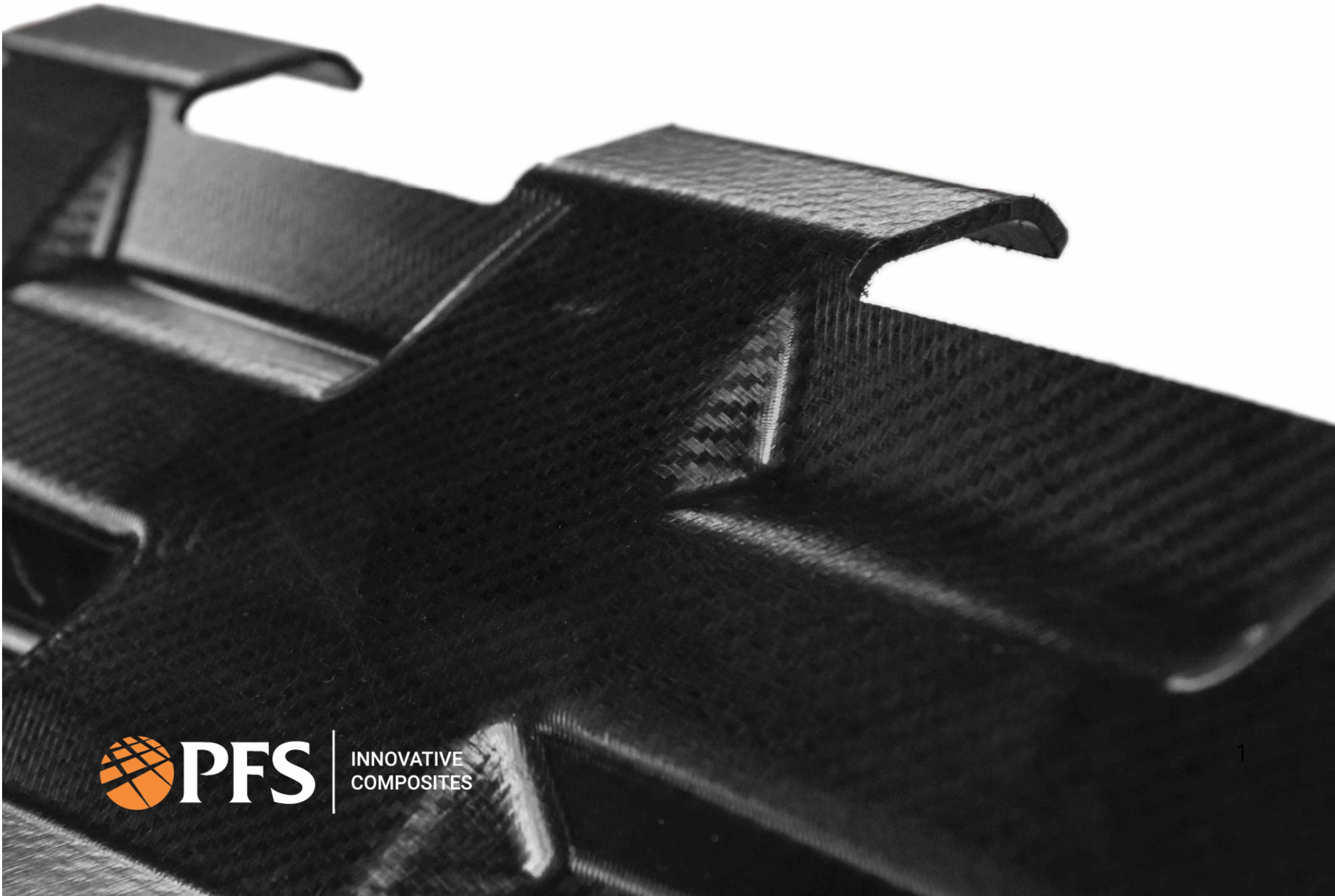
Processing Guide



INNOVATIVE
COMPOSITES

1 Processing Overview

Standard Curv® and VersaComp™ are 100 % polypropylene (PP) 'self-reinforced' composites. In a unique and patented process, highly drawn polypropylene tapes are heat-treated to selectively melt every surface. The molten material bonds the tapes together and yield in a single polymer composite. In short, the material properties are enhanced through molecular orientation resulting in 'self-reinforcement'. This unique structure creates a bridge between the performance of isotropic PP and conventional composites. The material can be used in a variety of forms, depending upon end-use requirements.

