

Engineering Polyurethanes – RIM Part and Mold Design Guide



Quick Design Reference Guide for RIM

Parameters	Elastomers	Rigid Rim			Composites	
	Solid Bayflex System (Unfilled)	Foamed Baydur System	Solid Baydur GS System	Solid PRISM System (Thin Walled)	Foamed Baydur STR/F System	Solid Baydur STR/C System

Part Design

(t)Wall Thickness (in)	0.2 – 1.0	0.2 – 1.5	0.25 – 4.0	0.125 – 0.5	0.125 – 0.25	0.09 – 0.15
Rib Thickness at Root ^a	0.75t	t	t	0.75t	Use box beam or corrugation	Use box beam or corrugation
Draft (degrees) This is function of Part Draw or Depth	0.5 min +0.25/inch greater than one inch of draw	0.5 min +0.25/inch greater than one inch of draw	0.5 min +0.25/inch greater than one inch of draw	0.5 min +0.25/inch greater than one inch of draw	1.0 min	1.0 min
Molded Holes/Slots	Yes	Yes	Yes	Yes	No	No
Undercuts	Slight undercuts	Use side pull or removable insert	Use side pull or removable insert	Use side pull or removable insert	No	No
Snap Fits	Possible	Possible	Possible	Possible	No	No
Fillets (Inner Radius)(in)	1/16	1/8	1/8	1/16	1/4	1/4

Finishing

Best Surface	Class A	Class A	N/A	Class A	No Class A, use texture	Class A with veil
Screw Assembly	Use bolt and nut ^b	Thread cuts skin	Thread cutting	Thread cutting	Thread cutting	Thread cutting

Mold Design and Processing Parameters

Material of Construction	Metal preferred (depending on prod. volume)	Metal preferred (depending on prod. volume)	Metal preferred (depending on prod. volume)	Metal preferred (depending on prod. volume)	Steel	Steel
Preferred Gating	Fan	Dam	Dam	Dam	Center/Direct	Center/Direct
Shot Time, Max. (sec)	2 (9 ^c)	9	15	5	5	15
Mold Pressure (psi)	100	100	100	100	200	200
Mold Temperature (°F)	140 – 160	140 – 160	140 – 160	140 – 160	130 – 140	175 – 185

Physical Properties

Flexural Modulus (psi)	5,000 – 100,000	53,000 – 240,000	130,000 – 190,000	270,000 – 310,000	150,000 – 750,000	Up to 2,000,000
Part Density (lb/in ³)	60 – 65	15 – 55	63 – 68	61 – 67	20 – 40	90 – 110
Flexural Strength (psi)	N/A	3,000 – 12,000	5,300 – 7,700	9,300 – 10,300	3,500 – 17,000	50,000
Tensile Strength (psi)	1,900 – 4,000	1,000 – 4,800	3,600 – 5,300	5,500 – 6,600	2,500 – 9,000	26,000
Elongation at Break (%)	100 – 360	6 – 10	16 – 29	11 – 12	2.5	2.5
DTUL at 66 psi (°F)	N/A	160 – 212	140 – 215	190 – 205	205	400
Hardness (Shore D)	30 – 69	40 – 81	70 – 75	73 – 75	60 – 70	60 – 70
% Reinforcement	0 – 25	N/A	N/A	N/A	20(mat)	55(mat)

^aRoot includes both radii. ^bCan also screw through to metal substrate.

^cLonger shot times are possible with a Bayflex XGT system, which has an extended gel time.

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Today, various Reaction Injection Molding (RIM) polyurethane systems are replacing many traditional materials because of their inherent advantages, including:

- Large-part molding; . Wall-thickness variations;
- Excellent encapsulation capabilities;
- Excellent surface reproducibility and in-mold paint finishing;
- Good dimensional stability;
- Good chemical resistance;
- Good weatherability.

Generally, RIM processing uses less expensive molds, less energy and lower-tonnage presses than thermoplastic processing. These characteristics add up to superior design, economic and processing flexibility.

The extensive number of RIM polyurethane systems with their various physical and mechanical properties can make selecting the right system difficult. The purpose of this manual is to help you – the design engineer, product designer and others who work with RIM polyurethane materials – make practical design decisions.

This manual is divided into two sections: part design and mold design. The section on part design begins with a brief discussion of the RIM polyurethane process and design considerations common to all RIM polyurethane systems. Unique properties and design guidelines for various polyurethane systems are discussed next, followed by design considerations for assembly and postmolding operations. The second section of this book contains information on mold, gate and runner design.

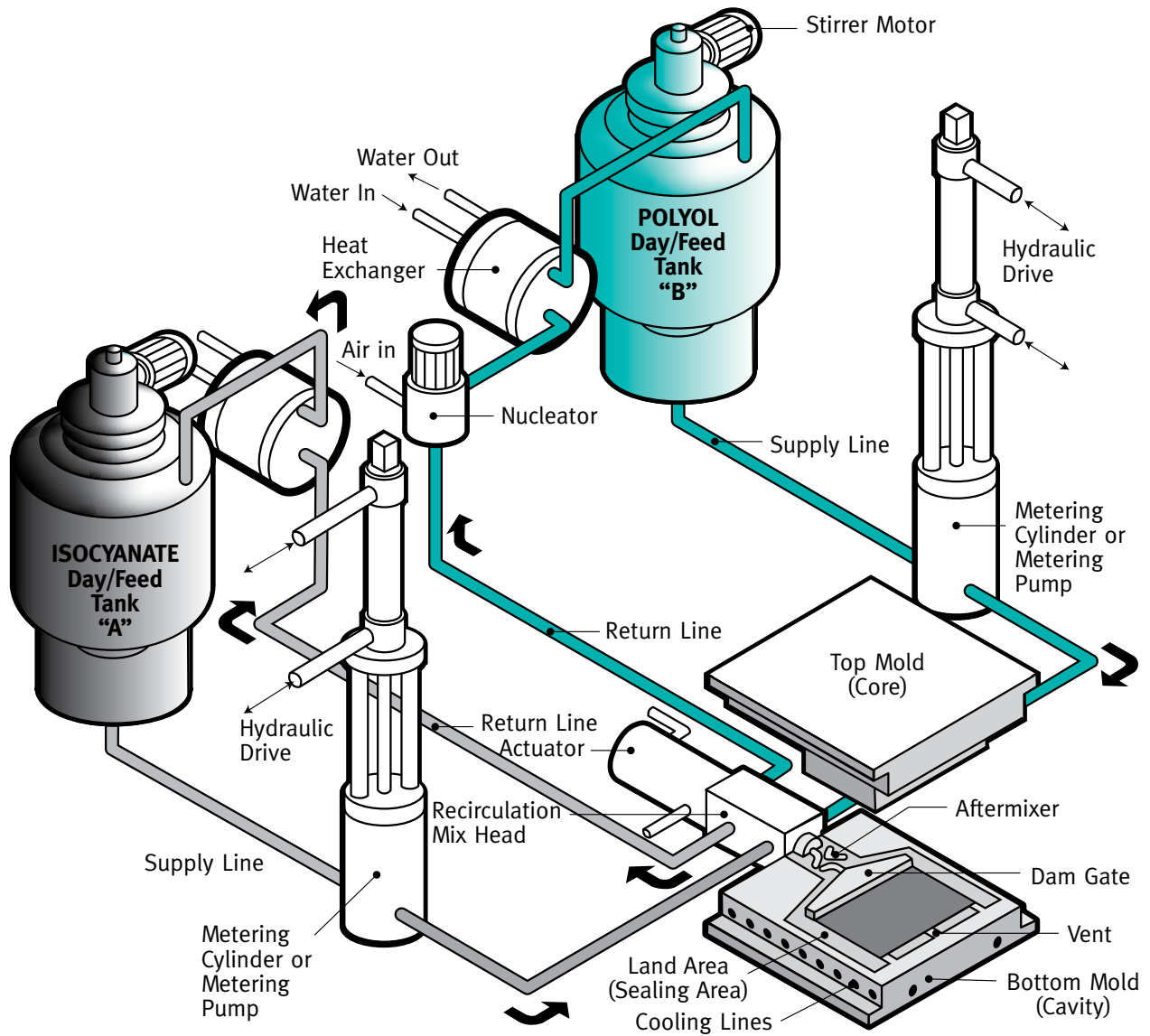
Many rules of thumb appear in the text. Naturally, there may be some exceptions to these rules of thumb or times when one conflicts with another. If this happens, talk with your mold maker/designer and BaySystems personnel for appropriate action. While this manual provides a good overview of the topics you should address when designing for polyurethane parts, you should also have a good understanding of polyurethane systems before making final decisions. For a quick reference, see the part-design matrix on the inside back cover for key information.

Specific system data and typical property information have not been included in this manual except as examples for general information. All values that appear in this manual are approximate and are not part of the product specifications. Do not use this data for product specification. For more specific information on a particular system, please read the appropriate BaySystems Product Information Bulletin (PIB). Published data should be used to screen potential material candidates. Your understanding of materials and processing and your part's requirements determines the suitability of a material for your product or application. Ultimately, material selection must be based upon your prototype testing under actual, end-use conditions.

Bayer MaterialScience offers a full range of RIM polyurethane systems, including foamed, solid and structural composite materials. As a service to our customers, we also have technical personnel ready to help you with part design and production. A list of these services appears in the back of this booklet. Please feel free to contact us with specific questions at 412 111-2000.

Reaction Injection Molding (RIM) Process

Figure P-1



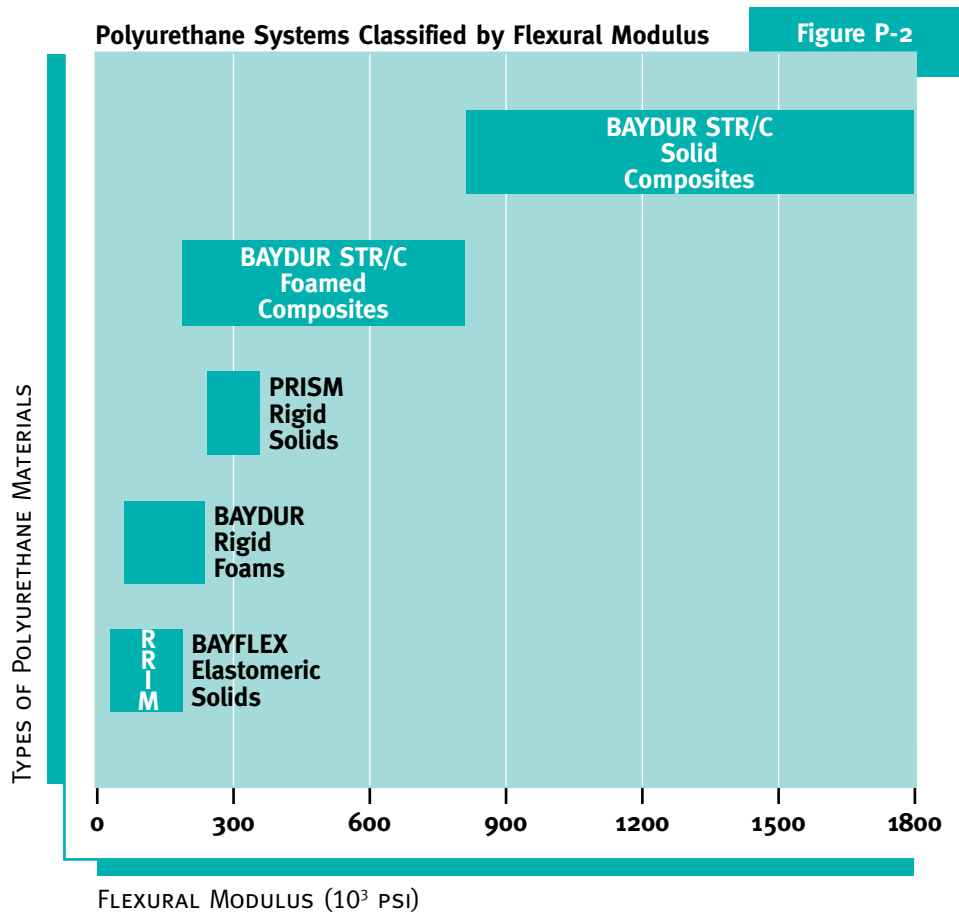
THE RIM PROCESS

In contrast to thermoplastics where a molten plastic is compacted in a mold and then solidifies upon cooling, RIM systems are composed of two liquid components that chemically react in the mold. The liquids, isocyanate and polyol, are commonly referred to as the “A side” and “B side” components, respectively, in the United States. In Europe, these demarcations are reversed. A matched set of “A” and “B” components is referred to as a “RIM system.”

Generally, the “B” component contains additives such as stabilizers, flow modifiers, catalysts, combustion modifiers, blowing agents, filler, pigments and release agents to modify physical characteristics in the final part. When the “A” and “B” components combine, the isocyanate reacts with the hydroxyl in the polyol to form a thermosetting polyurethane polymer. This reaction is exothermic: when the “A” and “B” components combine, heat is released. To prevent scorching and/or other part defects, cooling lines on the mold help dissipate this heat.

In figure P-1, the pressurized day tanks typically hold from 30 to 250 gallons of isocyanate or polyol. Recirculation pumps and agitators maintain a homogeneous blend of the individual components. The heat exchangers maintain components’ temperature. Either high-pressure, metering pumps or hydraulically driven chemical cylinders – commonly referred to as “lances” – meter isocyanate and polyol into the mixing head. Flow rates and pressures are precisely controlled to ensure high-quality parts.

The mix head contains injector nozzles which impinge the isocyanate and polyol at ultra-high velocity to provide excellent mixing. Additional mixing is accomplished using an after-mixer, typically constructed inside the mold.



MATERIAL DESCRIPTIONS

The degree of rigidity usually defines a polyurethane system, placing it in one of two categories: rigid or elastomeric. A **rigid polyurethane material** generally has a higher flexural modulus and degree of hardness.

This class of materials normally offers good thermal resistance, electrical properties, chemical resistance and acoustical insulation. An **elastomeric polyurethane system** is often found in applications requiring superior impact strength. Elastomeric polyurethane

systems exhibit good toughness and dimensional stability throughout a wide temperature range and have excellent corrosion, abrasion, wear and cut resistance.

Physical properties for these two categories are not absolute and the flexural moduli ranges of these materials overlap (see figure P-2). Within these two classifications, there are three types of polyurethane systems (see figure P-3):

- **Foamed polyurethane systems** use a blowing agent to make parts with a higher-density skin and a lower density, microcellular core in a sandwich-like composition. Baydur structural foam and other rigid systems have hard, solid skins and are found in business machines, electronic and medical housings, automobile spoilers, skis and other load-bearing applications. All foamed RIM materials are microcellular systems, having cells as small as 0.001 inch.

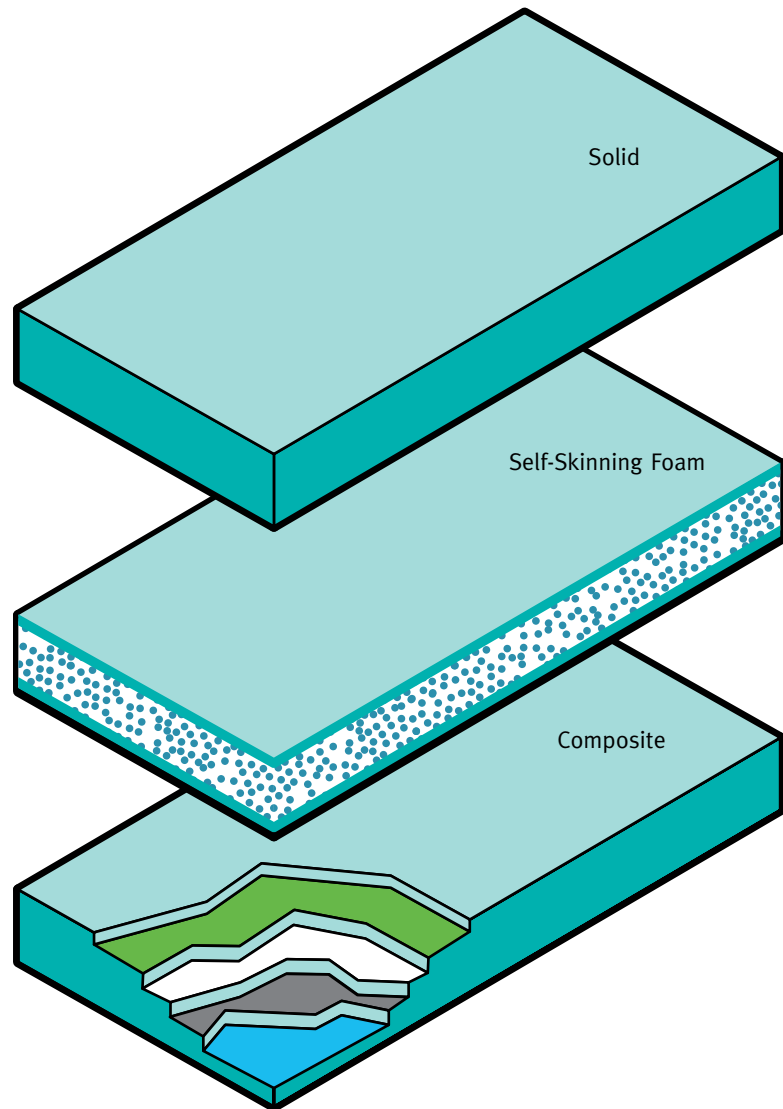
- **Solid polyurethane systems** do not use blowing agents, resulting in a *homogeneous*, rigid or elastomeric plastic. Bayflex solid elastomeric materials are used in many applications, including the automotive, specialty transportation, construction, agriculture and recreational industries. Common parts include fenders, fascias, trims and vertical panels. Glass or mineral fillers can be added to solid elastomers for improved stiffness. This is commonly referred to as Reinforced RIM or RRIM.

