Thermoforming Benefits

MATERIAL USE GUIDELINES

Technology Advancements in Boltaron Sheet and Thermoforming

Innovations in thermoforming equipment, production techniques and tooling methods make possible formed parts with excellent surface and design detail. Similarly, formulation and production technology advancements in Boltaron sheet continue to expand their performance range and aesthetic options. The result is a continued growth for these high performance sheet materials in thermoformed applications ranging from sports equipment, to electrical and medical equipment housings, and interior aircraft seating and components that satisfy stringent FAA flammability criteria.

Benefits in Thermoforming

All Boltaron grades are manufactured under tightly controlled conditions for consistent behavior during thermoforming. Because of their proprietary compositions, forming temperatures differ to some degree from other materials, such as ABS and acrylics.

By following the recommended design and processing guidelines for Boltaron sheet, thermoforming companies around the world routinely realize these benefits using standard production equipment:

- Consistent forming conditions from lot to lot
- Uniform wall thickness even in deep draws
- Uniform surface appearance with excellent texture retention and detail

Thermoforming Advantages

Thermoforming offers distinct characteristics and benefits compared to injection molding, related to tooling costs, production economics, and the design configurations possible:

- Lower tooling costs, ideal for short production runs
- Short tooling development time, faster and easier tooling modifications
- Ideal for very large parts at low tooling costs
- Faster and simpler production set-up and shut-down
- Excellent design and surface detail, depending on the method chosen

Guidelines for Part Designers and Thermoformers

This guide provides information on the thermoforming conditions for Boltaron sheet, and on the part design related to the choice of thermoforming methods and mold designs. All are interlinked and must be considered for the production of high quality, cost-effective thermoforming.

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Thermoforming Methods

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Thermoforming Methods and Advantages

Thermoforming involves clamping a sheet into a frame, heating it to a formable state, then applying vacuum, pressure, or both to form the sheet to the shape of a mold. Part design generally determines the thermoforming method and the type of mold used. Depth of draw, level of detail in surface and design features, and the need for ribbing, fillets and undercuts may be carefully considered.

The following information summarizes the most common forming methods and their impact on part design and appearance:

Vacuum Forming

A vacuum created between the heated sheet and the mold draws the sheet over a mold (male mold) or into a mold cavity (female mold). This technique allows very deep draws with uniform wall thickness. Molds can be created from aluminum, wood, or epoxy, depending on the finished part design requirements.

Advantages

- Low tooling and modification costs
- Large size capability
- Fast tooling turn-around time
- Fast, easy production set-up
- Ideal for simple designs where fine detail is not needed

Pressure Forming

This method applies air at high pressure to the sheet while it is being vacuum formed. Female molds are most commonly used. A pressure level approximately five times greater than the applied vacuum forces the sheet against the mold surface. The result is greater detail in textures, patterns, corners and other design features of finshed parts, approaching that of injection molding at far lower tooling costs.

Advantages

- More well-defined surface and design detail than vacuum forming alone
- Sharper corners and undercuts can also be achieved
- Allows zero or near-zero draft angles
- Overall part detail similar to injection molding at lower costs

Note: pressure forming requires a two platen machine with high claiming force to keep the platens closed while applying air pressure.

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Pre-Stretching Methods

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Pre-stretching for Improved Wall Thickness Uniformity

When heated sheet contacts a mold, it can cool and resist "flowing" uniformly as it is formed. Pre-stretching heated sheet before it contacts the mold surface allows more control of thickness uniformity. Two methods are commonly used, depending on mold design:

1. Snap-back Vacuum Forming

In this process, vacuum or compressed air forces the heated sheet into the pre-stretch box, causing it to "sag" or form a bowl shape. Typically, the sheet is stretched to about 2/3 of the designed depth of the part. An electric eye can help regulate the level of stretch. As a pre-stretching technique, this method uses the least expensive tooling: a male mold and a simple pre-stretch box, compared to a costlier plug assist with a negative mold (see *plug-assist* below).

Once the sheet reaches the desired stretch or "sag," the vacuum or air pressure is shut off. A secondary vacuum between the mold and the sheet then causes the sheet to "snap back" onto the mold surface.