For example:

- Flat sheet
  - Thickness from 0.35 – 2.95 mm
  - Width up to 1.36 m
  - Sheet lengths cut to customer requirements
  - Rolls available for 0.35 – 1.0 mm thicknesses
- Molded parts, using matched-die thermoforming or diaphram forming
- Laminate skin for multilayer sandwich composite sheets using:
  - Expanded PP (ePP) foam
  - Honeycomb core (paper, PP, aluminum)
- Localized reinforcement in compression / injection molded parts. The outstanding impact performance of Curv® and VersaComp™ at low temperatures makes them ideal as a localized reinforcement with glass-reinforced composites.

In addition, a number of post-processing techniques can be used with Curv® and VersaComp™ composites:

- Decoration Methods
  - Painting, Printing
  - Self-colored
  - Fabric and carpet lamination
- Attachment Methods
  - Thermal bonding
  - Adhesives
  - Vibration welding
  - Ultrasonic welding
  - Mechanical fasteners
- Trimming Methods
  - Laser Cutting
  - Milling/routing/Gerber
  - Water jet cutting
  - Die cutting
  - Circular saw

2 Making Parts by "Thermoforming"

Curv® and VersaComp™, like all thermoplastics, are processed by heating to a point where the material becomes soft. However, unlike most conventional thermoplastics, even at mold temperatures Curv® and VersaComp™ have a relatively high stiffness and it requires a few bars of pressure to shape the material. Curv® and VersaComp™ cannot be vacuum formed in the traditional 1-sided tool plus plug-assist configuration.. For best results, a two-sided tool with a a min. pressure of 15 bar (217PSI) is required.

In the following pages all technical details will be described regarding thermoforming of Curv® and VersaComp™.

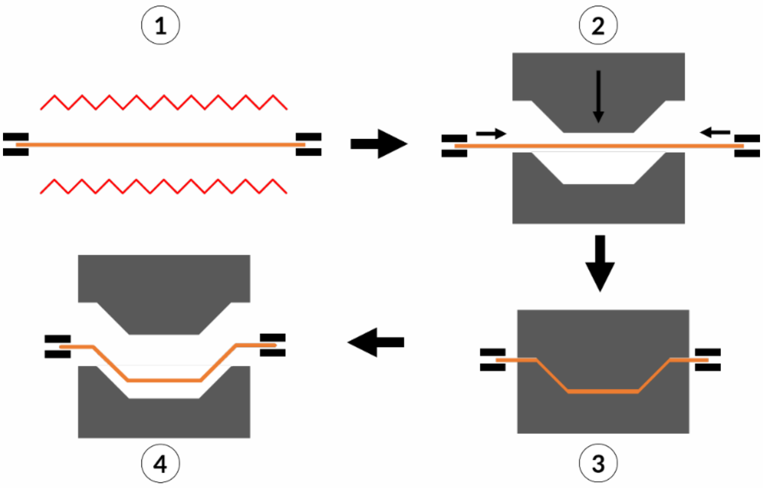
The process comprises the following steps:

1. Preheating of the Curv® / VersaComp™ sheet

2. Transporting and Positioning the heated sheet in the mold

4. Forming using appropriate mold technology

5. Cooling and demolding



2.1 Preheating

Appropriate preheating is a critical step in molding Curv® and VersaComp™. There are three preheating methods that can be used successfully, depending on the amount of draw and geometry required. In all cases it is of vital importance to get temperature into the middle of the material without overheating the surface.

In principle three heating methods can be used:

- contact heating
- convection heating
- infrared heating

Depending on the heating method the heating time will be different. The infrared heating method needs approx. 60 seconds heating time for a 1 mm thick Curv® or VersaComp™ sheet whereas convection heating methods needs a much longer ~400 seconds.