PRISM solid polyurethane systems have many properties similar to those of engineering thermoplastics. They can be used to mold many thicker or thin-walled parts and may be more economical than thermoplastics.

- **Structural composite polyurethane systems** are solid or foamed materials, molded in combination with long-fiber reinforcements, such as glass mat, to improve the system's mechanical characteristics. Sometimes referred to as "SRIM," for Structural RIM, these systems have extremely high stiffness and high impact strength because of the mat. Typical applications include door panels, shelves, automotive horizontal/ load-bearing panels and recreational equipment parts

Figure P-3

Types of Polyurethane Materials





Bayflex® polyurethane systems impart excellent durability and impact resistance to molded automotive panels and fenders.

AESTHETIC CONSIDERATIONS

When designing parts made of RIM polyurethane systems, make sure that your part or assembly meets all performance parameters and can be molded successfully and cost effectively. Before selecting a polyurethane system for part production, you must address three areas : aesthetic considerations, the part's functional needs and your economic concerns. Involving the material supplier, mold maker and molder/processor throughout a project will make the development process from concept to finished part much easier. Look in the back of this manual for a Quick Design Reference Guide for RIM Materials. See BaySystems' s Engineering Polymers: Property Guide for material property information.

When establishing aesthetic requirements for your part, remember the old adage, “form follows function.” If you are designing a car fascia or fender, your part will need a “class A” finish, because most automotive applications are aesthetically sensitive. On the other hand, if you are designing an unexposed structural member, aesthetics may not be as important as load-bearing characteristics. While it is important to make your part look good, specifying unusual finishes or paints can increase your postmolding costs. Some aesthetic guidelines to consider when designing parts include:

- Determine if your part will need a smooth, mirror-like, “class A” finish, a textured finish, or other type of finish because some polyurethane materials may be more suitable for your part (see photo).
- Decide if your part will need color. Polyurethane parts can be painted, pigmented and/or in-mold coated.
- Determine if pigmentation without painting is acceptable. Darker colors – blacks, grays or browns – may not need painting because color shifts caused by ultraviolet light will be less noticeable.
- Consider applying a good polyurethane paint or clear coat to prevent chalking or color shifts caused by UV exposure. Polyurethane coatings inherently have excellent adhesion.

FUNCTIONAL CONSIDERATIONS

When defining functional requirements, consider all the environments to which your part will be exposed, as well as its end-use conditions. Ambient temperature, humidity and UV radiation are of particular importance. Consider the following guidelines when addressing functional requirements:

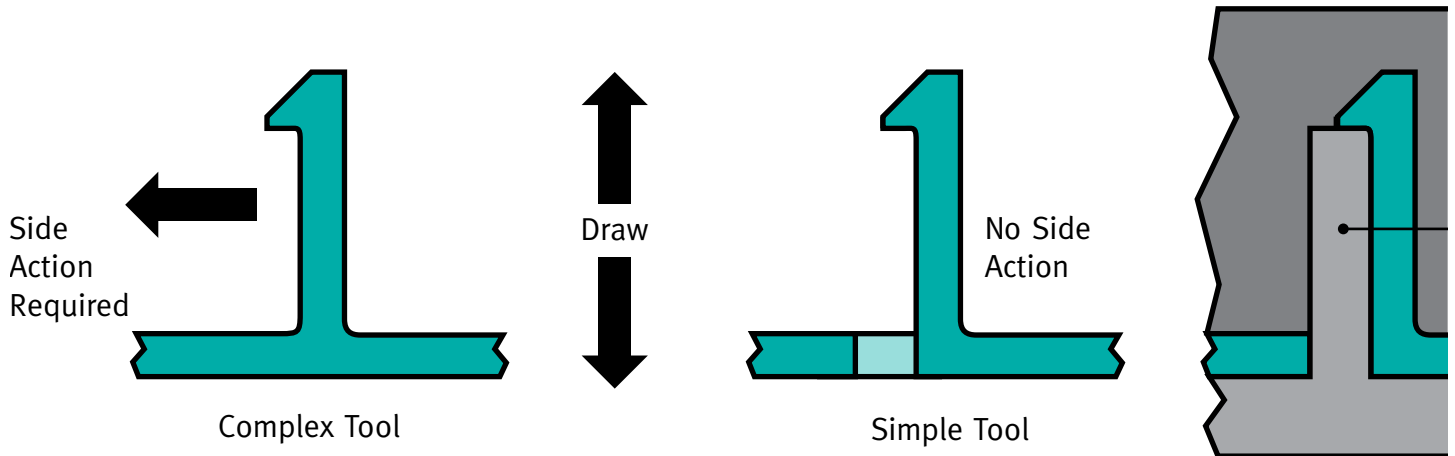
- Determine if your part needs high impact resistance and/or high stiffness.
- Define the part's loading conditions, fastening or attaching parameters and other physical requirements. The physical properties of the RIM material must withstand the structural conditions to which your part will be subjected.
- Determine the chemicals to which your part may be exposed during processing and assembling, as well as in end use. These include, but are not limited to solvents, de-greasers, cleaning agents and household products. Ensure that these chemicals are compatible with your material selection.
- Determine if stiffening inserts should be encapsulated in the part.
- Consider elastomeric RIM polyurethane systems, if your part needs good impact characteristics.
- Consider rigid polyurethane systems for parts that need high stiffness.
- Use a structural composite polyurethane system if your part needs high stiffness and high impact strength.
- Use self-skinning, rigid, foamed systems when you need to reduce density and part weight.
- Use BaySystems' *Engineering Polymers: Material Selection* and consult with your BaySystems representative for more information on material selection.

ECONOMIC CONSIDERATIONS

The final cost of a part involves more than the per-pound cost of the material. Different materials – steel and plastic, for instance – have different costs associated with processing, finishing, productivity and quality control – all of which can alter the cost dramatically. RIM polyurethane systems, for instance, offer quick cycle times for large parts made of elastomers and, in many cases, can use less-expensive equipment than thermoplastics. Additionally, parts made of polyurethane may weigh less than comparable parts made of other materials.

Because the part's shape, not its weight, is fixed in the design, you should also compare the cost per volume ($\$/\text{in}^3$) instead of cost per pound. A ton of low-density material will produce more parts than a ton of high-density material.

Example 1: Snap-Fit Undercut



Part geometry also plays an important role. When comparing polyurethane systems for a load-bearing application, optimize part geometry for each material's characteristics. For example, you may be able to design a part with thinner walls and fewer ribs to achieve the required stiffness by using a higher-density system. Consider these guidelines when determining costs:

- Identify your cost target.
- Know the current cost of manufacturing and assembly, particularly when replacing a part made using a different process.
- Optimize wall thickness to reduce part weight and mold-cycle time.
- Core thick sections where possible. Use other reinforcing techniques such as ribbing, corrugating and encapsulating structural inserts to improve the part's stiffness.
- Simplify part design. Complex parts with multiple side pulls will increase mold costs significantly (see figure 1-1).
- Consider the added costs for finishing, painting, or coating.

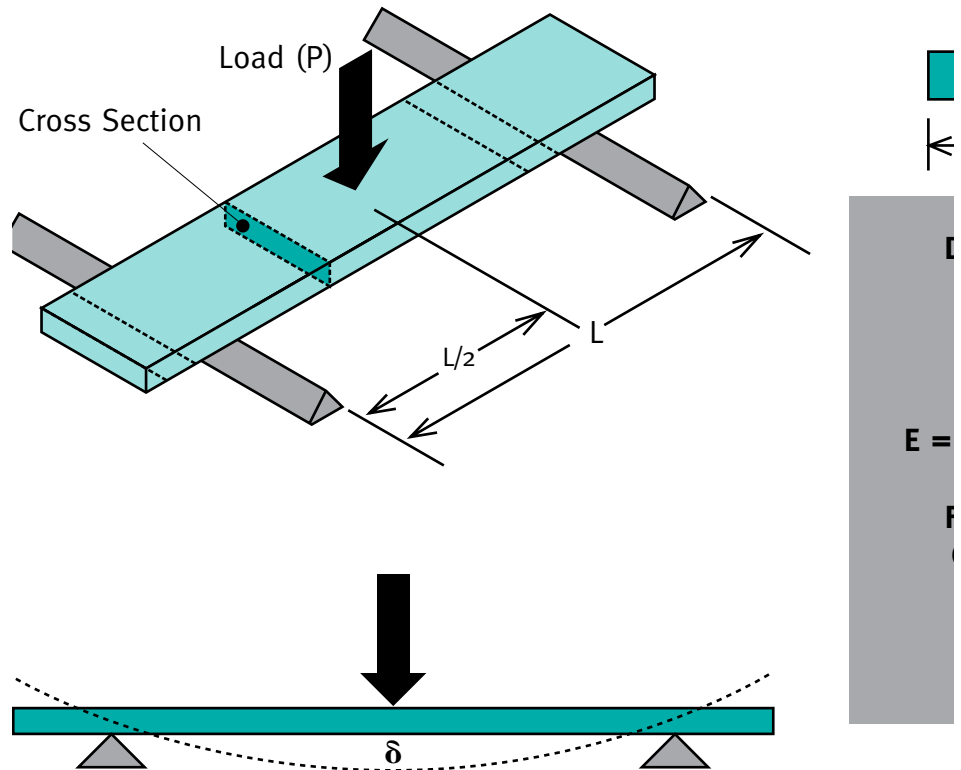


This boat dashboard is molded in one piece from a BaySystems Baydur® 667 polyurethane system. The styrene-free fabrication process produces a lightweight dash with a high-strength-to-weight ratio and an excellent surface finish, all with significantly less labor than the hand spray-up process.

Other design parameters beyond material-specific guidelines must also be considered when designing parts, including:

- Wall thickness
- Warping
- Ribs and ribbing direction • Slots
- Vents
- Grooves
- Inserts

These design parameters are discussed in this section.



PART STIFFNESS

When designing for part stiffness, you may have to balance a part's wall thickness and the material's flexural modulus or, in foamed systems, material density. To improve stiffness while minimizing wall thickness, consider using a higher-modulus system, improving part geometry, or adding reinforcements and encapsulations.

The flexural test, a simply supported, three-point loading test, determines the material's flexural-modulus value, the basic physical property used to determine stiffness in typical bending applications (see figure 2-1). The flexural modulus is defined as the initial slope of the stress-strain

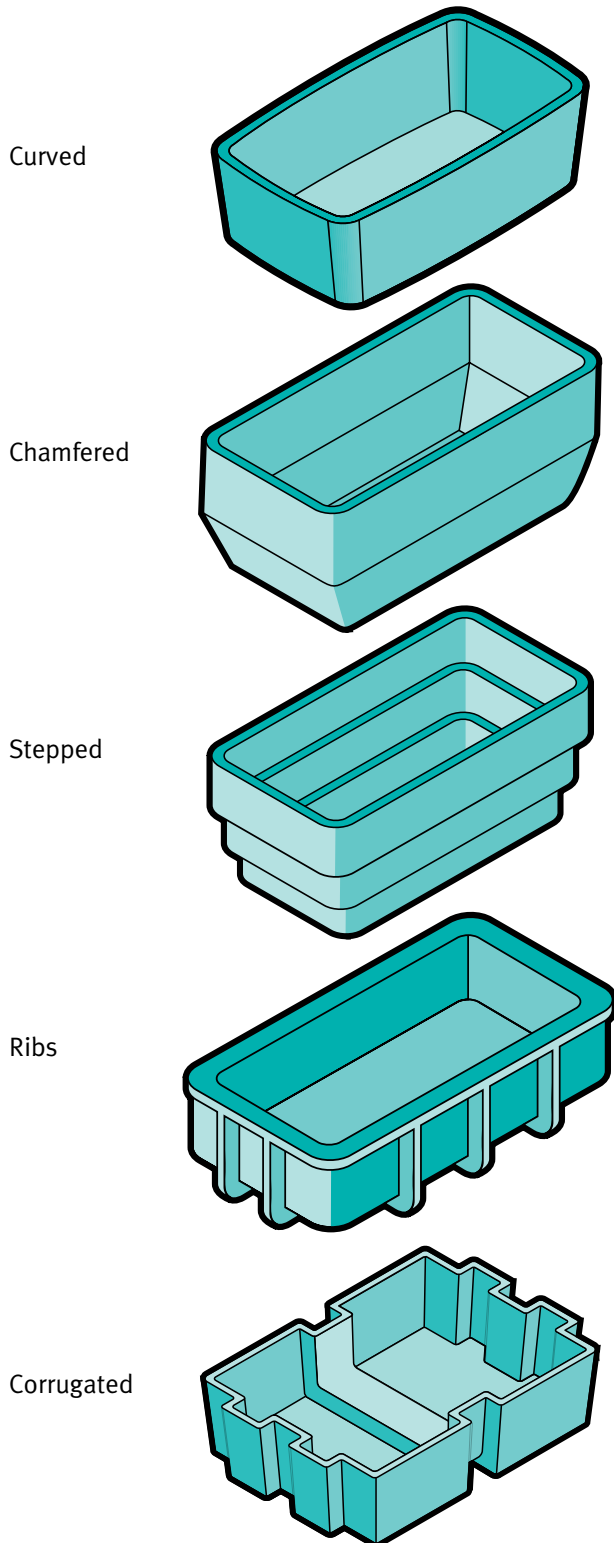
curve generated in this test. Greater flexural modulus values indicate higher inherent stiffness. A part subjected to bending has a stiffness indicator defined as the flexural modulus multiplied by the moment of inertia, a geometric property. This indicator gives a comparative value to use when optimizing different materials and part geometries.

WALL THICKNESS

Parts made from polyurethane systems can be designed with varying wall thicknesses more effectively than traditional thermoplastics. Thicker walls have higher stiffness.

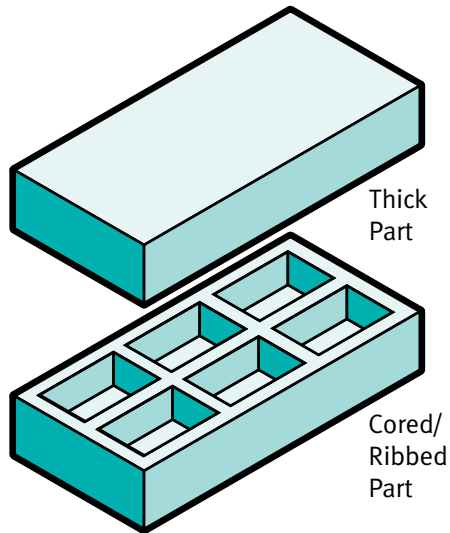
Part-Stiffening Techniques

Figure 2-2



- If you double wall thickness in a flat part, the part's stiffness will increase by a factor of eight.
- Wall thickness for solid materials is typically $1/8$ inch, although parts with walls as thick as $1/2$ inch have been molded successfully.
- Wall thickness for Baydur STR/C or STR/F composite materials typically ranges from $1/16$ to $1/4$ inch, although parts with thicker walls have been molded.
- Another method to stiffen a side wall in the direction of draw is to curve it at the base, or redesign the flat section so that it has steps, angles, or corrugations(see figure 2-2).
- Wall thickness for parts made of Baydur structural foam can range from $1/4$ to $1-1/2$ inches

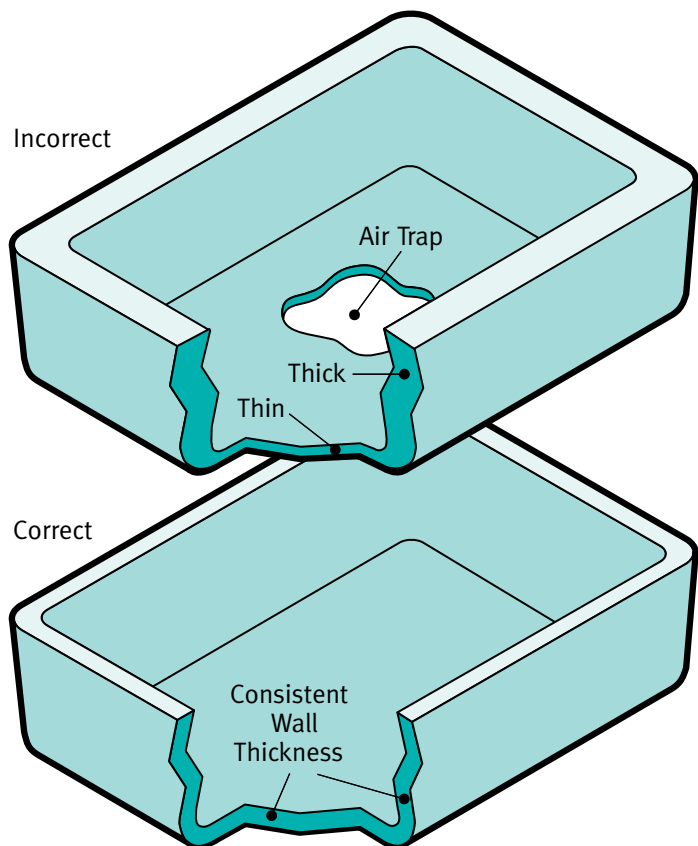
Because a part's thickest cross section determines molding time, excessively thick cross sections may cause uneconomical and long molding cycles. Thin-walled parts have the shorter mold-cycle times, because the heat of reaction dissipates more rapidly.

Cored Part**Figure 2-3****RIB DESIGN AND CONFIGURATION**

Taller, thinner ribs are more effective than shorter, wider ones (see figure 2-5). In this figure, both ribs have the same cross-sectional area, but the stiffening effect of rib B is far greater than that of rib A. Ribs should run continuously from side-to-side or corner-to-corner whenever possible. The lowest rib height determines the effective stiffness of notched ribs (see figure 2-6).