Advantages

- Least costly tooling for pre-stretching sheet
- Allows for very deep draws
- Uniform wall thickness control, minimizes thinning

2. Plug-assist Forming

A plug-assist allows pre-stretching sheet when using female molds. The plug, similar in configuration to the mold cavity but typically 10-30% smaller, pushes the heated sheet into the mold. As it contacts the sheet, air pressure applied between the sheet and the mold surface causes the sheet to billow around the plug, keeping it from contacting the mold surface and setting up prematurely. When the plug-assisted sheet is pushed near the bottom of the mold, a rapidly applied vacuum draws the sheet tightly to the mold surface.

Advantages

- Greater depth of draw with female molds
- More control of wall and bottom thickness
- Minimizes sheet thinning

Note: Using heated plugs made of insulating materials (wood, syntactic foam, thermoset) helps avoid cooling the sheet during contact. Aluminum plugs with temperature controlled electric heaters also work well, but are usually more costly.

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Mold Designs and Factors

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MOLD DESIGNS AND FACTORS

Types of Molds

Male Molds

- Produce gentle radii and limited outer surface detail
- Provide better detail inside the part
- Textured sheet imparts outer surface detail where needed
- Allow closer tolerance control than female molds
- Corners and sheet areas first contacting the mold will be thicker
- Pre-stretching can improve thickness uniformity
- Lower cost than female molds

Female Molds

- Sharper exterior detail possible
- Surface texture created by texturing the mold
- Greater thinning occurs at the bottom of the mold
- Pre-stretching can improve thickness uniformity
- Thicker areas occur at the flange or clamped area
- Higher cost than male molds

Mold Shrinkage

Shrinkage of the sheet during forming occurs with all materials, and must be factored into mold design. The level of shrinkage will vary according to:

- The level and type of orientation in the sheet
- Mold temperature: higher = more shrinkage
- Time in contact with the mold
- Male vs. female mold configuration

Draft Angles and Radii

- Observe minimum draft angles to facilitate part removal
- Note that female mold designs allow tighter radii

Mold Design Recommendations

	Male Molds	Female Molds
Draft angle, min.	2-4°	1-2°
Radius, min.	2.4 mm (3/32")	1.6 mm (1/16")
Mold shrinkage	0.4 - 0.6%	0.5 - 0.7%*

**0.4-0.5% for female pressure molds*

Multi-cavity Molds

Tools can be designed with multiple cavities to allow for higher production rates, and to improve yields from single sheets by minimizing trim scrap. Single tools with molds for different part configurations can also be designed.

Guideline: space mold cavities at 2x the part height to allow for good material distribution and wall thickness uniformity.

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Pre-drying Guidelines

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Pre-Drying

Boltaron sheet is non-hygrospcopic, and requires no pre-drying under typical production conditions. However, if extraordinary exposure to extreme humidity or moisture necessitates pre-drying, follow these guidelines:

- Drying temperature: 15 to 20° F (-9 to -6.7°C) below the Boltaron grade's heat distortion temperature*
- Drying times:
    - 10 hours for thicknesses up to 0.080" (2.0 mm)
    - 16 hours for thicknesses up to 1.25" (3.2 mm)
    - 24 hours for thicknesses up to 0.250" (6.4 mm)
- Oven type: use 2-sided or sandwich type heaters for thicknesses ⩾ 0.080" (2.0 mm)

**Refer to Boltaron data sheets for product heat distortion temperature.*

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Heating Elements

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Heating Elements

Boltaron sheet can be thermoformed using all heating element and heater types.

Source	Description	Advantages	Limitations
Calrod	Metal tubes most often found in older equipment	Low cost Long heating life	Long heat-up time, non-uniform heating Degrade, become inefficient in time Inadequate for multiple heat zones
Ceramic	Commonly used industry wide	Long lasting, versatile Easy to zone for good balance Uniform heat over long runs Moderate cost	Slower heat-up and response time vs. halogen and quartz
Halogen, Quartz	Growing in use, ideal for shuttle type equipment	Fast heat-up and cool down times Excellent control, easy to zone Allow heat levels or steps in a cycle Fast cycling times; high efficiency	Fragile, made of glass Typically higher cost
Gas Catalytic	Diffusion heater; chemical process produces infrared energy	Far lower energy cost than electric resistance type heating elements	Temperature zone balance can be more difficult or sensitive than the other heating elements

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Heating and Forming Guidelines