The preheating of Curv® and VersaComp™ depending on the following:

- Part-depth (deep-draw area)
- Part complexity (geometry)
- Final application

The temperature must be selected so high that there is still sufficient plasticization after the movement to the mold. The heat distribution should be uniform over the surface and should not be held for a long time to reduce the degradation of the material.

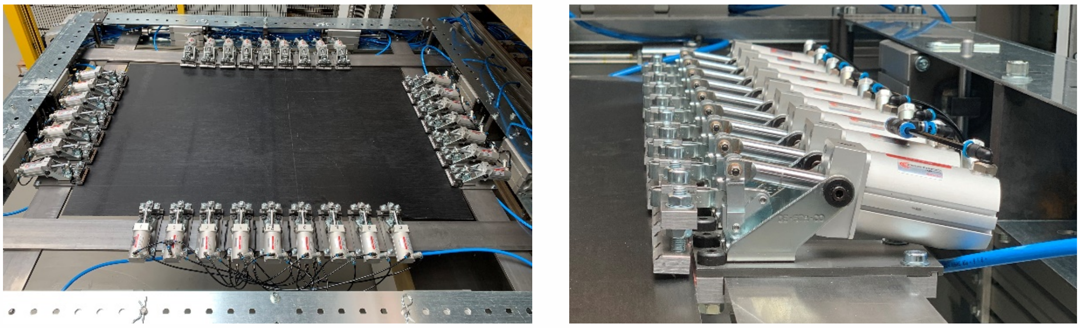
2.1.1 Preheating Curv® and VersaComp™ without a frame

During heating of Curv® and VersaComp™ without a frame the temperature should not exceed 160 °C. Above this temperature the sheet material will shrink heavily due to its high orientation.

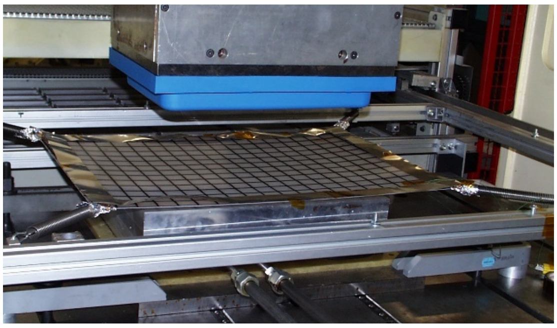
2.1.2 Preheating Curv® and VersaComp™ with a frame:

When preheating a Curv® or VersaComp™ sheet clamped in a frame, the heating temperature can be increased up to 190 °C while still keeping the high orientation of the tapes. This allows opening up of the temperature window where the process stability is also optimized.

When using only simple tool designs a fixed frame can be used to achieve best results. Parts with a deep draw area like luggage shells need a flexible frame where the material can flow into the mold. This will avoid any overstretching of the the single tapes.



Sheet held in frame during heating and molding cycles



Curv® sheet held in sprung frame during heating and molding cycles

Conditions will vary based on equipment and product design. Specific needs can be discussed with Propex experts for fastest results.

2.2 Molding Curv® and VersaComp™

Due to the self-reinforced effect of the Curv® and VersaComp™ sheets it is necessary to use the compression molding process, to achieve the best possible shape and properties in the finished part. Also possible is the diaphram process.

2.2.1 Tool design

- *Tool substrate:* Process Curv® and VersaComp™ with matched (e. g. male/female) die. For production purposes aluminum is recommended, however tools may be of wood or resin for prototype work.
- *Tool geometry:* The tool gap should be matched to the thickness of the Curv® / VersaComp™ sheet being molded. In areas of extended draw, the material is likely to thin slightly and this effect should be taken into account in the tool design. In addition, areas of the tool which may trap air during molding should be vented.
- *Maximum draw:* Depends greatly on the part design and if a "slip clamp" frame is used during molding.
- *Minimum radius:* Depends on the part design, but typically 2x sheet thicknesses.
- *Pressure:* Modest pressure is needed at the tool face, in the range of 15 – 30 bar (150 – 300 N/mm^2, 217 – 435 psi).
- *Mold shrinkage:* typically ~1 %
- The overall tool design depends to a great extent on the complexity of the part to be molded. Parts with relatively little depth of draw can be successfully molded using simple matched tool, where the sheet is positioned - by hand or by robot - between the tools immediately prior to closure. Parts with deeper draw usually require some type of clamping frame which restricts the material as it is drawn into the mold to prevent creasing.
- For *vertical areas* an angle of >3 ° is recommended to reduce the sheer during molding, to get enough pressure for good surface quality and to get an easy de-moldable part.
- *Tool temperature:* Curv® and VersaComp™ forms best with a tool temperature of ~80 °C. Lower temperature will cool down the matrix before finishing the forming process.