Unusually thick cross sections can also cause dimensional difficulties. Because the material in thick cross sections takes longer to cool, parts may shrink more and can possibly warp. In extreme cases, scorching or splitting may occur. Whenever possible, core thick sections to avoid this effect (see figure 2-3). Consider using ribs or other local reinforcements to increase part stiffness as an alternative.

While RIM polyurethane systems can be used to make parts with varying wall thicknesses, designing parts with excessive wall-thickness variations may cause uneven filling and racetracking. Figure 2-4, showing a five-sided box, is a good example of racetracking. The liquid components fill the thicker walls, leaving air entrapments in the thinner base. To correct for this racetracking effect, design thinner side walls or a thicker base.

Figure 2-4**Racetracking**

Taller ribs with draft may lead to a wide base, resulting in problems in processing, with cycle time and with product appearance.

Ribs and other protrusions that are thicker than the nominal wall can cause “read through” – sink marks or visual blemishes on the opposite show surface (see figure 2–7). In general, sink marks are much less of a problem with RIM polyurethanes than with thermoplastics. These sinks appear where the rib and mating wall meet because the increased wall thickness leads to increased local-area shrinking as the part cools. Designing a step in the part where the rib meets the mating wall helps to avoid sink marks (see figure 2–8).

If you need the support of a thick rib, design it as a series of thinner ribs with equivalent height and cross-sectional area. The space between these thinner ribs should be no less than the nominal wall thickness (see figure 2–9).

Figure 2-5

Thick Versus Thin Ribs

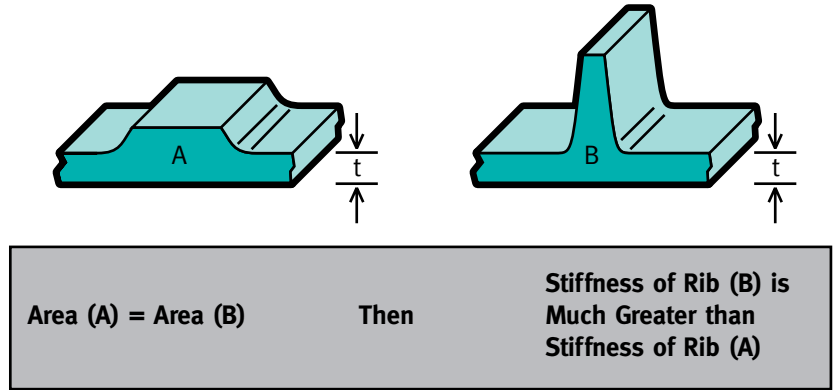


Figure 2-6

Notched Rib

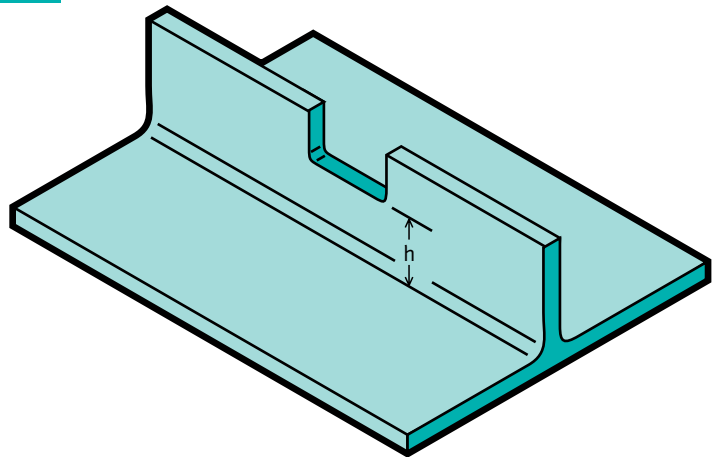
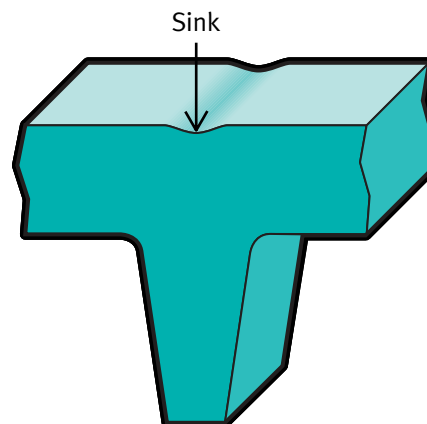


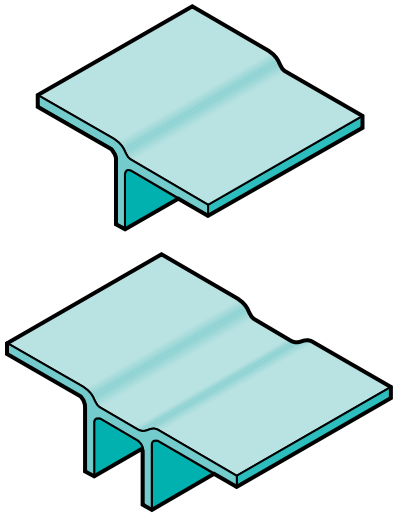
Figure 2-7

Sinks Caused by Thick Ribs



Offset Rib

Figure 2-8



Side walls may need to be stiffened in the direction of draw and/or perpendicular to the direction of draw. For stiffening in the direction of draw, use simple ribbing. When perpendicular ribbing is necessary – such as in walls – you may have to use sliding cores, which may add significantly to mold and finishing costs. Additional design considerations for ribs include:

- Ribbing increases stiffness only in the ribbing direction of that rib.
- If a rib is notched, the lower section of the rib will determine strength, unless the notch is bridged with a metal stiffener (see figure 2–10).

Ribs are quite difficult to mold in parts made of composite materials. Typically these ribs may have resin-rich, potentially brittle areas at their tops, because it is difficult to get mat into this tight area.

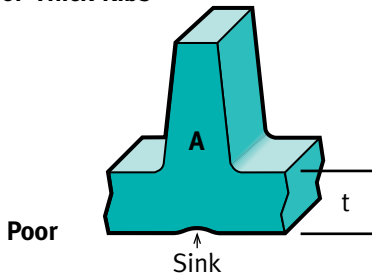
Ribbing Direction

Figure 2–11 illustrates three common ribbing configurations. If a part needs to be reinforced in only one direction, use **parallel ribbing**. Use **bidirectional ribbing** if your part needs to be reinforced in both directions of the plane surface. Apply bidirectional ribs sparingly because excessive ribbing can make your part heavy and uneconomical to produce. Additionally, avoid placing ribs perpendicular to the anticipated flow direction, because they may trap air and cause filling difficulties (see figure 4–3).

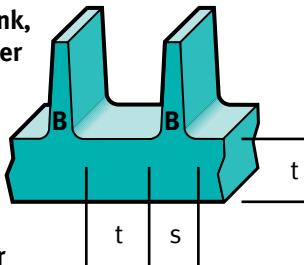
Rib Configuration

Figure 2-9

For Thick Ribs



No Sink, Quicker Cycle



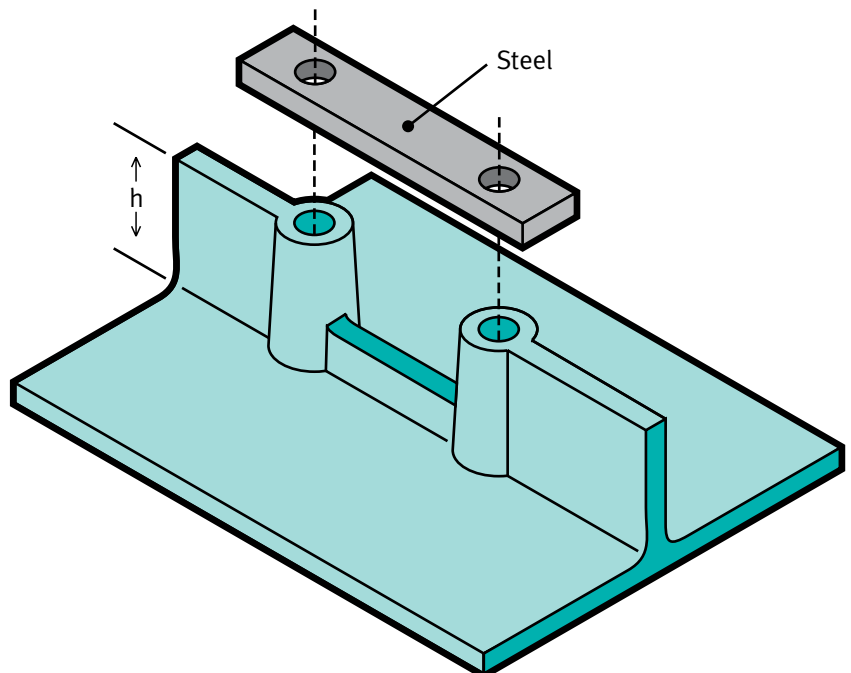
Make Sure
Area (B + B) = Area A

$s \leq 0.75t$ for Solids
 $s \leq t$ for Foams

Convert thick ribs into evenly spaced, thin ribs

Figure 2-10

Notched Rib with Bridge



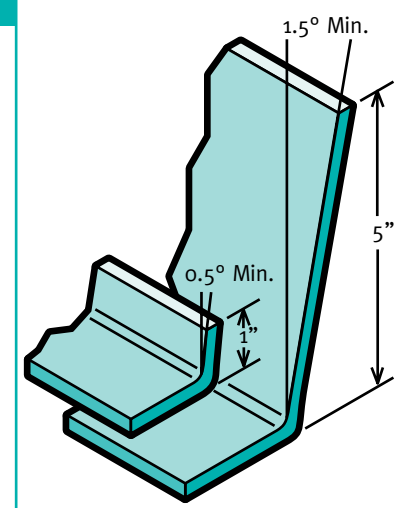
If your part needs torsional stiffness as well as longitudinal stiffness in both directions of the plane surface, use diagonal cross ribbing. Possibly the most-economical ribbing pattern for material usage, this ribbing configuration is easier to fill and less likely to trap air.

DRAFT

Every surface parallel to the direction of draw needs a draft angle to facilitate demolding. The recommended draft angle increases with part height.

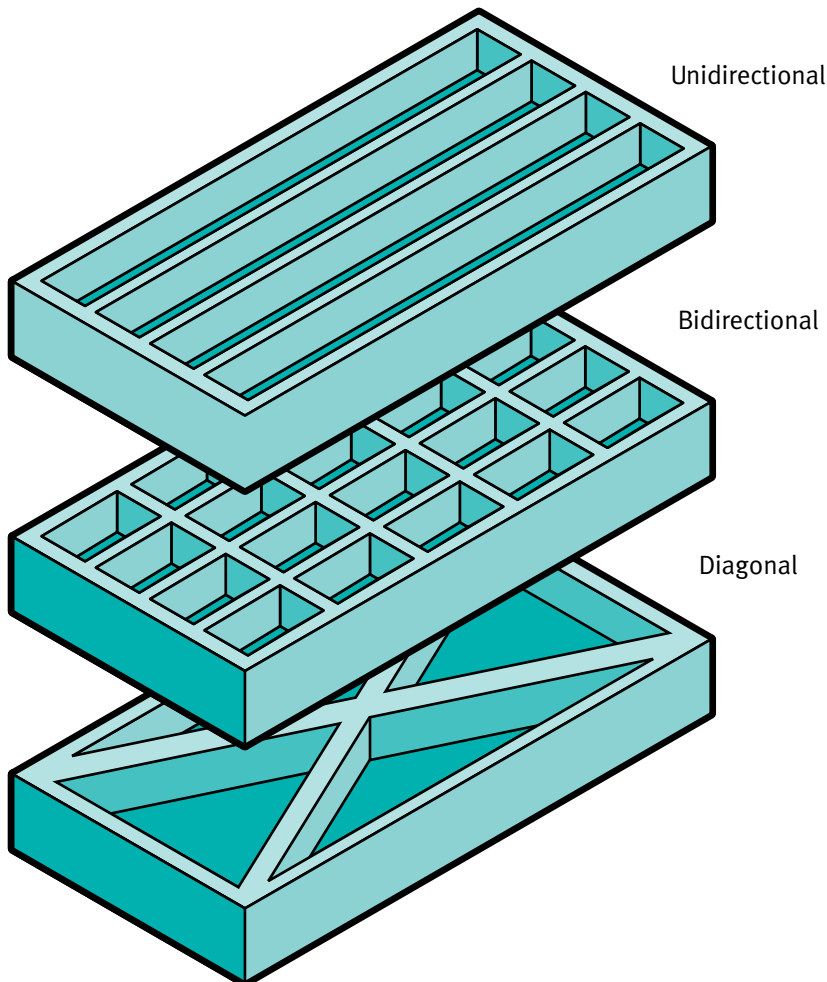
Do not design deep wood grain textures on side walls. Even light textures in this orientation require additional draft. Elastomeric systems may require less draft in textured parts. Generally, draft is more important on the core side (usually the

Figure 2-12 Recommended Draft



Different Types of Ribbing

Figure 2-11



top half of the mold) than it is on the cavity side, because parts generally shrink onto the core during cooling. Other rules of thumb for draft angles include:

- A minimum of $1/2^\circ$ is usually adequate for parts with low side walls or ribs, typically those up to 1 inch deep,
- Add at least $1/4^\circ$ of draft for every additional inch of draw, such that a 5-inch draw would require a minimum of $1-1/2^\circ$ draft (see figure 2-12).

BOSSSES

Use bosses for support, as spacers or as attachment points. Attach bosses and other projections on the inside of parts to the side walls with connectors that allow air to escape during molding (see figure 2-13). Avoid isolated bosses, also known as “blind bosses.” If you cannot attach a boss to a side wall because of interference or distance from the wall, design gussets or vent the boss with a core. Open bosses, those cored from one side and attached to an exterior side wall, are frequently used for assembly to eliminate the need for connectors or gussets (see figure 2-14). All bosses should have radii at their bases. Follow standard radii recommendations listed under the sections on solid, foamed and composite materials in this brochure.

If you are using a boss to accommodate an insert, such as a screw or press fit, make the hole as deep as possible, preferably leaving only one nominal wall thickness to prevent sink marks. Other design guidelines include:

- If you cannot avoid an isolated boss, add gussets that extend from the base to the top on the side in the direction of flow to facilitate air removal and mold filling.
- Attach bosses to side walls with a connector of nominal wall thickness for foamed materials and $\frac{3}{4}$ nominal wall thickness for solid materials.

Figure 2-13

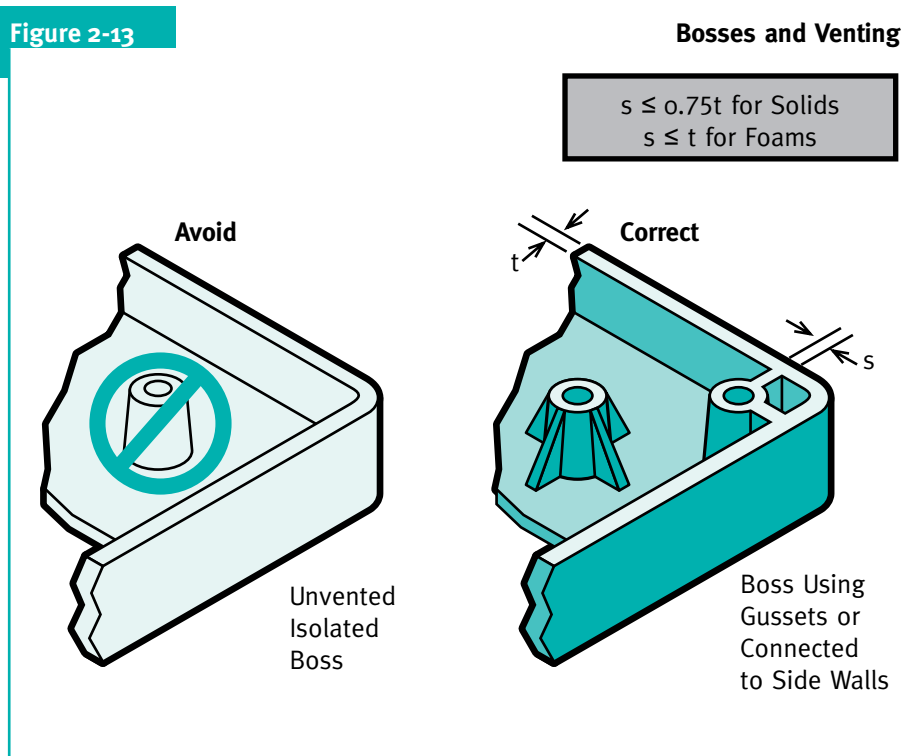
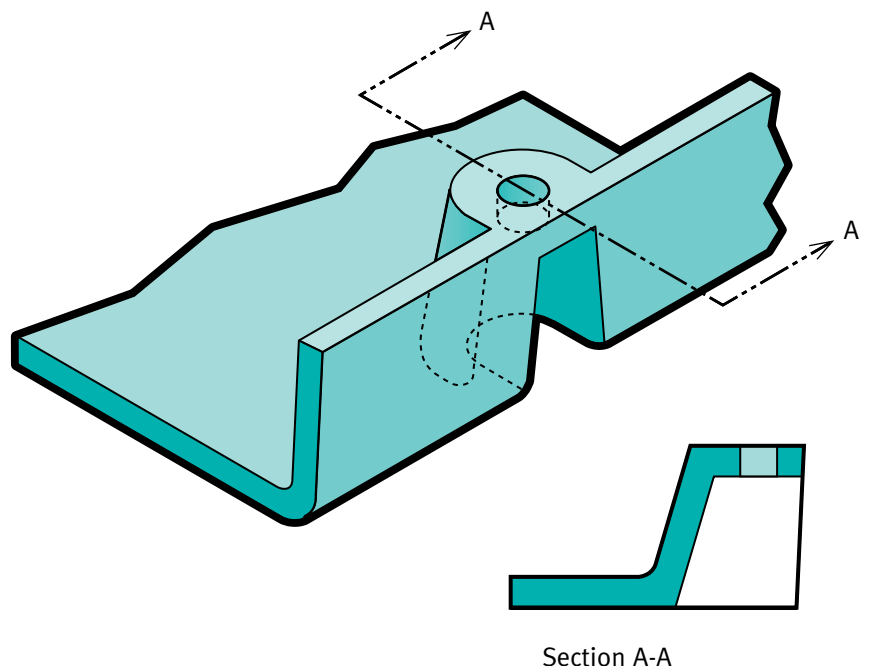


