thickness.

For example, below Fig.2 shows 100 x 300mm rectangle with a 50mm diameter circular cut out in the centre.

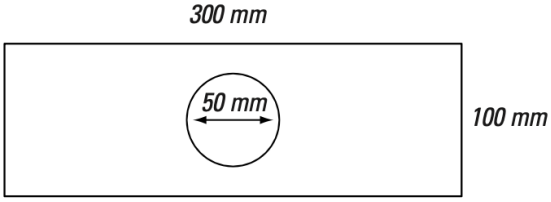


Fig. 2

Total length of cut	= 2L + 2W = D = (2) (300mm) + (2) (100mm) +π(50mm) = 600mm + 2000mm + 157mm = 957mm
Shear area	= (total length) x (thickness of film) = 957mm x 0.25mm = 239.25mm^2

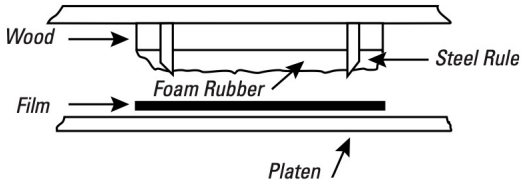
Finally, press tonnage :

$$F = \frac{(P)\,(A)}{9830} = \frac{70 \times 239.25}{9830} = 1.7\ ton$$

Of the three die cutting methods described earlier, steel rule die cutting is the most popular and least expensive method used. Generally, a 2-point rule (0.7 mm thick) is used to cut Tenopex® films (sheets) up to 0.375 mm thick, whereas a 3-point rule (1.0 mm) is used for films greater than 0.375 mm in thickness. When careful make-ready is applied, over 25,000 cuts can be obtained from a steel rule die.

Steel rule dies are manufactured by two different methods: laser and jig. The laser cut die will maintain the most accurate dimensional tolerances (to ± 0.1 mm), while the jig cut die will provide the least (± 0.4 mm). In manufacturing a die, a steel rule is fitted into a pre-cut pattern in a wooden die board. Stripping rubber on each side of the rule eases part ejection. Generally, stripping rubber should be no more than 3 mm above the height of the rule. Below Fig. 3 illustrates a typical steel rule die.

Fig. 3 Steel Rule Die



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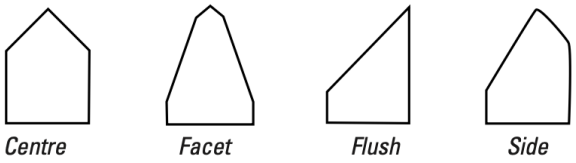
Several different steel rule bevel designs are available, as illustrated below Fig. 4 :

Fig. 4



Although the centre bevel rule is the most common and provides the longest life in terms of wear, cleaner cuts can be attained by using a facet bevel rule.

The longer bevel reduces material displacement, especially with thick material, while the broad tip remains sharp. The flush bevel rule also provides clean cuts, but has a weak tip that is susceptible to roll-over. To maximise both cut quality and rule longevity, the side bevel rule is recommended. In this case the long bevel side should face the scrap or trim of the piece.

Depending on rule design, size and shape of part and thickness of film, the cut parts will be slightly different in size than the rule: holes will be smaller and cut outs will be larger. Therefore, dies are usually manufactured on either end of the tolerance range. For example, dies to cut holes are made slightly larger than the part size indicated on the print.

Tenopex® polycarbonate films (sheets) can be successfully "kiss cut" with platen presses having close tolerance impression adjustment controls. In kiss cutting, a side bevel is recommended in the die design. The problem of cutting through both the printed Tenopex® polycarbonate films (sheets) and transfer tape or liner can be solved by using a heavier or thicker liner. For instance, using a 0.15 mm liner (3M, 9668) versus a 0.10 mm liner (3M 468) will provide a flatter piece and cushion the impact of the steel rule.

Obviously the thicker liner will be more difficult to cut through completely, and so the kiss-cutting problem will be reduced.

Finally, two other methods are used to die cut Tenopex® polycarbonate films (sheets) ; matched metal and rotary. Matched metal dies consist of hardened male and female die halves. Match metal die cutting operates by shearing the film and is used to cut intricate patterns, to maintain tight dimensional tolerances (± 0.025 mm), and to cut thicker films on larger volume production runs (100,000+). Clearance between dies should be less than 0.025 mm.