- *Removal from the mold:* The formed part should be removed from the tool after temperature has decreased to <100 °C to prevent warping.
- *Cycle times:* Cycle times are dependent on tool design and material thickness. However, most parts can be produced in approx. 60 seconds. The overall limit to cycle time is the time required to heat the sheet, which may be overcome by preheating multiple sheets in a convection oven or multi-stage IR oven.

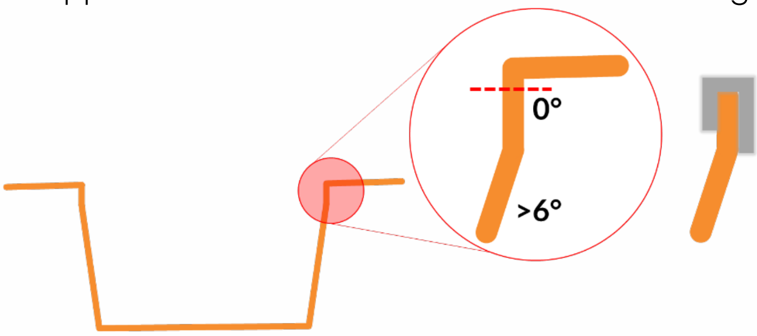
2.2.2 Alternative thermoforming process

An alternative to matched tool compression molding is to use a single-sided tool with a rubber diaphragm and compressed air to produce the required pressure. Minimum air pressure of 10 bar is recommended. One advantage of using a diaphragm with compressed air is that equal pressure is applied over the entire mold regardless of the orientation.

2.3 Design Guidelines for Luggage Shells made of Curv® and VersaComp™

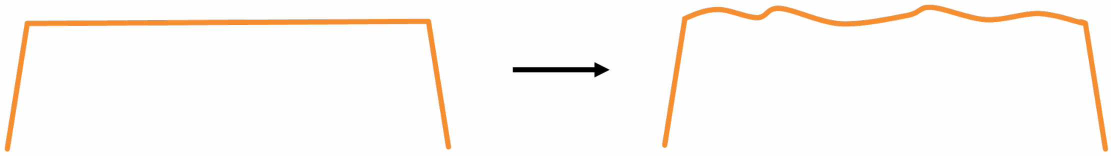
These guidelines are intended to help the designer to understand the basic constraints in development of suitcase shells with CURV® and VersaComp™. It is important however to discuss any new shape with Propex specialists and/or to validate a design by a trial mold.

1. Main draft angle is >6 °. Local deviations, especially in non-visual areas are possible (0 ° in main zipper area: main zipper can only work when border is 0 °). The Zipper and Zipper extension hide the 0 ° area and the cutting edge.