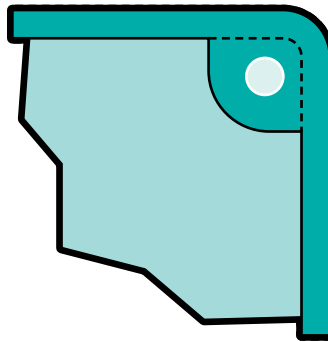
Figure 2-14

Open Boss

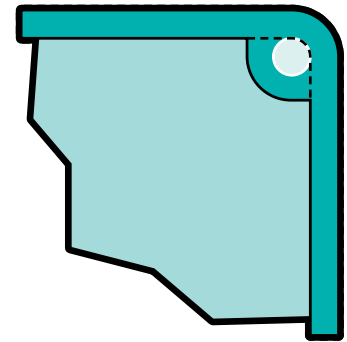
- Design bosses away from corners unless the boss can be connected to the wall directly (see figure 2–15) or indirectly (see figure 2–13). This will help prevent localized heat build up and possible warpage.
- Consider molding a hollow boss to maintain nominal wall thickness (see figure 2–16).
- Core bosses instead of drilling when using thread-cutting screws and thread-cutting inserts in parts made of structural foam to increase pullout strength.
- Consider designing an elongated boss and having the excess ground off as a postmolding operation, only as a last resort (see figure 2–17)

Figure 2-15

Corner Bosses



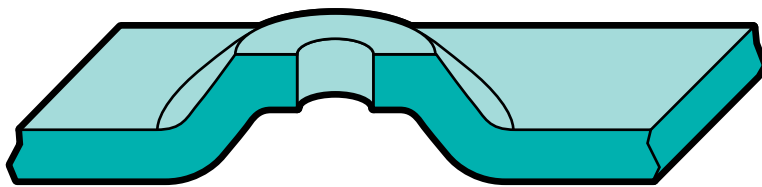
Incorrect
Excessive Wall Thickness



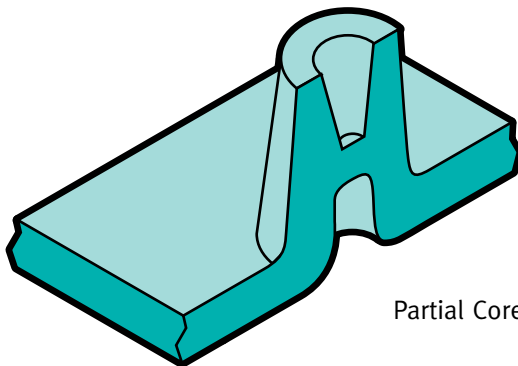
Correct
Maintain Nominal Wall

Hollow Bosses

Figure 2-16



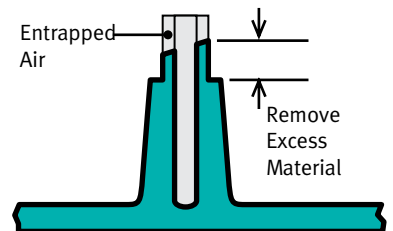
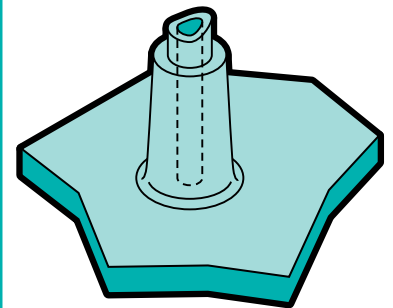
Cored Boss



Partial Core

Figure 2-17

Elongated Boss



HOLES, GROOVES AND SLOTS

Holes can be postdrilled, molded in the direction of draw or formed by a retractable pin actuated by a hydraulic cylinder. A hole in a side wall with enough draft can also be formed by having the mold core and cavity meet at the hole (see figure 2-18). In this design, holes can be positioned anywhere on the wall.

Orient grooves and slots in the flow direction to minimize air entrapments or knit lines. Make sure that grooves are rounded or chamfered rather than sharp to help flow, vent air and reduce stress concentrations (see figure 2-19).

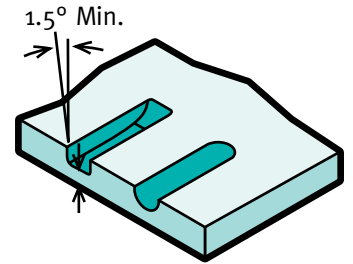
Grooves should not reduce the wall thickness to the extent that foam flow

is impeded. As a rule of thumb, do not recess grooves more than $3/16$ inch for foamed materials and $3/32$ inch for solid materials. Groove width should follow the rules established for slots in figure 2-22. Wider grooves run the risk of racetracking and air entrapments.

Consider positioning slots in a side wall, curled around the base plane, to allow for molding without slides (see figure 2-20). Another option is to design slots with stepped cutouts, positioned in a sloping wall section (see figure 2-21). Thicker walls will require more slope. If using this last option, do not make the mating sections too sharp, as this could damage the mold. Rules of thumb

Figure 2-19

Grooves



Foamed = $3/16$ " Min.
Solid = $3/32$ " Min.

Hole in Side Wall

Figure 2-18

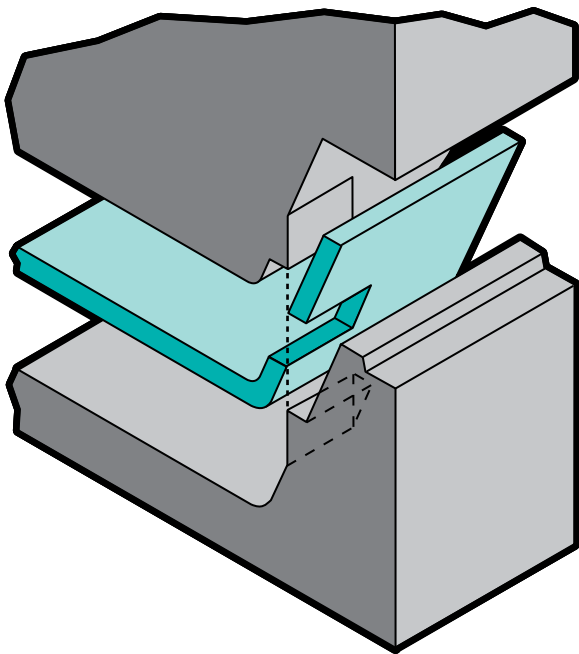
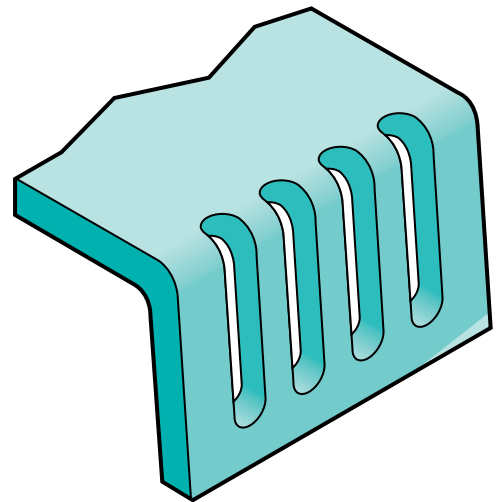


Figure 2-20

Slots Curled Around Corner



Slots or Louvers on Sloping Wall **Figure 2-21**

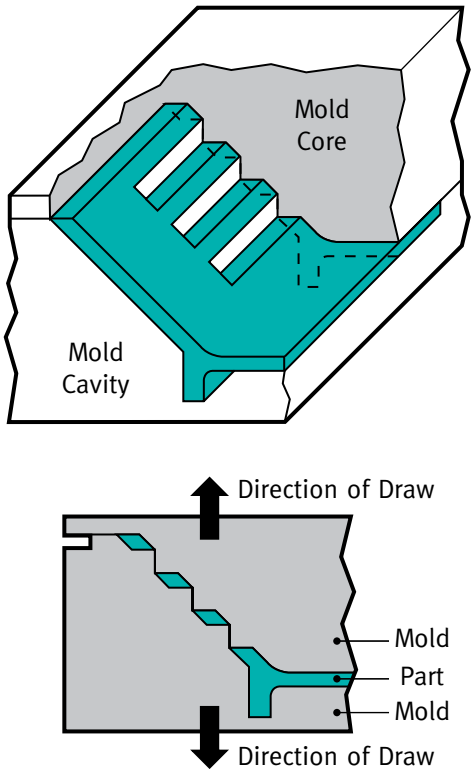


Figure 2-22

Basic Dimensions for Slots

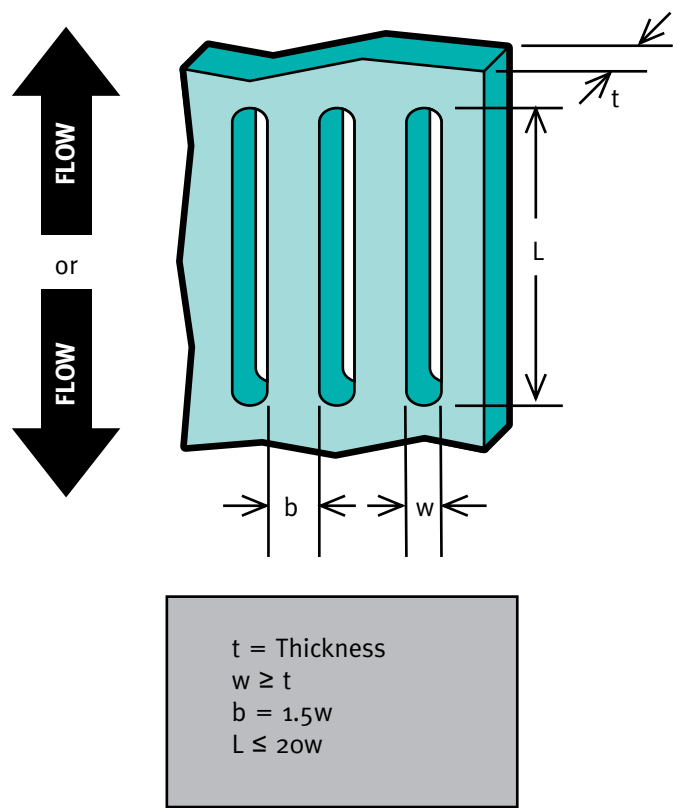
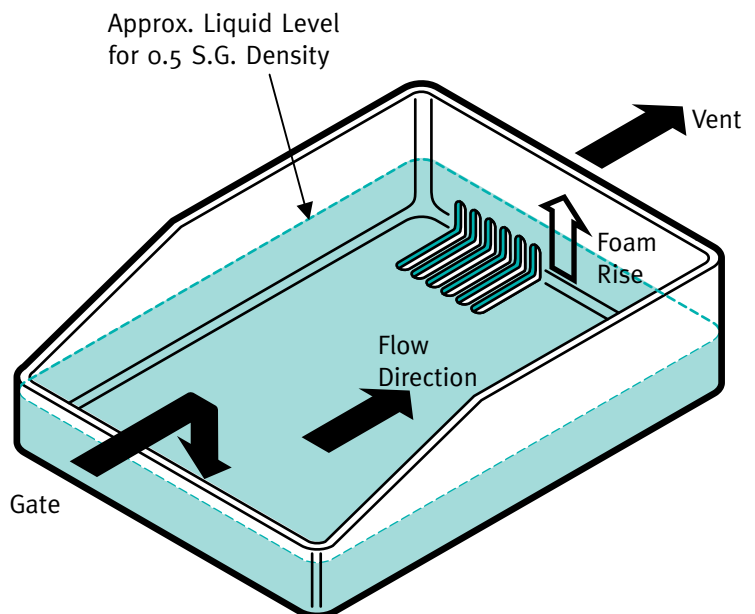


Figure 2-23

for slots or louvers are shown in figure 2-22. Design slots and grooves with a minimum $1-1/2^\circ$ draft to help with demolding. In foamed materials, grooves, slots and holes should be located under the liquid level and lie in the direction of foam rise to help prevent air entrapment (see figure 2-23)



As a good design practice, locate slots, grooves and holes under liquid level. Place in foam-rise direction.

INSERTS

Polyurethanes have low molding temperatures and pressures, making them ideal for encapsulating reinforcing inserts. The insert should not impede material flow. If using a hollow insert, the ends must be sealed. Thermoplastic end caps have been successfully used to seal inserts. To promote good adhesion with the polyurethane, clean and roughen the inserts and, if necessary, treat them with an adhesion promoter.

The type of RIM system used determines the recommended minimum distance between an insert and the mold wall. For solid materials, this minimum distance is 1/8 inch; for foamed systems, 1/4 inch. For example, a solid material with a 1/8-inch nominal wall thickness should have a minimum distance of 1/8 inch between the wall and insert (see figure 2–24).

Encapsulated inserts are used for any number of reasons. For example, they:

- Increase stiffness
- Reduce wall thickness
- Absorb high stresses
- Control thermal expansion

The most-common types of inserts are discussed in the following sections.

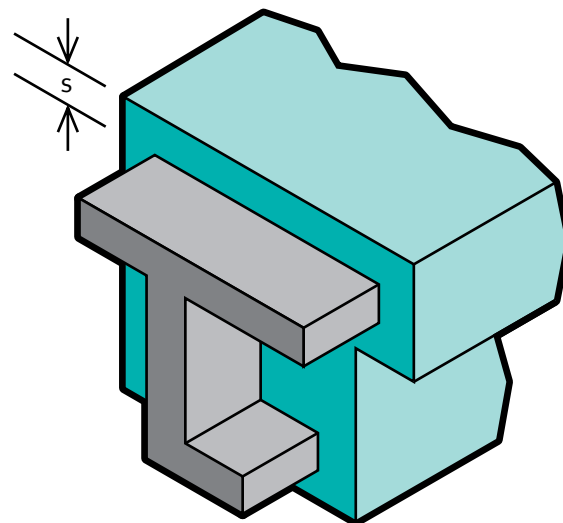
Metal Stiffening Inserts

Molding metal inserts into RIM polyurethane materials will increase stiffness significantly. Inserts of all types – including flat plates, extrusions, tubes and bars – have been easily and successfully encapsulated. Fully encapsulating inserts eliminates metal corrosion, while reducing thick cross sections, controlling deflection and thermal elongation and absorbing high stresses.

Calculate the centers of gravity for both the RIM material and metal insert to reduce the potential for warping (see figure 2–25). The centers of gravity should coincide to prevent the part from bending because of the movement due to the differences in the coefficients of linear thermal expansion. As the temperature increases, the polyurethane material will be in compression and the metal insert in tension. As the temperature decreases from the ambient, the reverse is true: the polyurethane material is in tension; the insert in compression. The relative cross-sectional areas of the two materials determine the ultimate elongation of the part.

Figure 2-24

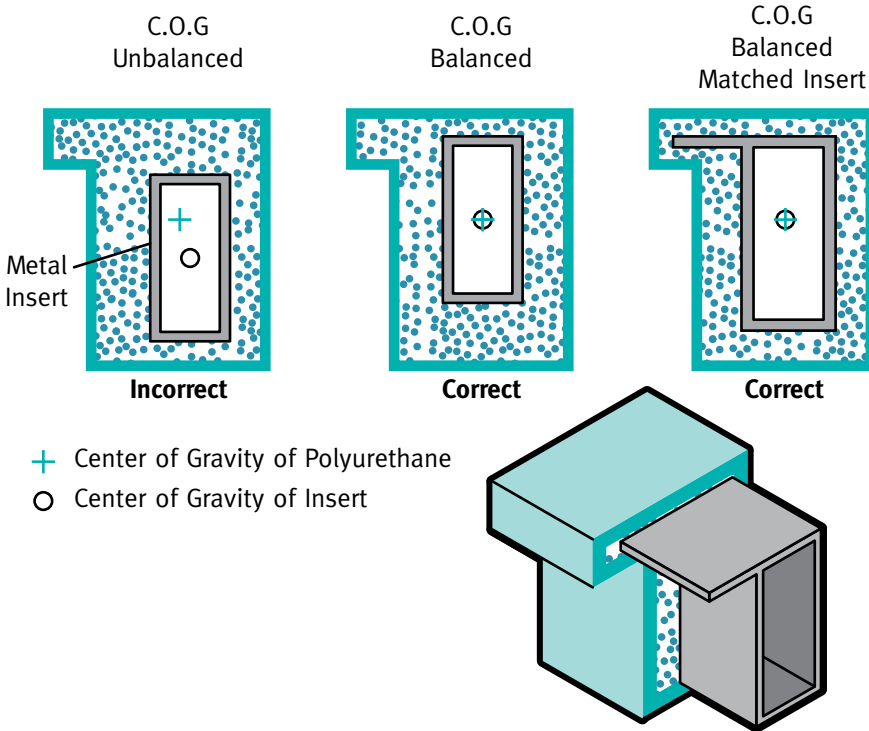
Minimum Wall Thickness for Using Inserts



$s = 1/4''$ for Foamed Systems
 $s = 1/8''$ for Solid Systems

Balancing the Cross-Sectional Centers of Gravity

Figure 2-25



When using Baydur structural foam, molded-in inserts may offer greater pullout strength, because skin forms over the entire insert surface. When using press-fit inserts with structural foam parts, mold the hole so that skin forms inside.