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Heating Temperature Guidelines for Forming Boltaron Sheet

- Make sure to heat the sheet uniformly. A shiny surface is evidence of heating too quickly
- Forming temperatures range between 325° - 400 °F (163 - 204 °C) depending on sheet thickness
- The internal (core) temperature should be within 10 °F (-12 °C) of the sheet's surface temperature
- Cycle times depend on oven conditions and the grade of Boltaron sheet
- Refer to Boltaron product data sheets for specific forming temperatures by grade
- Heater settings or percentage timers:
    30-50% top
    50-70% bottom

Typical Heating Conditions

Sheet Thickness	Typical Dwell Times	Temperature Range
0.028 - 0.080 in. (0.71 - 2.03 mm)	15 - 80 sec	325 - 345 °F (163 - 174 °C)
0.080 - 0.125 in. (2.03 - 3.175 mm)	80 - 140 sec	335 - 365 °F (168 - 185 °C)
0.125 - 0.250 in. (3.175 - 6.35 mm)	≥ 140 sec	355 - 400 °F (179 - 204 °C)

Oven Temperature Settings

These recommendations will help achieve the desired temperature profiles for heating Boltaron sheet:

- Position the sheet at greater distance from the bottom heaters than the top heaters (*)
- A higher temperature profile in the bottom heaters will contain the heat below the sheet, and allow it to be absorbed uniformly, reducing the necessary heating time (**)
- A lower temperature profile in the top heaters helps avoid overheating, which can create unwanted gloss on the sheet surface (**)
- A profile of 30% on the top heaters and 70% on the bottom provides a good baseline (*) (**)
- Set perimeter temperatures 5 - 10% higher than other settings, depending on ambient temperature, to compensate for the effect of ambient air flow across the oven

(*) Only applicable with open-oven thermoforming machines where additional vertical spacing is necessary to allow for sheet sag and is dependent upon sheet size and material type.

(**) Dependent upon vertical spacing. A uniform surface temperature on the top and bottom of the sheet at the end of the heating is desirable for an initial setup.

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Visual Guide to Effective Heating

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While surface temperature measurement tools are useful, high quality forming depends on achieving the right temperature at the core of the sheet. This helps relieve internal stresses in the material, and yields parts with consistent quality, uniformity, and dimensional stability. However, it is also difficult to measure.

In addition to cycle times, many experienced operators rely on the visual appearance of a heated sheet to determine its suitability for forming. This has proven to be an effective complement to cycle time guidelines.

SIMONA Boltaron sheet goes through four visible phases during heating. The appearance of the sheet in these phases can help operators make appropriate oven adjustments and determine whether the sheet is in the best state for forming:

Phase 1: Sheet softens, billows

The sheet softens from the heat under it and wil slightly bulge or billow upward

Phase 2: Rippling occurs

Near its forming temperature, ripples or undulations can be seen on the sheet. This is caused by the release of stresses induced in all materials during sheet manufacturing

Phase 3: Ripples begin to disappear

Ripples begin to smooth out during this phase. The sheet is not yet at an optimum temperature. Forming at this point would likely result in poor definition and thinning.

Note: if measurements indicate the sheet surface is at the recommended forming temperature, the sheet may be heating too quickly, requiring adjustment of oven settings and dwell time.

Phase 4: Sheet is smooth, sags slightly

A smooth, ripple-free sheet with a slight sag indicates that the sheet has reached the right core temperature, with minimal internal stress levels. SIMONA Boltaron sheet sags less than ABS and many other materials due to its higher melt strength. At this point, the sheet is ready for forming in the 10-30 seconds after achieving this visible phase.

Note: smoking or blistering on the sheet before achieving this stage indicates that it is being heated too fast or excessively. Reduce temperatures and increase dwell times.

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Troubleshooting

MATERIAL USE GUIDELINES

Incorrect heating is the most common cause, when a forming problem arises.
If a probelm identify the possible cause and solution using the chart below.

Step 1: Check the heating times, temperatures, controls, and gauges

Heating Boltaron sheet too rapidly, at incorrect temperatures is the most common cauess of thermoforming problems. Verify the accuracy of the gauges and controls and correct the conditions as necessary.

Step 2: Review the information in this guide

If the cycle times and temperatures are correct and the problem still persists, review the possible causes and solutions below.