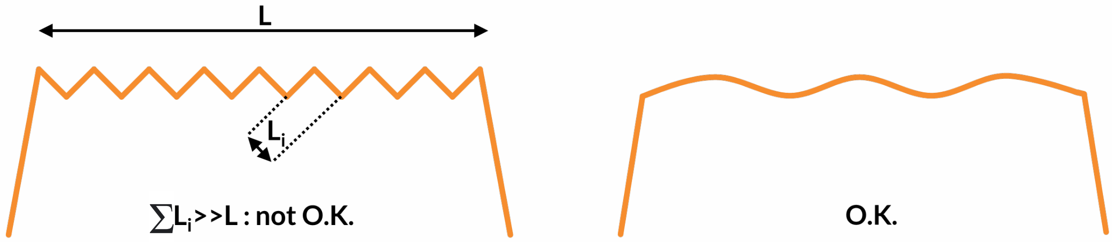


2. Keep corner radius big enough to avoid wrinkles in the corner. Sharp corners to be minimized.

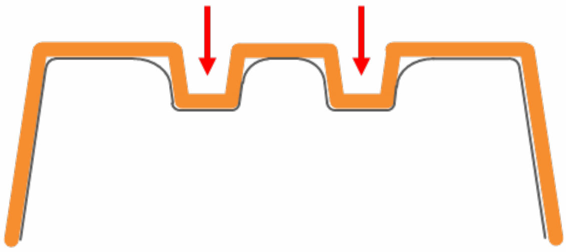
3. Avoid big plain surfaces. Due to the internal stresses and low thickness of CURV® and VersaComp™, plain surfaces will not remain flat and will deform and not be nice.



4. Aim for fluent ribs and avoid to elongate the material too much.

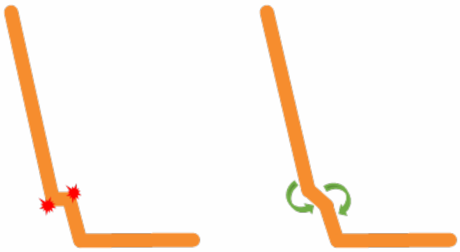


5. Avoid big local deformations in shape, especially when using baked-in lining. Baked-in lining will come loose. In general; design should focus on more gradual/fluid shapes: the more local deformation, the more tension in the material.



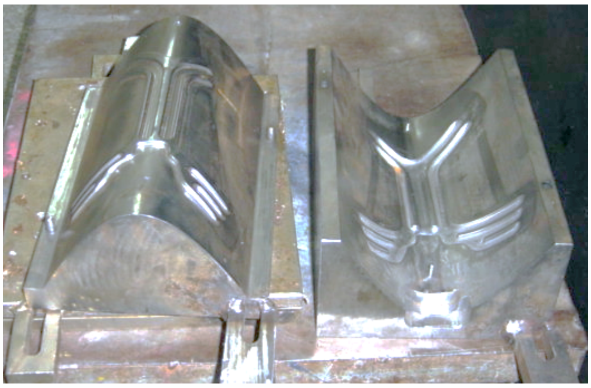
6. Provide strong structure in corner and wheel area to avoid denting of these areas in extensive use. Plan some shock absorbent shape at 10-15 cm away from corner.

7. Avoid sharp corners where possible. The material risks to "block" during forming in sharp corners. The material can get more fluid in the mold with a minimum of corners and edges.



2.4 Examples for thermoforming of Curv® and VersaComp™

The example shown below, a soccer shin guard insert, has many ribs and a high degree of curvature, but the overall depth of draw is small. No clamping frame is used.