Generally, molders prefer press-fit inserts, even though these inserts may not be as strong as molded-in ones. Placing inserts on pins inside the mold can increase cycle time significantly. Although rare, inserts may also fall off pins during molding.

The insert design, hole diameter, part density and screw size determine the pullout force and stripping torque of threaded inserts. Contact your insert manufacturer for more information about obtaining whole-diameter values. See BaySystems's *Plastics: Joining Techniques* manual for more information on inserts.

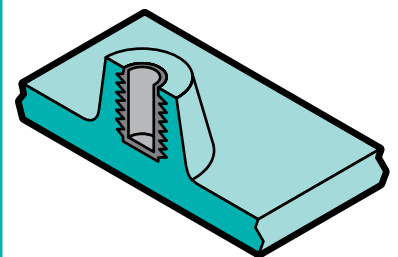
Wood Stiffening Inserts

Wood inserts – generally less expensive and lighter than metal inserts – can also be used as stiffening inserts in polyurethane parts. When a finished part is subjected to repeated loads, wood inserts may separate from molded polyurethane if the wood's moisture content exceeds 6%. If the wood insert cannot be dried to meet this limit, it must be sealed with a lacquer before molding.

Threaded Inserts

Threaded inserts are particularly useful when components must be attached to RIM-molded parts (see figure 2-26). Use appropriately sized, press-fit inserts with respect to boss-hole diameter. Use threaded inserts if your part is going to be frequently assembled and disassembled.

Figure 2-26 Typical Threaded Insert



UNDERCUTS

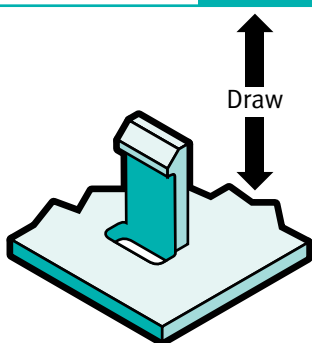
If possible, avoid undercuts when designing parts made of rigid RIM polyurethanes (see figure 2–27). They add to cost and may create demolding problems. Modify the part geometry or mold orientation or divide your part into two separate molds to avoid undercuts. For parts made of elastomeric materials – including reinforced RIM Bayflex systems – minor undercuts can be a design advantage. The flexible nature of these materials accommodates easy mold release even with minor undercuts.

SNAP FITS, WIRE GUIDES AND HINGES

A simple, economical and rapid joining method, snap-fit joints offer a wide range of design possibilities. All snap fits have a protruding part on one component – a hook, stud or bead – which deflects briefly during joining and catches in a recess in the mating component, thus relieving the deflection force (see figure 2–28). For more information on snap fits, please ask for a copy of Bayer MaterialScience’s *Snap-Fit Joints* brochure.

Snap Fit Hook

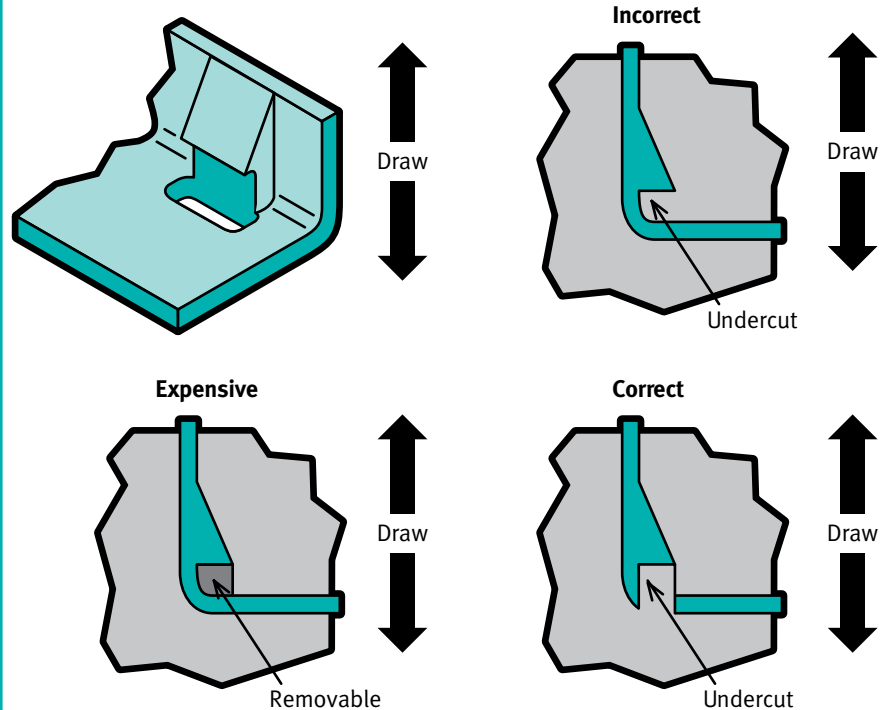
Figure 2-28



Snap fit hook molded through hole to form undercut

Figure 2-27

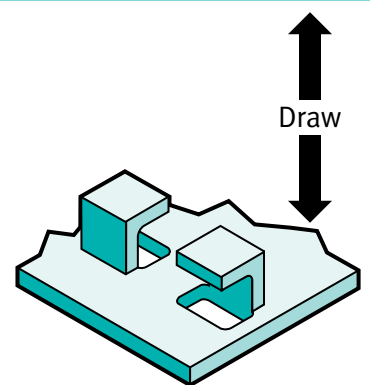
Mold Configurations Showing Undercuts



Used extensively in business-machine and appliance housings, wire guides offer simple design solutions to keep cables in position (see figure 2–29). Generally molded into the part, wire guides can be designed as a restraint that is molded without undercuts. When designing hinges, consider the end use: will it be a permanent connection, will it be used often and/or will it have to disengage after a certain opening angle. All of these factors will affect design. For permanent, frequently used joints, consider metal hinges, which can be molded-in or postmold assembled. While they add to costs, they may be optimum in long-term applications.

Figure 2-29

Wire Guides



For permanent, infrequently used hinges, consider the living hinge (see figure 2–30). Typically, they are made of the same material as the part, but can be made of a different material. Bayflex elastomeric materials have excellent flexural fatigue strength. Molded strips of Bayflex elastomers can be cut and placed into a mold to form a living hinge for a more rigid part. However, if such a hinge breaks, it will be virtually impossible to repair.

Another hinging method is to mold a part that looks and operates like a metal hinge, with alternating sections on opposite part halves. These partial hinges offer a designer a method of forming hinges without undercuts (see figure 2–31). While they have a reduced load-carrying capability, partial hinges offer lower tooling costs and use hinge pins, as full metal hinges do. A rod pushed through the assembly completes the hinge. This design will disengage when the joint angle reaches 180°. If you do not want the hinge to disengage, consider designing full holes at the ends with a retractable core pin.

FILLERS

Using materials that have glass or other inert fillers will affect your part's shrinkage, coefficient of linear thermal expansion (CLTE), stiffness and impact strength. A filled Bayflex elastomeric polyurethane material can have a CLTE closer to steel. Generally, fillers include fiberglass flakes, short glass fibers, or other mineral fillers. Usually, fillers need to have a sizing treatment to promote adhesion.

As filler content increases, stiffness increases. Short fibers usually orient in the direction of flow, causing greater stiffness and lower CLTE parallel to the fiber orientation. Adding 15% glass filler to a Bayflex elastomer can almost double its flexural modulus. Test your part to ensure that it performs acceptably with the suggested filler content. When specifying materials with fillers, always check the material safety data sheet from your filler supplier for safe handling practices for their products.

Living Hinge

Figure 2-30

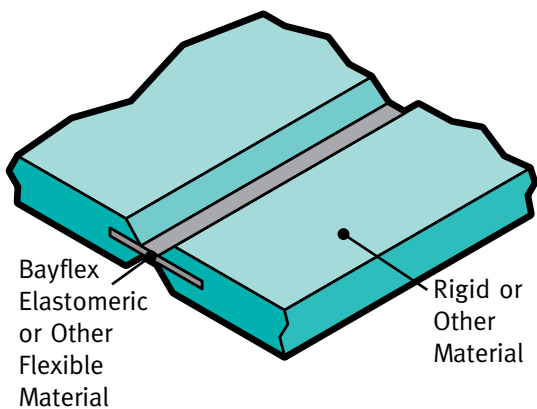
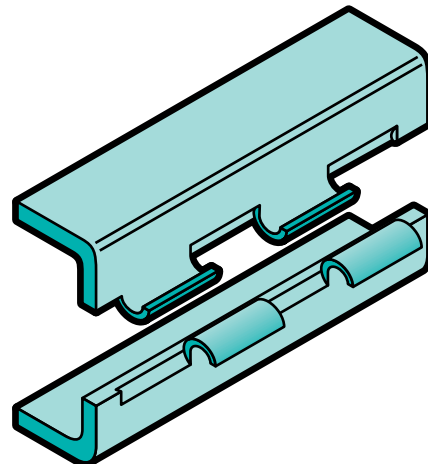


Figure 2-31

Partial Hinges



WARPAGE IN PART DESIGN

Warpage has many causes, including uneven mold and part cooling, incorrect positioning of inserts, unfavorable part geometry and forces caused by incorrect stacking before a part has fully cured. As a designer, you should be aware of the potential for part warpage early in the design process.

Plastics have significantly higher CLTEs than metals, a major consideration if you are designing a part with structural metal inserts. Please refer to the section on metal stiffening inserts in this brochure for more information.

Warpage is more noticeable in flat parts than in those with more complex geometries. Table 2-1 lists typical coefficients of thermal expansion.

Please see the section on back molding on the next page for more information on how to help avoid warpage with dissimilar materials.

CREEP CONSIDERATIONS

All materials show a certain amount of irreversible deformation under long-term load, known as creep. Polymer-chain movement under stress causes creep in polyurethane materials. Creep is usually measured in tension or flexure, with measurements taken at several different temperatures and at different loads.

Figure 2-32 shows the data obtained in a flexural-creep test for a Baydur foamed system, normalized to show the retention in modulus over time. This data should not be taken out of context for two reasons: 1) The data represents parts subjected to continuous loading; 2) Manufacturers usually require instantaneous displacements to be very small. Manufacturers and designers should determine acceptable safety factors for the part's life.

FATIGUE CONSIDERATIONS

Repeated loading causes fatigue, a progressive, permanent change in a part subjected to cycling stresses and strains. While at first no noticeable damage may appear, over time and with continued stresses, parts may begin to fail. For instance, consider a discharge chute on a lawn mower. As you use the mower, the chute occasionally bumps into a tree or wall. While at first there is no apparent damage, after several years, you will notice that the chute has cracked.

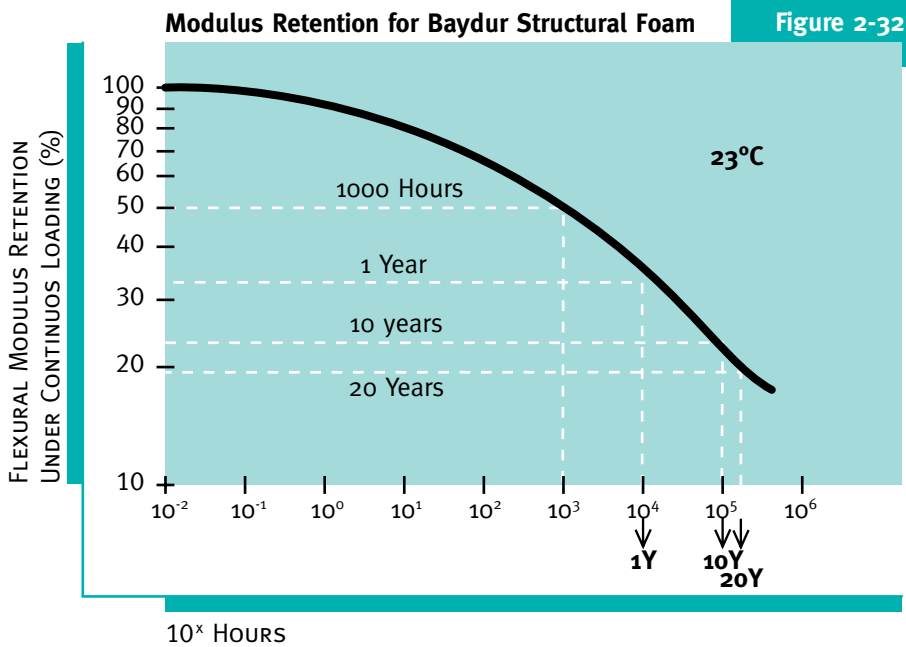
Typically, fatigue tests consist of repeatedly putting a sample under tension. Generated results show a material's ability to endure these repeated loads.

Table 2-1

Coefficients of Linear Thermal Expansion (CLTE) for Common Materials

Material	in/in/°F $\times 10^{-6}$
Steel	6
Composite RIM	8
Nylon GF*	13
Polycarbonate GF*	17
Baydur XGT-GF	28
Polycarbonate	39
ABS	44
Nylon	45
Polyester	60
Baydur Structural Foam	65
Polyurethane	70
Elastomeric RIM Unfilled	78

* glass-filled resins



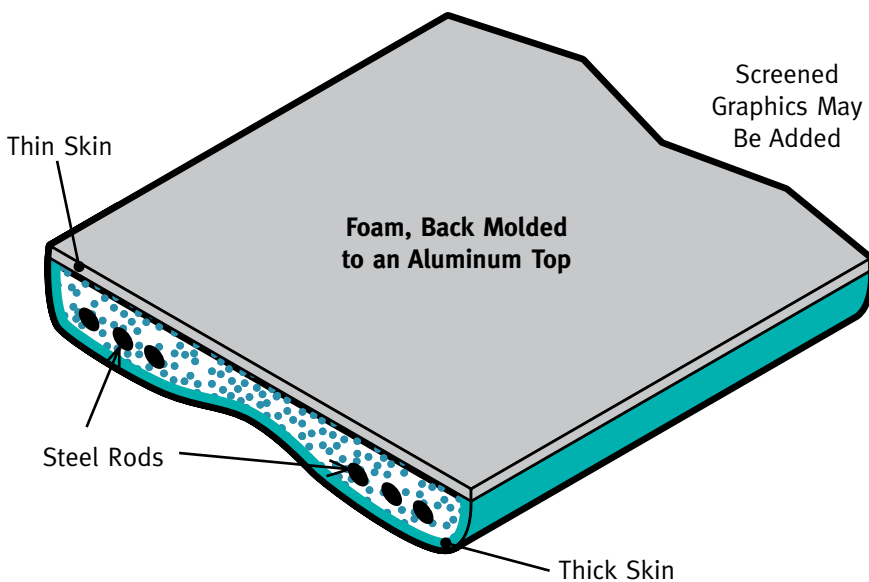
BACK MOLDING

One unique design feature of RIM systems is that other material types, such as vinyl, metal, glass, polycarbonate, acrylic and others can be placed in the mold prior to molding. Polyurethane materials will then mold against this second material. When using RIM systems for back molding, one-sided molding against a different material, some warping can result, even when the CLTEs are similar. While most methods to address warpage are application specific, consider these general suggestions:

- Place additional inserts to balance the centers of gravity (see figure 2-25).
- Adjust the cooling system in the molding process.
- Modify design of the substrate.
- Create specialized jigs for post-curing.

Waterski

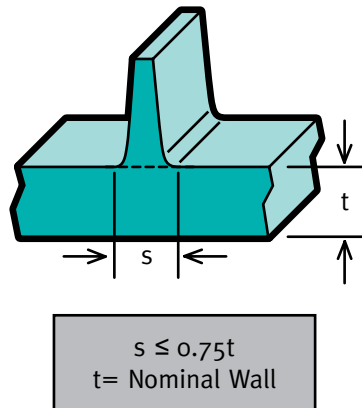
Figure 2-33



For instance, because of its different rate of heat conduction, a metal sheet - such as those used in the production of snow skis - may cause different skin thicknesses on the opposite sides of the part made of structural foam (see figure 2-33). Different skin thicknesses exhibit different shrinkage behavior, possibly leading to warping. Inserting steel rods just under the skin on the side opposite of the sheet metal can help compensate for this warpage. Contact your BaySystems representative for more information to address this topic.

Filled Bayflex and rigid PRISM systems can have high flexural moduli, making them a good choice for thin-walled applications. Because of their excellent impact properties, flexibility, toughness and ductility, elastomeric solid materials find many uses in automotive panels and bumper fascias. They also have excellent resistance to scratching and tearing. Rigid, solid materials are good choices for business machines, electronic and medical housings, load-bearing applications, appliances and consumer-product housings. Typically, parts made of solid polyurethane materials incorporate many of the same design principles as those made of thermoplastic resins.

Figure 3-1 Rib/Wall Ratio for Solids



WALL THICKNESS

Parts made of solid polyurethane materials have similar wall thicknesses to those made of thermoplastic materials (1/16 to 1/4 inch). Additionally, RIM parts can have walls as thick as 1-1/2 inches. A wall thickness of 1/8 inch for solid PRISM systems, or 1/4 inch for Baydur GS systems, is typical for parts that need a UL 94 VO and 5V rating. Please note that flammability results are based upon small-scale laboratory tests for comparison purposes only and do not necessarily represent the hazard presented by this or any other material under actual fire conditions.

RIB DESIGN AND CONFIGURATION

If your part requires ribs, use the following rules of thumb with solid systems:

- For solid materials the thickness at the rib root - including both sides of radii - should not exceed 75% of the nominal wall thickness for parts requiring a show surface (see figure 3-1).
- For non-aesthetic applications, you can design thicker ribs, up to the nominal wall thickness. Your part may develop sink marks causing visual blemishes on the surface opposite the rib (see figure 2-7). These sink marks appear where the protrusion and mating wall meet because the locally increased wall thickness leads to increased shrinking as the part cools.