In roll-to-roll film processing (i.e. flexographic printing), rotary dies can be used for cutting Tenopex® polycarbonate films (sheets). This process offers a high-speed production capability versus steel rule and matched metal die cutting.

9. Embossing

Tenopex® polycarbonate films (sheets) can be embossed to form raised areas for membrane switch keys, or raised letters and design. Thicknesses up to 0.25mm can be readily embossed, and films (sheets) up to 0.5mm can be embossed in certain configurations.

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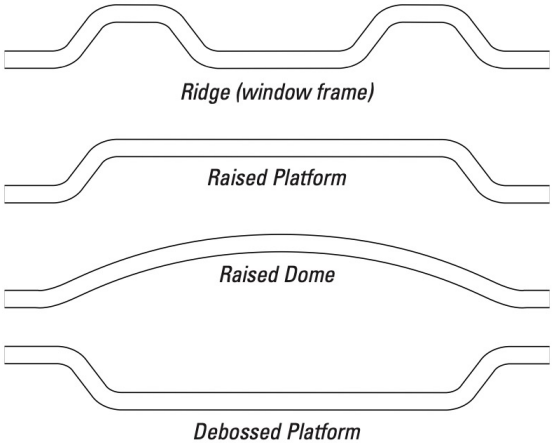
For films (sheets) over 0.5mm thick, thermoforming should be used to create three dimensional effects. Embossing raised areas for membrane switch keys may significantly decrease switch life. Since switch size and travel, film (sheet) thickness, embossed height and working environment can all be factors, product life cycle testing is strongly recommended.

A wide variety of embossing configurations is possible with Tenopex® polycarbonate films (sheets), as shown below. Fig. 5

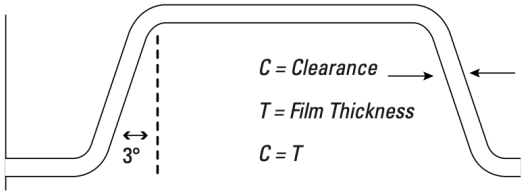
Fig. 5



Die Design

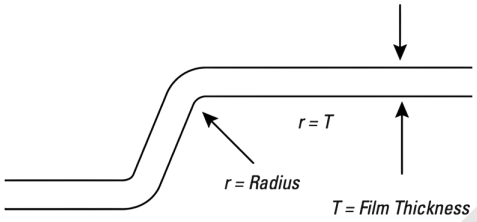
Dies for embossing can be matched male/female or either male or female with a rubber counter die. Materials include metals such as zinc, magnesium, brass, aluminium and steel, as well as polyester/fibreglass and silicone rubber. Sharp detail usually requires the use of metal dies. Dies should be designed so the clearance between the male and female sides is approximately equal to the film thickness. Minimum draft angles of 3° should be designed into both male and female walls, as shown in Fig. 6

Fig. 6 Draft Angles



To keep localised stresses in the embossed overlay to a minimum, embossing dies should contain no sharp corners at points in contact with Tenopex® film (sheet). Radii at all internal corners will reduce stress concentration and help prevent failure from fatigue or impact. As a rule of thumb, radii should be equal to, or greater than, the thickness of the film. In other words, a 0.250 mm thick Tenopex® film (sheet) should contain a 0.250 mm minimum radius at any corner. Fig. 7

Fig. 7 Radii



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Embossing Press

Several types of press can be used to emboss Tenopex® polycarbonate films (sheets). The most popular of these is the platen press, which also can be used in steel rule die cutting.

Part Design

The following design recommendations for embossed parts will help to minimise stress and maximise key life in membrane switch applications.

a) ***Embossed Width***

The width of ridge-type embossing should be equal to, or greater than, five times the film thickness. If adhesive and liner are not zoned away from the embossed area, their thickness must be added to the film thickness when determining width (Fig. 8)

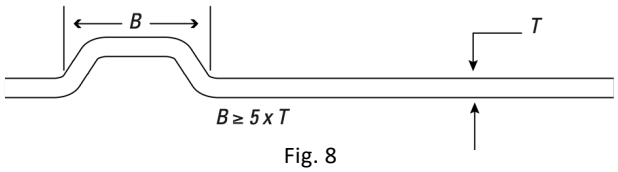

Fig. 8

b) ***Embossed Height***

The height of an embossed area should be no greater than 2.5 times the material thickness (excluding adhesive and liner), with material thickness included in the measurement (Fig. 9). Greater embossed heights can be attained, but are not recommended for membrane switch keys.