Problem	Possible Causes	Solution
Bubbles, blisters in sheet or part	Sheet heating too rapidly Sheet overheating Sheet too close to heaters	Reduce heater temperatures Reduce heating time Increase space between heaters and sheet
	Uneven heating, hot spots	Use screening to deflect heat from hot spots Verify heaters are operating correctly Balance heater zones
	Sheet exposed to excessive humidity or moisture	Pre-dry sheet Heat sheet on both sides Reduce heater temperatures Increase dwell time as needed
Scorching, discoloration	Sheet surface overheated Sheet too close to heaters	Reduce heater temperatures (may need to increase dwell time) Reduce dwell time Increase space between heaters and sheet
Blush marks; whitening at corners	Sheet not heated sufficiently	Increase dwell time Reduce platen time and or vacuum delay Check heaters for accuracy
	Uneven heating, hot spots	Use screen to deflect heat from hot spots Verify heaters are operating correctly Balance heater zones
Localized glossy spots, streaks	Specific areas of sheet are being overheated	Adjust heaters where the problem appears If adjustments can't be made, use screens to deflect heat from the problem areas
Excessive sag in sheet	Sheet getting too hot	Reduce heater temperatures and/or dwell time
Webbing, wrinkling, bridging	Sheet getting too hot	Reduce heater temperatures and/or dwell time
	Vacuum not sufficient	Verify mold's vacuum level Check vacuum lines for blockages
	Improper draw ratio or mold design for part	Increase mold draft angle, radii Add a plug-assist Use take-up blocks to pull material from corners Use web moats or pockets in web areas In multi-mold designs, increase spacing between
Nippled part surface	Sheet getting too hot	Reduce heater temperatures and/or dwell time
	Vacuum holes too large	Plug holes and re-drill to smaller diameter

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Troubleshooting

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Problem	Possible Causes	Solutions
Poor detail in surface texture or design features	Vacuum inadequate	Check vacuum holes, hoses for blockage Check hoses, fittings for vacuum leaks Add vacuum holes or increase hole diameter
	Sheet not heated adequately	Increase dwell time and/or heater temperature Verify heaters are operating correctly Eliminate any cool ambient air drafts Pre-heat clamping frame
	Vacuum draw too slow	Check vacuum level with gauge Inspect hoses, fittings for leaks, blockage Increase vacuum capacity Use slots rather than holes
	If pressure forming, pressure low	Ensure pressure of 20 - 50 psi (0.137 - 0.345 Mpa)
Mark-off; chill marks	Mold is too cold	Increase mold temperature to recommended level of 10 °F (-12 °C) below the product's heat distortion temperature If molds are not heat-controlled, pre-heat the mold Increase pre-stretch bulge so mold doesn't contact sheet early
	Plug-assist is too cold	Use syntactic foam as plug-assist material Use a felt or flannel cover on plug-assist
	Sheet is too hot	Reduce heater temperatures and/or dwell time
Poor wall thickness uniformity	Improper or distorted sag	Ensure sheet is heated uniformly for even material flow Mount the mold on the top platen Use billow snap-back technique Add a plug-assist
	Hot or cold spots in the sheet	Ensure heaters are operating correctly Balance heating temperatures Eliminate any ambient air flow, cool air drafts Use screening to deflect heat at hot spots
	Mold is too cold	Increase mold temperature to recommended level of 10 °F (-12 °C) below the product's heat distortion temperature
Surface imperfections, pock marks	Pocks on mold surface trapping air	Sand blast mold surface using #30 grit
	Dirt, foreign matter on mold or sheet	Ensure mold surface and sheet are thoroughly cleaned
Shrinkage marks evident in corners	Inadequate level of vacuum	Check vacuum holes, hoses for blockage Check hoses, fittings for vacuum leakes Increase vacuum hold time, add vacuum holes
Corners too thin (with female mold)	Incorrect forming method	Use billow snap-back technique Add a plug-assist
	Sheet temperature not uniform	Check temperatures to ensure uneven heating of sheet Increase perimeter temperatures (5 - 10% higher than center)
Part difficult to remove from mold	Mold design; draft angle inadequate	Increase draft angle Increase air pressure for ejection Sand blast mold with #30 grit With undercuts, use a breakaway mold Apply a mold release agent

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