RADII/FILLETS

Radius the inner corners of all ribs, bosses and walls at least $1/16$ inch to reduce stress concentrations and help avoid air entrapment (see figure 3-2). Outside corners are not as susceptible to stresses and may not need radii.

BOSSSES

When designing bosses in parts made of solid polyurethane materials, allow a wall thickness equal to 75% of the part's nominal wall thickness around the cored hole (see figure 3-3). Hole depth should allow for a maximum of one nominal wall thickness of material at the bottom. Follow rib-design suggestions for radii and draft angles.

For the diameter of the boss hole, refer to the specifications of the insert or screw manufacturer. For example, inserts greater than one inch in diameter have been successfully used in the field.

Figure 3-2

Correct Radii/ Fillets for Solids

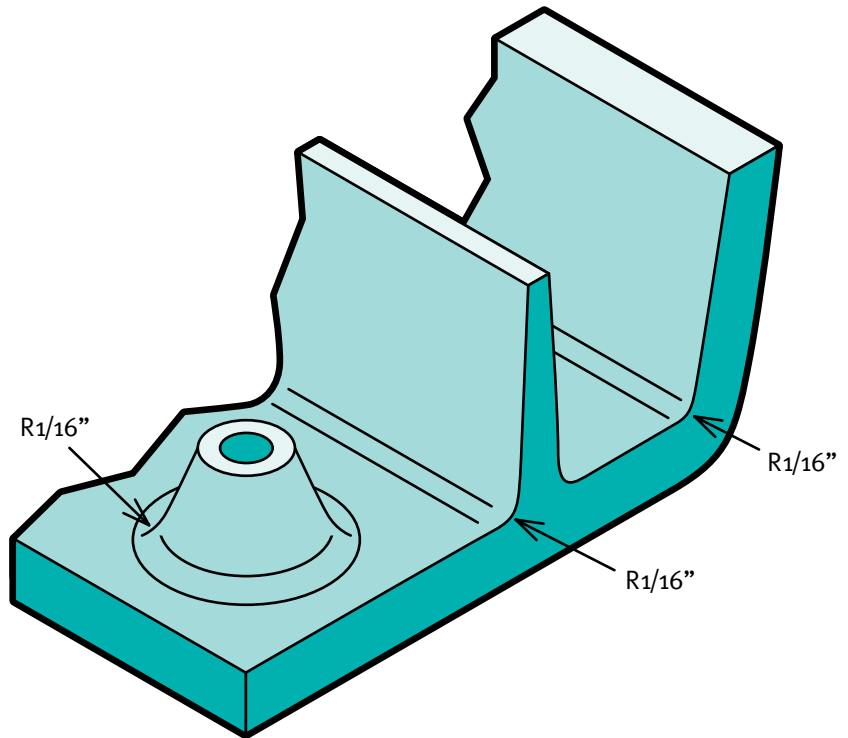
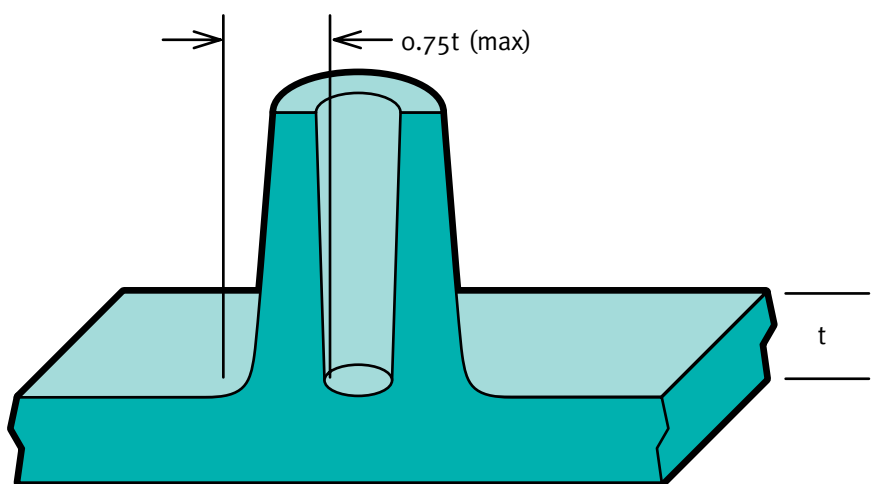


Figure 3-3

Boss Dimensions



Baydur structural foamed systems offer excellent strength-to-weight characteristics, because of their sandwich-like structure. These polyurethane materials are found in many large parts, such as electronic and business-machine housings, cab roofs, consoles, cabinets and shelves. Additionally, structural foamed materials are used extensively in aquatic sports equipment, such as skis and knee boards, because their density is lower than water, which allows them to float. They also offer designers more latitude than other materials: wall thickness can be varied; sink marks from ribs and bosses are less common.

While Bayflex flexible foams are not used in structural applications and are not subject to the same design restrictions, they offer some unique capabilities for designers. For instance, because these materials have high compressibility, you can design small undercuts without slides. For more information on design parameters, contact your BaySystems representative.

FOAM RISE AND FLOW

The liquids used in foamed systems fill a percentage of the cavity's volume, depending upon the final part density required. The level of liquid placed in the mold prior to expansion is referred to as the “**liquid level.**” The remaining volume is filled as the liquids react, creating foam. Foam expands upward and outward, a process called **foam rise**. Foam density can range from 0.3 to 1.0 g/cm³. Most parts have a foam density between 0.6 and 0.8g /cm³.

While freon was used as a blowing agent for many years, all BaySystems's RIM polyurethane systems are CFC- and HCFC-free today. Growing environmental concerns, coupled with advances in water-blown systems, have led to alternatives.

WALL THICKNESS

Wall thickness plays an important role in designing parts made of foamed materials. Baydur structural foam has been used in parts with localized wall thicknesses as thin as 1/8 inch to as thick as over 1 inch, although the typical nominal wall thickness ranges from 1/4 to 1/2 inch. Other rules of thumb include:

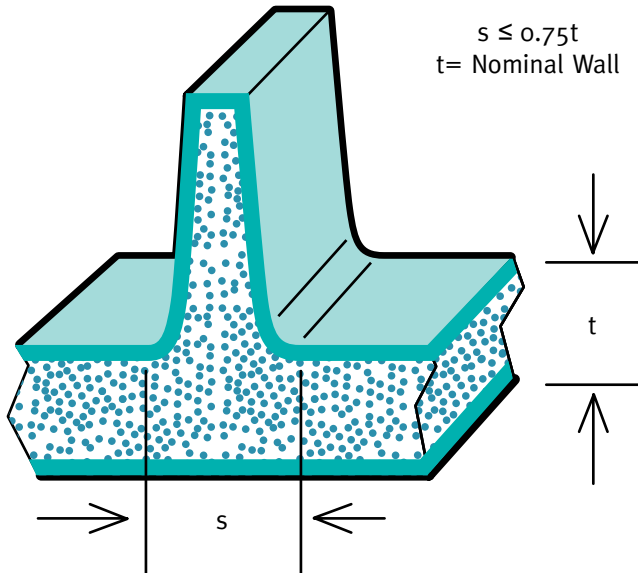
- Increase the wall thickness and reduce the part density to maintain part weight and optimize part stiffness.



The flow properties of BaySystems foams allow you to mold parts of varying thicknesses at different points in the part – to meet your needs to enhance strength, increase sound attenuating properties or reduce weight at any area in the part, as you can see in this complex truck floor mat.

Rib/Wall Ratio for Foamed Systems

Figure 4-1



RIB DESIGN AND CONFIGURATION

When designing ribs for parts made of foamed materials, the rib-root thickness including both sides of radii should not be greater than 100% of the nominal wall thickness to help avoid sink marks (see figure 4-1). When aesthetics are not a primary concern, you can design ribs thicker than the nominal wall thickness. Other considerations include:

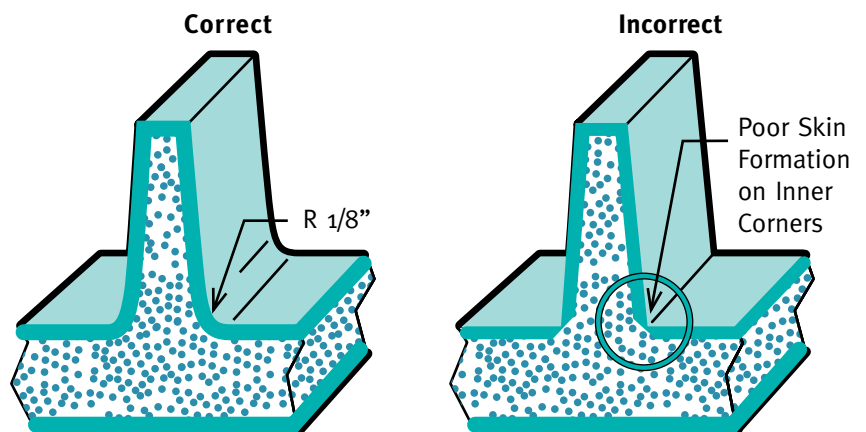
- Locate ribs in the direction of foam rise and flow. If this is not possible, provide for venting to prevent air entrapment.

For more information on ribbing direction and configurations, please refer to the general design considerations in this manual.

- Avoid having wall-thickness increases at the end of foam rise, near the vents. The increasing viscosity and resulting drop in flow-ability can lead to air entrapment, bad knit-lines and insufficient packing.
- Keep the ratio of wall-thickness change below a factor of two, if possible. While some award-winning applications have deviated from this rule of thumb, the differential friction in the cross sections can cause racetracking, leading to venting problems and surface imperfections (see figure 2-4).
- Keep the larger thickness changes under the liquid level.
- Avoid excessively thick cross sections as they cause long demolding times. Consider using a space-filling insert to help fill thick cross sections.

Figure 4-2

Effect of Radius on Skin Formation



RADII/FILLETS

Radius the inner corners of all fillets and adjacent walls a minimum of $1/8$ inch to reduce stress concentrations, promote good skin formation and help avoid air entrapment (see figure 4-2). Inside corners on parts are more difficult to cool than large, flat areas. This temperature difference can lead to poor or no skin formation in sharp inner corners, resulting in inferior mechanical properties. Outside corners are not as susceptible to poor skin formation and will form thick skins. Other rules of thumb include:

- Do not make sharp transitions. Radius corners $1/8$ inch to allow for proper skin formation.
- Radii are extremely important for parts made of foamed rigid systems because they are generally more notch sensitive than parts made of Bayflex solid systems.

BOSSES

Bosses facilitate mechanical assembly or act as supports or spacers. Connect them to the part's outer walls or design them with gussets (see figure 4-3). When bosses are used to accommodate screws or inserts, consider the following suggestions:

- Make the minimum wall thickness $3/16$ inch around the hole if an insert is used.
- Design bosses, including radii, with a wall thickness no greater than the nominal wall thickness around the cored hole (see figure 4-4).

- Core bosses when using self-tapping screws and inserts to form skin in the hole (see figure 4-5).
- Radius all bosses $1/8$ inch at their bases.

For the diameter of the boss hole, refer to the specifications of the insert or screw manufacturer. For example, inserts greater than one inch in diameter have been successfully used in the field.

Boss Versus Flow Direction

Figure 4-3

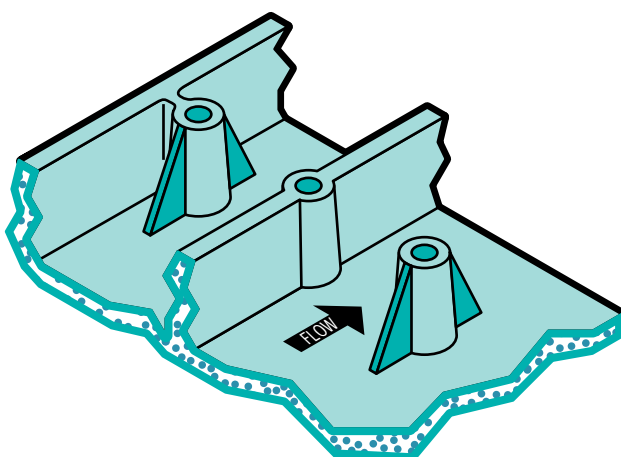
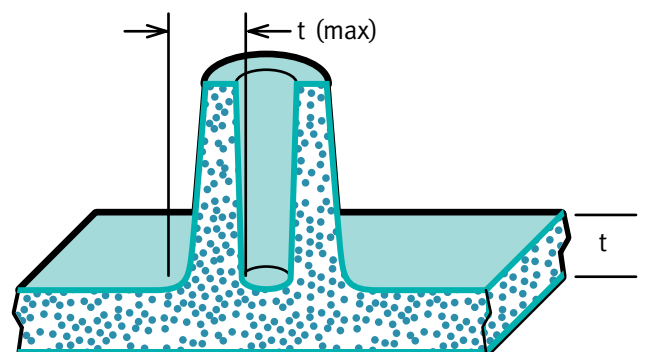


Figure 4-4

Boss Dimensions

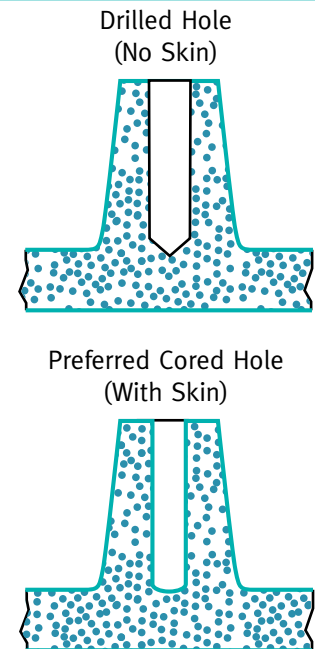


STRUCTURAL ANALYSIS CONSIDERATIONS

Because the mechanical properties are not uniform throughout a typical cross section in a non-isotropic material, the available physical-property data may not allow you to calculate reasonable deflections. Combining properties obtained from different testing methods is required for parts made of structural foam. For example, flexural modulus helps to predict deflection on horizontal surfaces (perpendicular to the load direction) and tensile modulus for vertical surfaces (parallel to load direction). Parts with complex geometries may require using both flexural and tensile moduli to help predict real-world behavior.

Finite-element analysis can use these values to estimate the part's displacement field. This type of analysis will complement prototype testing, but should not be substituted for prototype testing under actual, end-use conditions. For more information on analyzing Baydur structural foam, request a copy of *The Performance of RIM Structural Foam in Load-Bearing Applications* from BaySystems.

Figure 4-5 Cored Versus Drilled Bosses



Composite materials offer a unique benefit to part designers: you can place localized additions of glass mat within the mold to strengthen higher-stressed areas. This flexibility allows for enhanced material properties. Load-bearing parts made of Baydur structural RIM materials offer excellent impact strength and high flexural modulus.

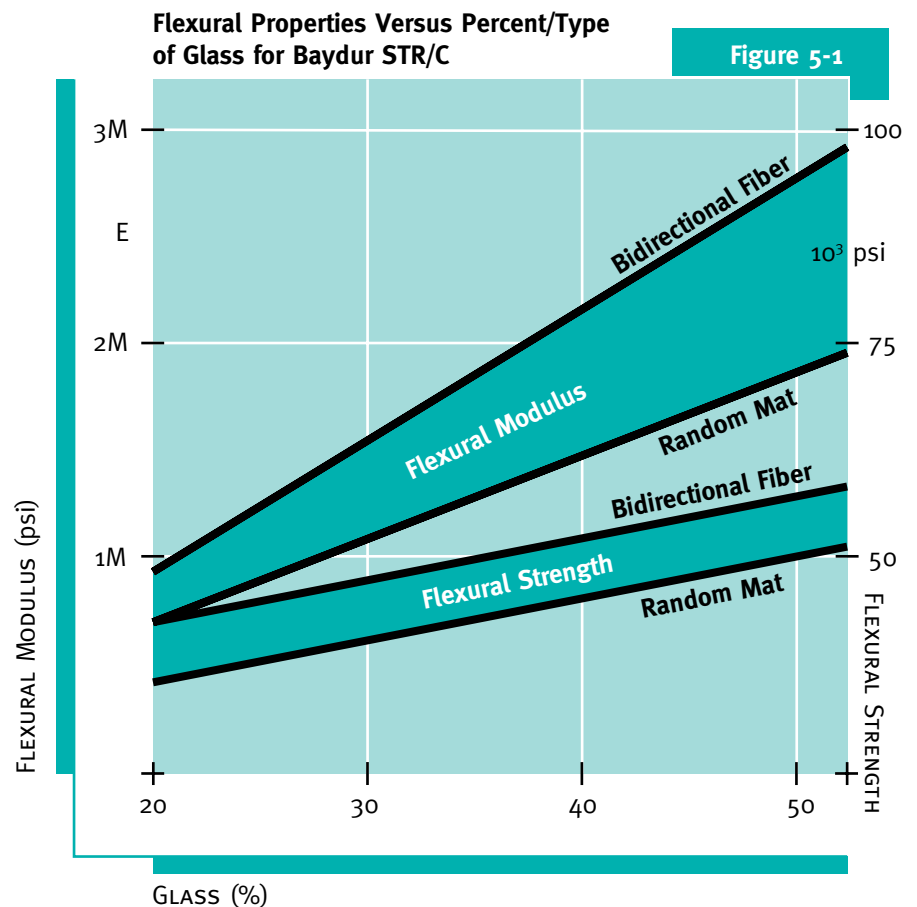
GLASS MAT

Composite materials, made of a polyurethane system reinforced with glass-mat fiber, have an extremely high flexural modulus that depends upon the fiberglass content (measured by weight), its location and the direction of the mat fibers. As the percentage of glass increases, the flexural modulus of the part increases. The highest modulus attained thus far is approximately 3.0 million psi in a part made of Baydur STR/C composite with 60% glass in several layers of bidirectional mat. At 30% glass, a flexural modulus of 1.2 million psi with random-fiber mat and 1.5 million psi with bidirectional mat are

not uncommon. The flexural modulus and part stiffness are greater in the direction of the glass fiber.