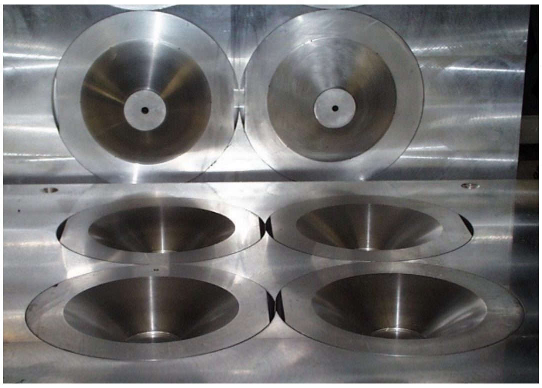


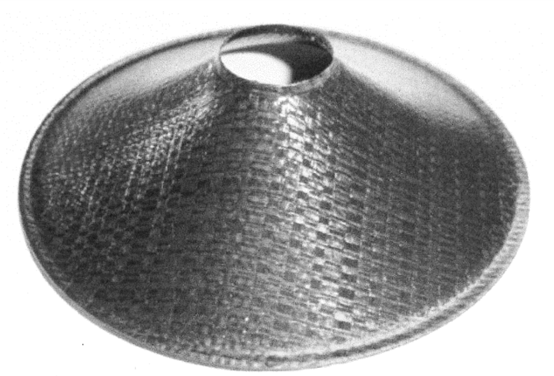
Simple male / female matched tool

Tool mounted in hydraulic press

Molded part

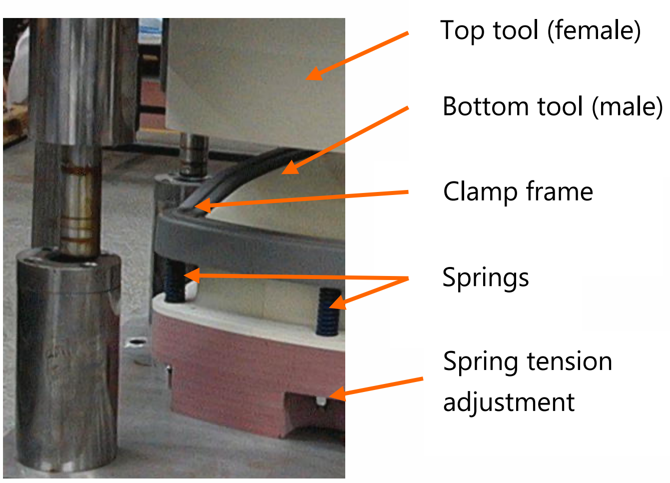
In the example shown below, the loud speaker cones are produced by tightly clamping the sheet during forming so that all the depth is created by stretching.

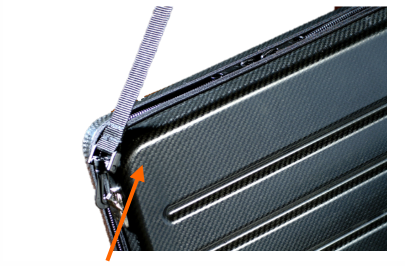




The example on the left shows a matched aluminum tool for the production of loud speaker cones. The material is clamped during forming such that the entire draw is achieved through stretching the material. Note the small holes at the points of deepest draw which allow trapped air to escape. The molded part is trimmed from the sheet by die-stamping

The maximum depth of draw attainable during molding depends greatly on the geometry of the part. However, a typical maximum strain-to-failure of the material, at molding temperatures, is around 50 %. For parts where a deeper draw is required it is important to allow the material to move or slide into the tool. By restricting the movement of the material, through back tension, creasing can normally be eliminated. Deeply drawn parts, such as suitcase shells, need a spring mounted clamp frame similar to the one shown below. In this example, as the tool closes, the sheet is automatically held by a clamp frame which is spring loaded. The sheet is able to slip under the frame but the back tension is high enough to prevent creasing in the corners.





Tight radius and deep draw achieved without creasing

3 Laminating Curv® and VersaComp™ to Core Materials

Curv® and VersaComp™ can be used with a variety of core materials to achieve specific properties. For example:

3.1 Curv® or VersaComp™/Expanded Polypropylene (ePP) Foam

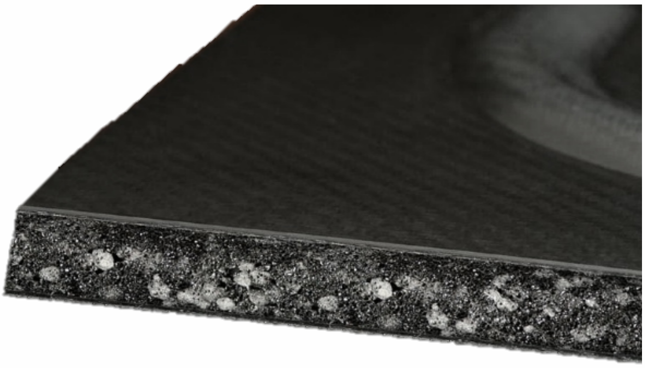
Curv® and VersaComp™ can be combined with ePP foam by thermoforming with matched tooling without the use of an adhesive. We suggest the following starting conditions:

Pre-heat the skins and core together to the required processing temperature of approx. 170 °C. These conditions result in a temperature of 140 – 150 °C between the foam and Curv® or VersaComp™ sheet, which melts the surface of the foam and gives good adhesion between the core and skins.

Sheets should be clamped in a frame, and the tool temperature should be adjusted to ~30°C.

For parts with simple geometry, a flat sheet of foam can be used as the core material. The tool will create minimal geometry in the final part.