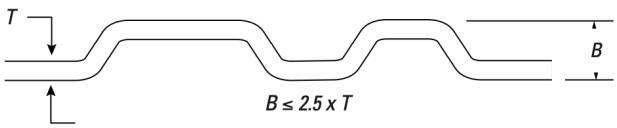

Fig. 9

c) ***Embossed Spacing***

Spacing between embossed areas should not be less than 1.5 mm to minimise distortion of the sheet after embossing (Fig. 10)

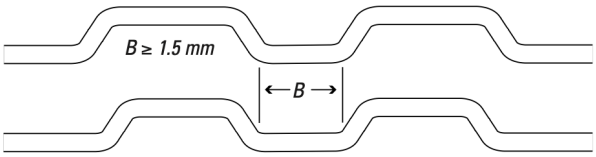

Fig. 10

d) ***Inks / Adhesives***

Inks used on Tenopex® polycarbonate film (sheet) that is to be embossed should be compatible with the material and also somewhat flexible. The ink coating will be stretched and bent, and may fracture slightly. This is an important consideration in back-lit applications, and may require special handling by the printer. Adhesives should be zoned away from the embossed area wherever possible to facilitate embossing. If adhesive is required in the embossed area, it should be carried on a polyethylene liner instead of on paper.

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10. Thermoforming

Forming polycarbonate involves heating the sheet or film above its glass transition temperature (Tg 145°C) and below its degradation temperature range. The material becomes flexible and can be shaped over a mould using vaccum, pressure or mechanical assistance.

Mould Design

Male moulds are preferred for deep draws and interior detail appearance parts. Good material uniformity can be maintained in depth of draw ratios between 1:1 and 2:1. A draft of 3-5° per side and a micro roughening surface finish provides for ease of mould releasing and will avoid air entrapment. Female moulds are recommended when exterior detail is important. Unless plug assisted or mechanically formed, parts made on female moulds will generally be limited to maximum depth : draw ratio 1:4 with a draft of 2-3° per side.

Because of its high tensile strength, Tenopex® film undercuts will be troublesome when forming 0.5mm and 0.75mm thickness. If these material thickness are specified, spilt moulds with sliding sections will provide ease of removal of part after forming.

Recommended materials for mould tooling are steel and cast aluminium for attractive, durable surface finishes, maintenance of close tolerances and rapid heating & cooling. While silicone, hardwood, fibreglass, melamine or phenolic should only be used for mould tooling on prototypes and very small scale production work. Vacuum holes of 0.50mm diameter and/or shims that supply adequate vacuum flow are recommended for male and female moulds. When fine details is rquir4ed, vacuum holes should be spaced as close as 6.0mm. On large flat surface, 25-75mm spacing is adequate. Back drilling with larger drills (ie > 6mm) is suggested to speed up evacuation.

Mould Temperature

Mould heating facilitate making deep drawn parts with plug assist, producing superior surface quality and minimised formed-in stresses. Mould temperature affects the appearance of the formed part. Minimum temperature of 90°C is recommended, 120-125°C when cosmetic requirements are critical. Oil and electrical systems are recommended for mould heating when forming Tenopex® films and sheets.

(Pre)-Drying

Polycarbonate is hygroscopic and absorbs moisture from ambient air. Excessive moisture causes surface defects such as splay marks, bubbles and haze during forming or printing. It is recommended that moisture content be reduced (by means of preheating of the sheets) before any forming or printing process.