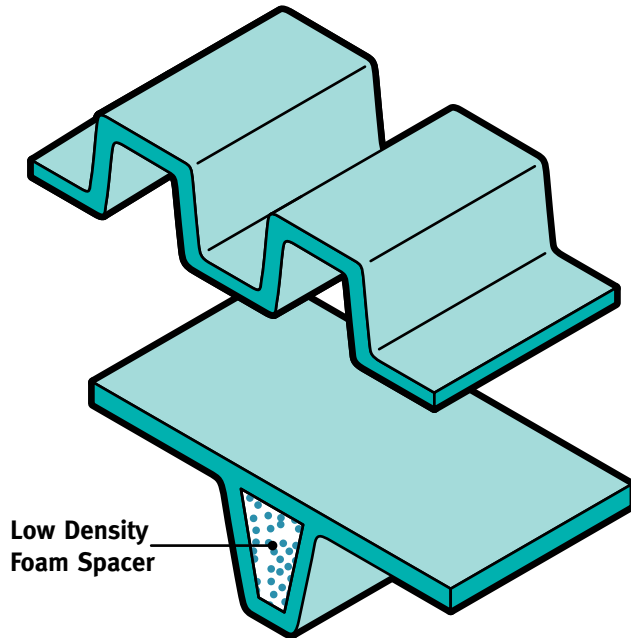
Glass mats are available in random or directional configurations, with various diameter fibers. Glass mats are fitted in the mold prior to injection. Resistance to flow increases as the percentage of glass mat increases. This resistance to flow, causing back pressure, can make mold filling difficult. Always check the material safety data sheets (MSDS) and consult with your glass-mat supplier for safe-handling recommendations for their products.

(Opposite) These exterior spa panels molded from a BaySystems Baydur® STR polyurethane system offer a strong, lightweight alternative to traditional wood panels. They are dimensionally stable and offer excellent heat, chemical and water resistance as well as enduring beauty.



Corrugations and Box Beams

Figure 5-2



If your part needs to be stiff and light-weight, consider using a foamed composite with more of a sandwich-like construction. This type of composite features glass fibers close to the surface, creating a less-dense cross section.

When the processor is using composite materials, he should follow these rules of thumb:

- Avoid specifying more than 50% glass in any area. At this high percentage, bulky glass can be difficult to compress in the mold and may be difficult to fill.
- Extend the mat to the mold edge. Under-sizing mats may lead to low glass areas - called resin-rich areas - around the periphery and create a preferential path for material flow. These resin-rich areas are weaker under load and exhibit more-brittle behavior than sections reinforced with glass mat.
- Use a thicker wall or a higher percentage of glass to increase stiffness. Figure 5-1 shows modulus and flexural strength as a function of the percentage and type of glass.
- Make sure that localized glass additions can be “wetted out” - thoroughly saturated with liquid polyurethane material - to minimize dry and unfilled areas.

Continuous Integral Beam Assembly

Figure 5-3

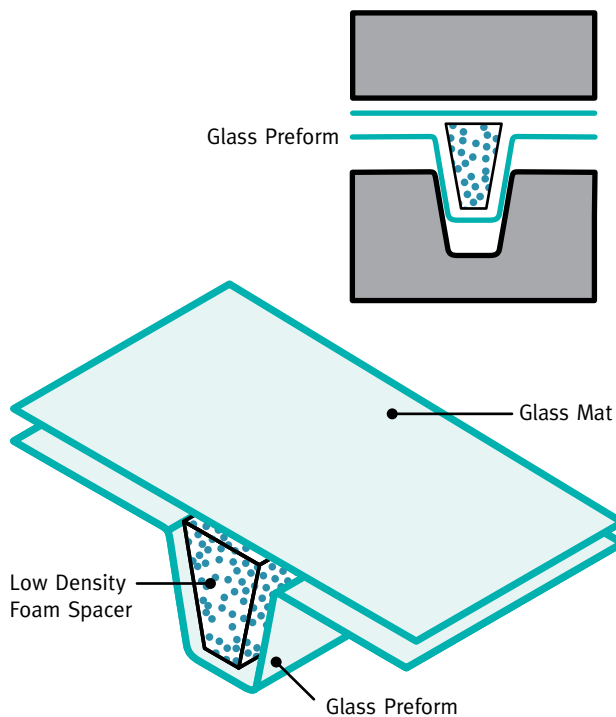
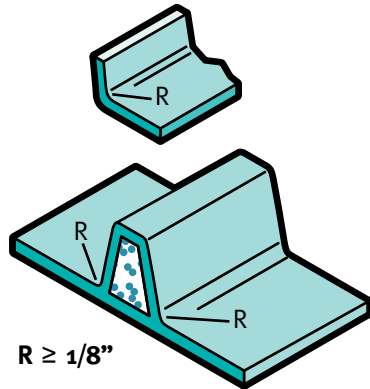


Figure 5-4 Radii/Fillet Configuration



- Position gates directly into the highest percentage of glass whenever possible. The mixture should flow from the higher-density glass to the lower-density glass to minimize dry areas.

REINFORCEMENTS

Do not design ribs in parts made of Baydur composite systems, as they are difficult to mold. Alternatively, consider designing in corrugations and/or box beams (see figure 5-2). To make a box beam, glass mat is placed around a low-density, preformed core or space-filling insert (see figure 5-3). The structural RIM system is molded around it to produce a continuous integral beam. The size of the cross-sectional area of the beam, along with the wall thickness and percentage of glass will determine the overall stiffness of the box.

RADII/FILLETS

When designing corners, allow for an inner radius or fillet of 1/8 inch minimum to allow for continuous glass transition (see figure 5-4).

PADS

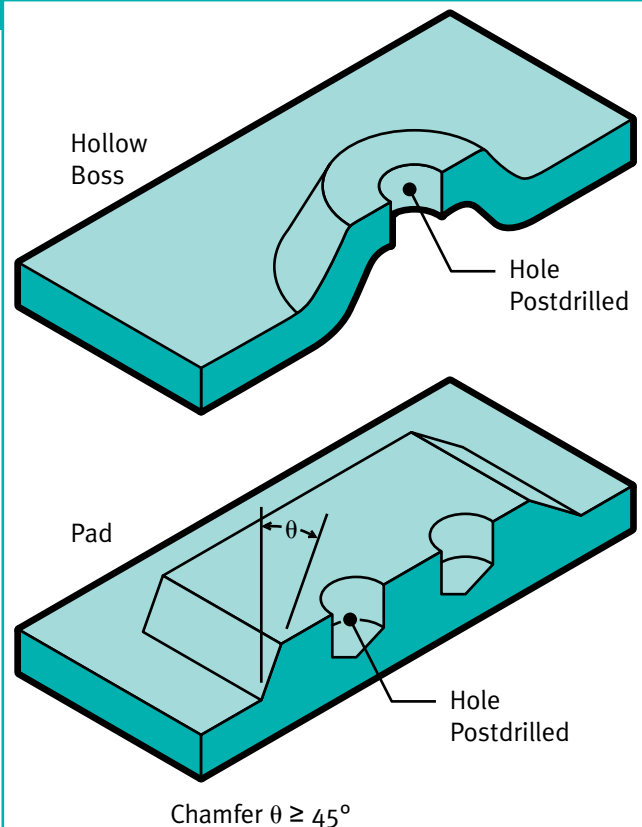
When working with composite materials, use pads or hollow bosses for assembly. Chamfer the ends of the pads for better mold filling (see figure 5-5).

PREFORMS

Preforms are required for complex parts with geometries that cannot be molded with a standard glass mat. They offer increased design flexibility for structural RIM parts, particularly in large production runs. Typically preforms are made of glass fibers that are held together by a thermoplastic or thermosetting binder in one of two ways:

- **Compression-molded preforms** use a glass mat treated with a binder. The mat is compressed in to the desired shape in a heated mold. As the binder cools or cures, it glues the fibers into shape.
- **Spray-up preforms** involve spraying chopped glass and the binder onto a perforated, positive form. A vacuum on the opposite side draws the chopped glass onto the form, creating a random, spray-up pattern. This type of preform can accommodate more complex shapes, but may be more costly.

Figure 5-5 Hollow Bosses and Pads for Mounting



FINISHES

Structural RIM materials can accommodate many surface finishes, from textures to “class A.” For visible parts requiring a “class A” finish, such as in automotive applications, specify a polished mold and surface-veil material. A veil is a very thin mat made of thin fibers that will help keep the glass fibers from protruding through the molded part surface.

In-mold coating is possible with Baydur STR systems. To create a good bond between the coating and glass matrix, allow the material to mold against a partially cured coating. For more information on in-mold coating, please contact your BaySystems representative. The next chapter on postmolding operations provides more information on finishing.



A roof module molded from a Baydur® LFT polyurethane system reduces weight and adds structural strength to the body of this 2007 Opel Zafira.

Most parts require postmolding operations, such as painting and assembling. These various operations are discussed in this section.

A lighter grade of steel encapsulated with a BaySystems Bayflex® polyurethane system produces a ladder rack that is lighter yet stronger than the former all-steel model. It's also more chemical and corrosion resistant and adds a certain style and flair to the truck's appearance.

FINISHING

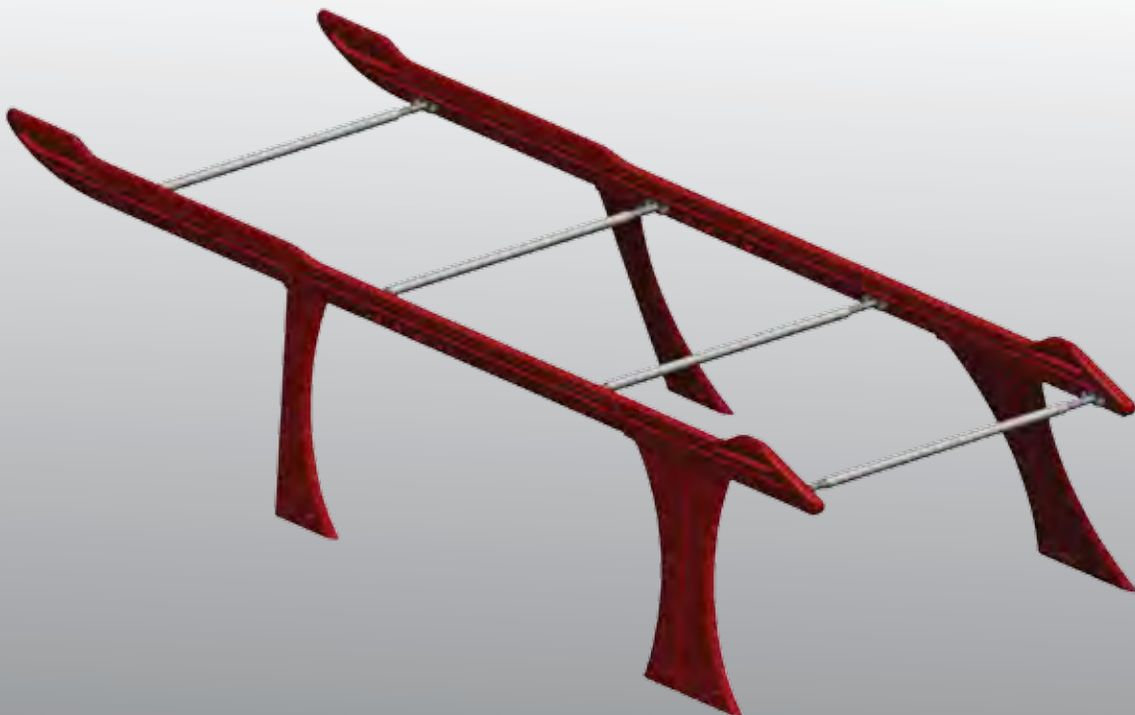
Parts made of polyurethane materials offer designers many options for color, texture and other finishing considerations. For more information on any of these options, contact your BaySystems representative.

Pigmentation

Pigments - organic dyes or color pastes added to the polyol - change the natural color of polyurethane materials. Polyurethanes are light to medium opaque brown when molded without color. Not inherently

UV-stable, they will eventually yellow or gain a greenish tint when exposed to sunlight. While this discoloration does not affect physical properties, it is usually aesthetically objectionable. The amount of pigment added to the system is expressed as a weight percentage of the polyol, usually ranging from 3 to 10%, if your part will be painted.

Consider specifying pigments to give your final part a base color similar to the final surface coating. A higher pigment concentration is needed if your final part is going to be a dark color and you don't want to paint it.



Most rigid RIM systems cannot be used to produce UV-stable, white or light-colored parts without painting. Pigments also will not hide surface imperfections and can cause color striations.

In-Mold Coatings

Consider in-mold coatings - special paints sprayed onto mold surfaces - as an alternative to postmold painting. After spraying, these paints dry for a brief period, so that the injected mixture flows over the semi-dry coating during mold filling. Typically in-mold painting is used for large, relatively simple molds, without complex details, such as agricultural-combine cab roofs and fenders. Other points to consider when selecting an in-mold coating include:

- In-mold coatings can save the cost of postmold painting.
- Mold surface cannot have imperfections, as every detail is reproduced.
- In-mold coating can reduce most secondary, finishing operations.

Patching

Occasionally, molded parts have air pockets, lower-density areas and other small imperfections that may need to be repaired. If your part will ultimately be painted, a patching compound can

fill these areas.

Smaller areas can use a single-component, commercially available patching compound; larger areas will need a two-component polyester compound, such as those used in autobody repair. For good patch adhesion, make sure the area is clean, free of mold-release agents or dust and roughened. After the patch has cured, sand the area until smooth prior to painting.

Postmold Painting

While more costly than pigmentation, postmold painting offers the added benefit of exact color matching to other parts and parts made of other materials. Postmold painting covers minor surface blemishes and allows similar parts to be painted in different colors. For example, a bumper made of polyurethane must match the steel side panels on the car to which it will be attached. However, the same bumper design is used on many different-colored cars. Postmold painting accommodates both of these design parameters.

Textures

Polyurethane molding techniques accommodate a number of different textures, including wood and leather grain, pebble and graphics. For wood and leather grain or other fine textures, a nickel-shell mold can be used. This material is hard, has good release characteristics, reproduces textures well and does not scratch

easily. While molds accommodate custom designed finishes with ease, pattern preparation can be expensive.

If considering a wood-grain finish, the mold must not have any nicks or scratches. Blemishes on the mold surface will appear in the finished part's grain and wood-surface finishes cannot be retouched after molding. To complete a wood-grain effect, the grain is stained in a darker color and the whole part is covered with a protective coat.

Pebble surfaces can be formed in the mold or added later with a coat of texture paint.

Graphics can be molded in. Simple masking will allow raised graphics and lettering to be painted in a contrasting color. For dense areas of text or small letters, consider using decals.

Decals and Silk-Screening

Decals work well with polyurethane parts, as long as the adhesion area has no texture and is clean and free of any release agents. While decals adhere well to painted parts, they will

be somewhat easier to remove than those applied directly to unpainted parts. Polyurethane parts can also be silk-screened. Contact your printer to discuss your needs.

ASSEMBLY OPERATIONS

Polyurethane parts that require assembly can be joined with screws, adhesive bonding and nailing. This section gives an overview of some of these common joining methods.

Screws

One of the most cost-effective, reliable and commonly used joining methods, self-tapping or wood screws can be used to assemble parts made of RIM polyurethane systems. To install

screws, you can either drill or mold a hole in the part. If you chose to postdrill a hole, make it slightly smaller than the screw diameter, as you would with wood. Both methods yield relatively high pullout strength in parts made of Baydur structural foam.

- Generally, the pullout strength is

proportional to the screw depth.

- Molded-in pilot holes will yield higher pullout strength than postdrilled holes for foamed materials.
- Parts made of structural foamed materials respond similarly to wood in most joining techniques.
- Parts made of elastomeric materials can be joined with screws, but the material can tear or stretch around the hole. Test your assembled part.

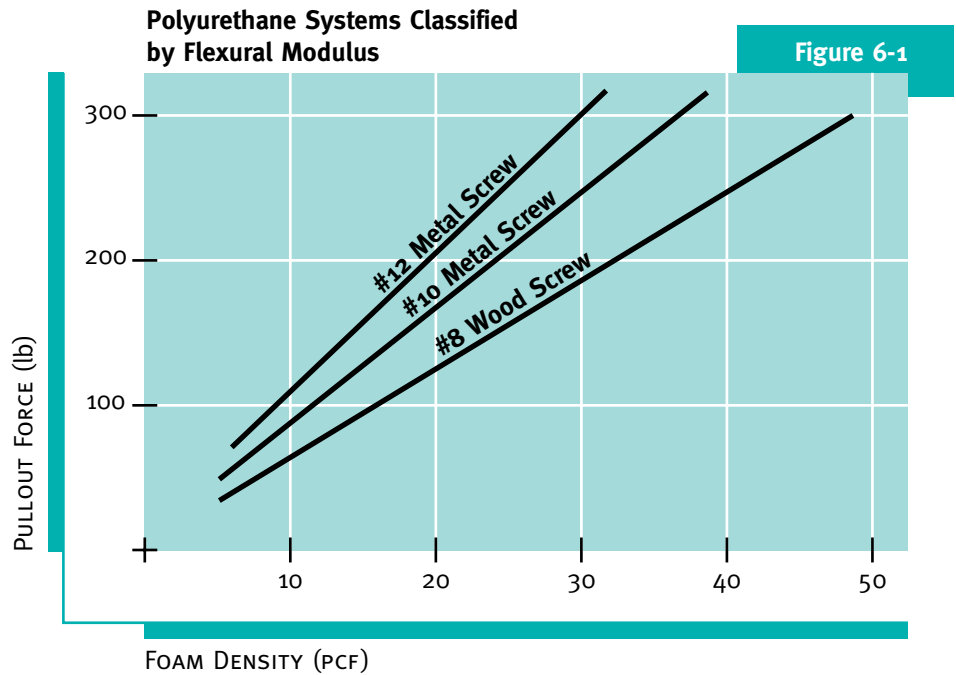


A Mack Truck fender cover molded from a colorfast BaySystems polyurethane system offers many years of tough, corrosion and dent resistant service.