For complex parts, it is better to use pre-formed foam.

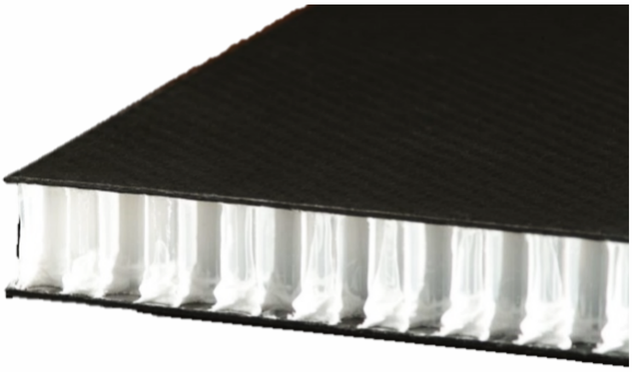


Curv® / ePP foam laminate with 'simple' rib, molded in one-shot process

Curv® / ePP foam laminate with more complex form - note tools used to close edges

3.2 Curv® and VersaComp™/Honeycomb (PP, Paper, or Aluminum)

Curv® and VersaComp™/honeycomb laminates offer high stiffness and light weight. Laminates made with PP honeycomb are also easily recycled. Curv® and VersaComp™ skins can be bonded to honeycomb cores with hot-melt film adhesives either by continuous lamination or a static press.



Curv® / PP honeycomb panel bonded with hot melt adhesive

Curv® and VersaComp™ / paper honeycomb laminates may be molded in a single shot process by heating both sheets and Curv® or VersaComp™ and placing in a matched tool along with hot melt adhesive. Alternatively, Curv® and VersaComp™ may be specified with a suitable heat activated adhesive already applied.

Curv® / paper honeycomb molded in a single shot process. Note honeycomb compresses to meet tool geometry and can be closed completely at the edges.

4 Surface treatment of Curv® and VersaComp™

Curv® and VersaComp™ are 100 % polypropylene and as such have very low surface activity, typically 28 dynes/cm as produced. However, standard Corona or Plasma treatment methods are sufficient to raise the surface activity to enable Curv® and VersaComp™ to be painted using conventional painting systems or conventional adhesive systems. Corona treatment will raise the surface activity to around 48 dynes/cm whereas the Plasma treatment will raise the activity up to 72 dynes/cm.

Curv can also be provided with a custom outer-layer consisting of PET. Curv with a PET surface can be printed, coated or painted similarly to standard PET films.

5 Surface refinement of Curv® and VersaComp™

5.1 Painting and Printing

To activate the Curv® or VersaComp™ surface for painting it is necessary to use a corona treatment or plasma treatment as mentioned before. Furthermore, a special primer can be used for pretreatment of the Curv® and VersaComp™ surfaces. Next to these methods conventional Polyurethane lacquer systems can be used to achieve "Class A" effects.

5.2 Fabric and Carpeting

Various fabrics and automotive carpet may be attached to Curv® and VersaComp™ using a heat activated adhesive suitable for polypropylene. In many cases carpet may be bonded as part of a one shot molding process.

5.3 Surface Films and Colours

5.3.1 Surface Films

Although Curv® and VersaComp™ is 100% polypropylene the material can be supplied with a special surface film of either polyester (PET) or thermoplastic polyurethane (TPU). Such films promote bonding with a wide range of adhesive types and the PET finish in particular gives a higher gloss / scuff-resistant surface.

5.3.2 Colors

Standard colors are black and translucent. Through the use of inner layer coloring, Curv and VersaComp can be made with almost any color imagined while still showing the interesting composite structure.

5.3.3 Textured surfaces

Standard Curv® and VersaComp™ has a smooth surface, although custom textures may be applied during production, (i. e. Anti-Slip., matte finish, holographic embossed etc)

5.4 Attachment Methods

5.4.1 Adhesives

For standard Curv and VersaComp, adhesives that adhere to polypropylene must be used. 3M™ Scotch-Weld™ Structural Plastic Adhesive DP8005 is recommended for a liquid system. The 3M 300LSE "low surface energy" series of double sided tapes can also be used for successful PSA (pressure sensitive application) bonding. Care must be taken to evaluate adhesives for compatibility with the matching bond surface.