Recommended drying conditions :

Thickness	Temperature(°C)	Duration (Hr)	Tray Spacing
≤ 0.25mm	120°C ≥ T ≥ 125°C	0.15	~ 10-25mm
0.375 - 0.50mm		0.25	
0.76mm		0.5	
1.00mm		2	
1.5mm		3	
2.0mm		4	

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- Use a circulating hot-air oven with dehumidified air. See Fig. 11
- Maintain consistent airflow around all trays to prevent local overheating.
- Cool the material to room temperature inside the oven before removal to avoid condensation.
- Transfer film / sheet directly to the forming machine as quickly as possible to minimise re-absorption of moisture
- Do not exceed 125°C to avoid warpage

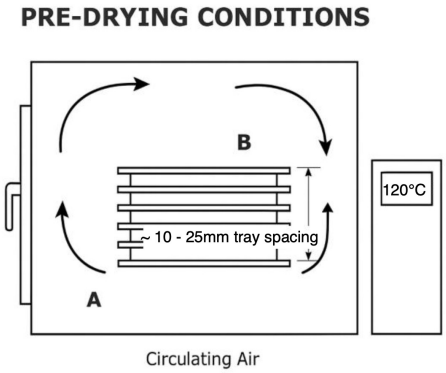

Fig. 11 - Pre-Drying Conditions (A) Circulating Air (B) Tenopex® PC Sheets
Temperature 120°C ≥ T ≥ 125°C

Web-fed forming of Tenopex® polycarbonate film rollstock up to 0.75mm maybe accomplished without pre-drying. Care must be taken to allow the film to reach forming temperature gradually to avoid bubbling in the web. Sandwich style heating units are recommended to be 4 times the length of the forming station dimension (i.e. 300mm tool = 1200mm tunnel)

Forming Temperatures

Standard processing temperature for Tenopex® polycarbonate film / sheet ranges between 170-225°C. For optimal gauge temperature parameters see below table as examples. Avoid local overheating and temperature variation (≤ +/- 3°C)

Gauges (mm)	Temperature (°C)
0.25	190 - 195
0.50	195 - 200
0.75	200 - 210

Standard stages of process :

i) Heating : The sheet is uniformly heated to 170– 225°C depending on thickness.
ii) Forming : The heated sheet is transferred to the mould, when vacuum or pressure shapes it .
iii) Cooling : Controlled cooling solidifies the formed part while preserving dimensional stability.

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Temperature uniformity across the sheet is critical, uneven heating causes differential shrinkage and distortion.

Sandwich heaters (top and bottom) are preferable so that both sides of the film (sheet) can be heated simultaneously. See Fig. 12 for for optimum sag appearance. This recommendation avoids overheating one side and underheating the other, which may create strains and stresses, excessive sag and degradation of material on the heater side.

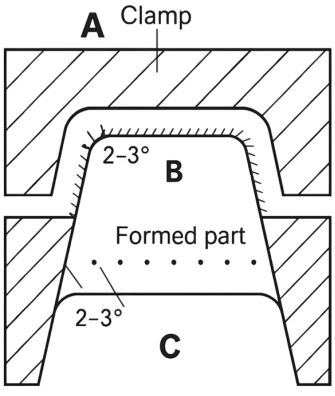
Optimal Appearance Sag
Fig. 12

Forming Process

The film (sheet) temperature is higher than the mould temperature because the polymer must first reach its forming window (above Tg) to allow stretching. The mould's lower temperature promotes quick skin formation and stabilizes the geometry.

- Vacuum forming : Use single sided mould ; typical vacuum 0.8 – 1.0 bar.
- Pressure forming : Apply forming pressue 1.5 – 2.0MPa for sharper definition
- Combination forming : Simultaneous vacuum and pressure applications yields the best replication accuracy.
- Draft Angle : ≥ 2-3°
- Cooling : Maintain cooling : 20-40s before removing.

Typical Forming Parameter	
Parameter	Typical Range
Pre-Heat Temp for Sheet	190 – 210°C
Mould Temperature	90 – 125°C
Pressure (for pressure forming)	1.5 – 2.0 MPa
Draft Angle	≥ 2° - 3°
Cooling Time	20 – 40s



– Vacuum/Pressure Forming Schematic
(A) Clamp Frame (B) Male Mould (C) Female Mould
Draft Angle 2-3°C
Mould Temperature 90-125°C
(Sheet Temperature 190-210°C, ΔT < 5°C)
Fig. 13

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