5.4.2 Vibration Welding and Ultrasonic Welding

Curv® and VersaComp™ may be bonded to itself and polypropylene compatible materials by vibration welding and/or ultrasonic welding. Careful selection of conditions will result in high quality bonding without witness marks on the "A" surface. Ultrasonic welding processes can achieve very short cycle-times.

5.4.3 Additional Methods

Laser Welding

Laser welding may be used. The carbon black used as a pigment in "standard" Curv® and VersaComp™ are excellent absorber of laser light but successful welding by this method requires that one substrate must be laser transparent. Non-pigmented Curv® / VersaComp™ can be supplied on request.

Bending of Curv® and VersaComp™

Curv® and VersaComp™ sheets can be bent in different angles by using a heated tool or press-brake. Elevated temperature applied to the local area will allow partial surface melting and enable clean and permanent bends.

Hotplate Welding

This method enables to heat up two separate Curv® and VersaComp™parts with a heated plate on one side; after the heating process both Curv® and VersaComp™ parts can be pressed together.

6 Trimming Methods

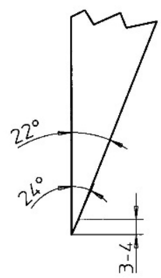
6.1 Water Jet Cutting

Starting parameters:

- orifice size: 0.15 - 0.2 mm diameter
- water pressure: 3300 – 3800 bar
- cutting speed: depends on thickness, but suggest starting at 200 mm/s

6.2 Die Cutting

The blade should be cut to an angle of 22 ° with the cutting edge ground at 24 ° to a depth of 3 – 4 mm.



6.3 Sawing

Curv® and VersaComp™ may be successfully trimmed using a circular saw with a fine cut blade typically used for cutting acrylic and plastic sheet. The following blade parameters have found to be successful:

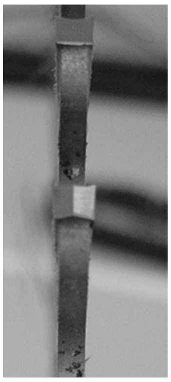
Blade diameter: 220 mm

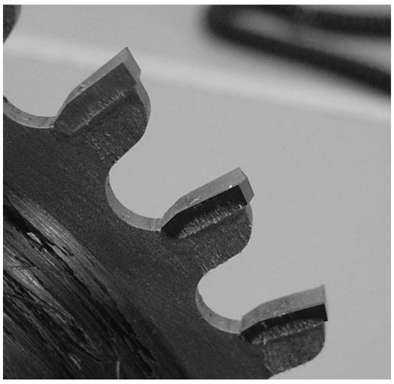
Number of teeth: 42

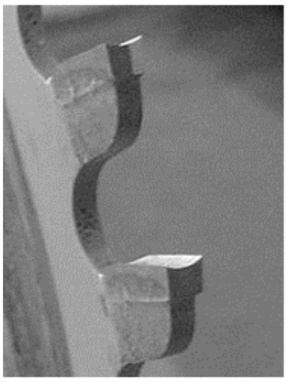
Cutting speed: 3000 revolutions/minute

Tooth angle: 5 - 8°

Metal type: high speed circular saw with DH teeth (special description of tooth form)







6.4 Milling

Standard milling tools and drills for plastic processing can be used. Cutting data can be found in the documentation of the tool manufacturer. The cutting speed should be as high as possible and the spindle speed as low as possible in order to reduce the melting of the polymer matrix. The tool can be air-cooled, no additional coolant is required. Care must be taken to use sharp tools to prevent the material from fraying.

6.5 Laser Cutting

Curv and VersaComp are easily cut using standard CO2 lasers. High vacuum/air flow is recommended to minimize vapor discoloration/staining on the cut edge. Typical parameters for a 280watt laser would be 100mm/second at 60% power for 1mm thick Curv and half of that speed for 2mm thick Curv. Customers must do initial testing to optimize laser nozzle distance-to-material, speed and power settings for their specific laser power, type and setup.

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Curv® and VersaComp™ are technical products and optical properties can vary and cannot be guaranteed.

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