In foamed Baydur systems, parts with lower density make installing screws easier. The most-common foam density for screw installation ranges from 25 to 40 lb/ft³ (0.4 to 0.65 g/cm³), roughly comparable to that of wood. While several screws designed specifically for plastic are available, normal wood or sheet-metal screws can be used with foamed parts (see figure 6-1).

- For parts made of Baydur structural foam, use thread-cutting or thread-forming screws. Thread-forming screws may leave higher internal stresses close to the thread.
- For parts made of PRISM polyurethane, use thread-cutting screws.

Screws can be inserted without a pilot hole into parts made of low-density foam. Use caution when installing screws, as the danger of stripping or foam breakout increases as the density decreases. Specify screws as a permanent attachment method on parts made of low-density foam. If your low-density part will be disassembled with any frequency, consider an other joining method, such as threaded inserts. For more information on inserts, see the general part design section in this manual or request a copy of BaySystems's *Plastics: Joining Techniques* design guide.



Adhesives

Polyurethane or epoxy adhesives work well with RIM polyurethane systems. The adhesion area in a lap joint should be at least three times the wall thickness. Bonds can have high strength in both tension and bending. Clean and roughen the adhesion areas to promote good bonding. For more information on adhesives, contact one of the following producers:

3M Industrial Specialties
St. Paul, MN 55144
612 133-1110

Ciba-Geigy Corporation
East Lansing, MI 48823
800 875-1363

Loctite Corporation
Newington, CT 06111
203 278-1280

Lord Corporation
Erie, PA 16541
814 868-3611

Ashland Chemicals
Columbus, OH 43216
614 889-3639

POSTFABRICATION

Nailing/Stapling/Planing

Many standard woodworking techniques can be used with Baydur structural foam, including sawing, drilling, nailing, stapling, sanding and routing. If your part will be fabricated via one of these methods, design for common woodworking techniques. Avoid these techniques for mass-produced products as they are crude and labor-intensive.

Do not plane foamed polyurethane parts. Planing will cause skin loss and possible exposure of foam core, with the resulting loss in structural integrity, as well as physical and mechanical properties.

Recycling Polyurethanes

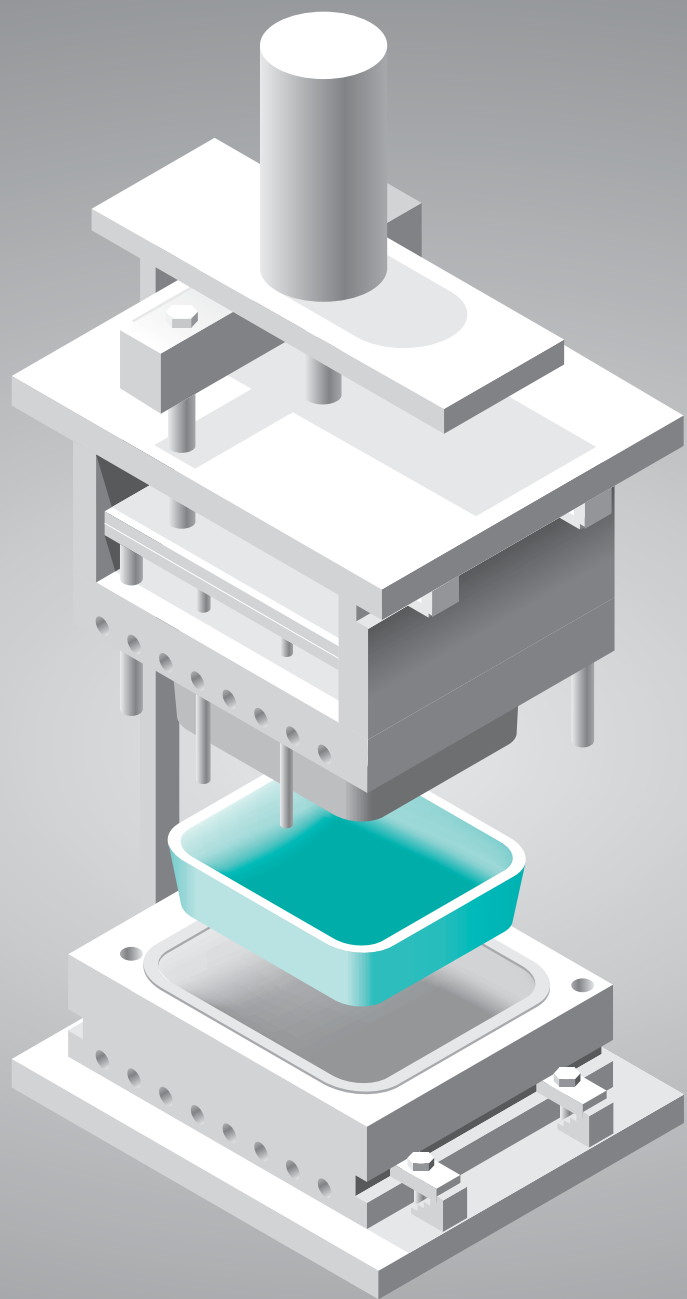
When designing a part, consider design for disassembly (DFD), a concept that is gaining emphasis because of recycling.

Because of recent advances, several methods can be used to recycle polyurethane materials, depending upon the type of material. Most polyurethane resins can be granulated and ground into powder for use as a filler in new parts. The amount of filler that can be used will be based upon your final part requirements. Granulated elastomeric continued material can also be compression molded under high pressure and temperature to produce new parts. Parts made this way may retain their original elongation and over 50% of their tensile strength.

Glycolysis, a new way to convert polyurethane materials back to their original raw materials, is also showing great promise. Polyurethane materials can be converted into energy: the heat of combustion for RIM polyurethane materials is between 12,000 and 15,000 BTUs per pound, approximately the same as oil or coal. Talk to your BaySystems representative for the latest information on polyurethane recycling.

Roof shakes molded from a BaySystems polyurethane technology offer the texture, color and beauty of real wood without wood's inherent susceptibility to rot.





MOLD DESIGN

To make good polyurethane parts, you must have a good mold. A correctly designed mold is the single most important factor in gaining maximum productivity, uniform part quality and trouble-free production (see figure M-1). Improvements in gate, mixing head and aftermixer designs are continuing to add to part quality and uniformity. Molds are sometimes referred to as “tools.” In this manual, we use “tools” and “molds” interchangeably.

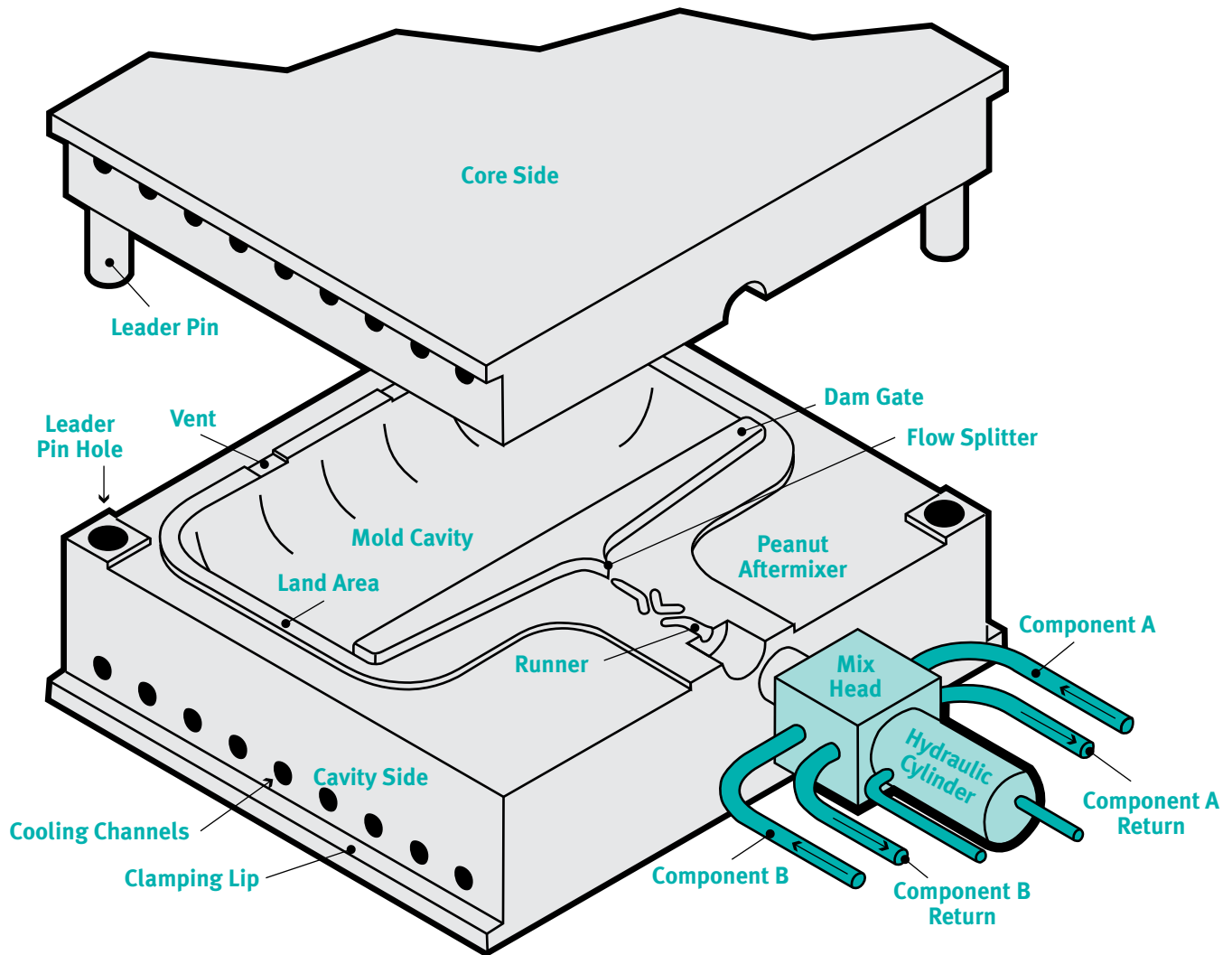
This section of the manual provides guidelines to help you successfully design and build molds, offering some practical rules of thumb. It begins with a discussion of general mold-design parameters, followed by suggestions for gate and parting-line positioning, mold details, finishing and special tools. Use the information presented herein as general guidelines. Your mold maker is responsible for producing a functional mold. Contact your BaySystems representative for information on your specific mold.



LifeTime Composites of Carlsbad, CA, produces LifeTime Lumber® for decking and fencing — a great “made of polyurethane” alternative to natural wood that will not rot, warp, discolor or mildew and can be sawed, drilled and worked with regular woodworking tools. And of course, LifeTime Lumber saves trees.

A Typical RIM Mold Configuration with a Peanut Aftermixer and a Dam Gate

Figure M-1

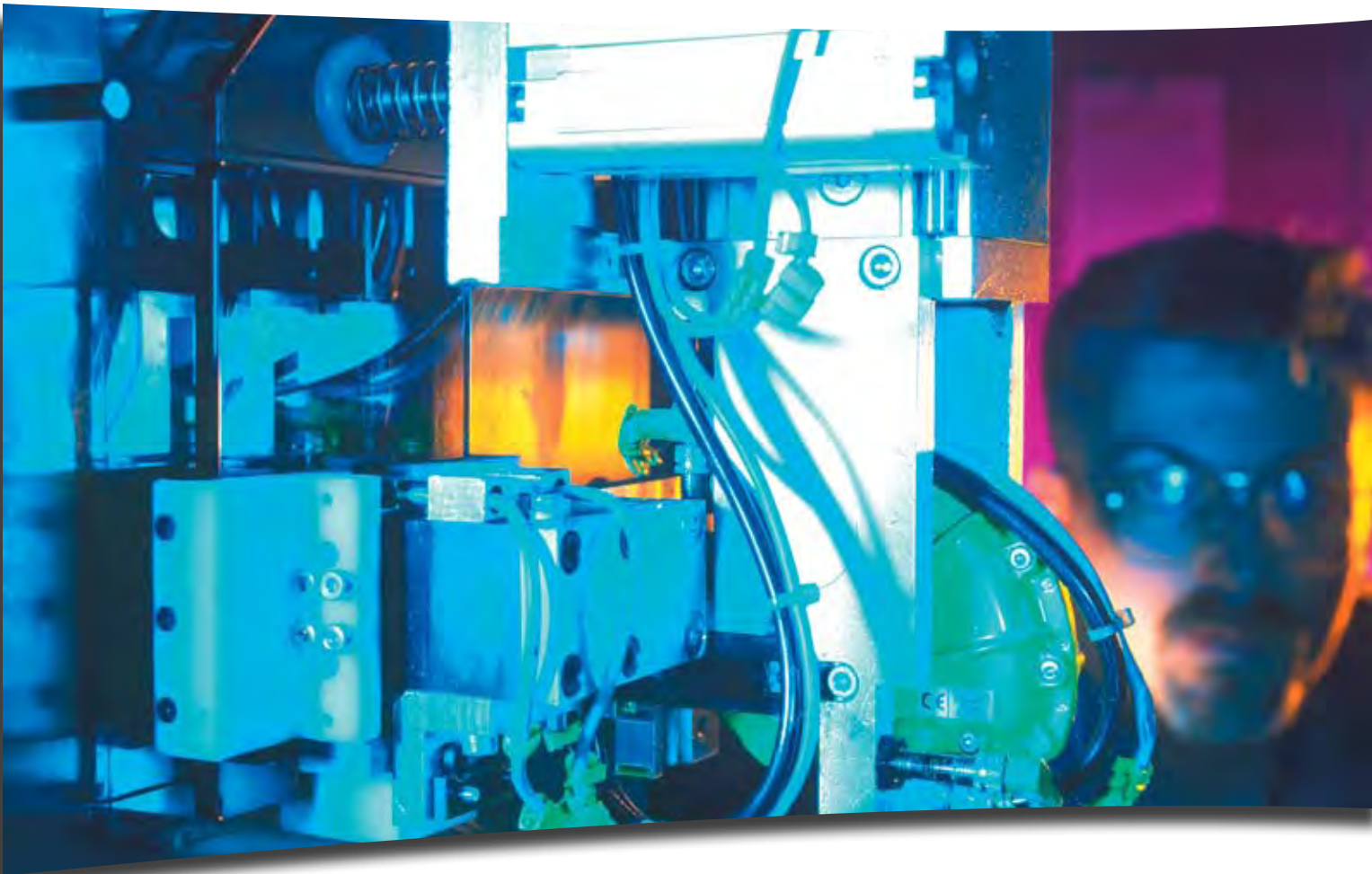


PART SIZE/CLAMPING PRESSURE

When designing molds for use with RIM polyurethane systems, you must address several issues, including mold size and cost, clamping pressures, part shrinkage, dimensional tolerances and part repeatability. These general considerations are discussed in this section.

With RIM materials, there are no upper size limitations on parts, other than equipment capabilities. Because of metering-machine capabilities, the minimum part weight or shot size is approximately 0.5 pounds (225 grams). For example, this weight roughly correlates to a 6-inch square with a thickness of 3/8 inch at a density of 64 lb/ft³. While specialty machines to make small parts are available, typical gating and aftermixer requirements would cause too much waste to make smaller parts practical or economical.

RIM polyurethanes are ideal for large parts, with parts heavier than 100 pounds having been made. If one metering machine cannot fill the mold fast enough, in theory two or more can be connected to a mold. Because of practical press-size and other equipment limitations, consider redesigning parts that exceed 50 pounds into smaller components for later assembly. For modular designs, two or more components of an



assembly may be produced from the same mold. Practical limitations on part size include:

- The capacity of the metering machines and mixing heads
- Press capacity and clamping pressures, if self-containment isn't possible
- Gel-time and cream-time limitations

Table 7-1 lists typical molding pressures for RIM systems. Notice molding pressures are more than an order of magnitude smaller than those used in thermoplastic injection molding. Make sure that clamping pressures for your part's projected area exceed the molding pressures.

Table 7-1

Typical Molding Pressures

System	Typical Molding Pressure* (psi)
Baydur Structural Foam	100
Bayflex Elastomeric Solids	100
PRISM Rigid Solids	100
Baydur STR Composite	200
Baydur GS	100

* Based upon projecting part area in direction of draw. Clamping pressure must be greater than molding pressure

Table 7-2

Relative Mold-Cost Comparison

Material/Fabrication Technique	Relative Cost %
Steel, Machined	100
Aluminum, Machined	80
Nickel Shell, Electro- or Vapor-Deposited	70
Aluminum, Cast	60
Kirksite, Cast	60
Zinc, Spray Metal	40
Epoxy, Cast (Prototyping Only)	30

MOLD COSTS

Because of lower in-mold pressures RIM systems use molds that are less expensive than conventional injection molds. Low-pressure RIM systems can be molded in softer mold-construction materials which are easier to machine. Table 1-2 shows a comparison of the costs of different materials and fabrication techniques for a mold to make a simple part.

To further reduce mold costs, simplify part design and avoid undercuts and other elements that add significantly to mold and postmolding costs. The mold's complexity and construction materials determine the total mold-making cost and consequently a large share of the eventual finished-part cost.

Other factors that influence mold cost include:

- Number and type of hydraulic slides
- Number and type of different surface finishes
- Part depth and complexity
- Part tolerances

When designing molds, try to weigh the mold cost against the production volume and the cost of postmolding labor needed to finish the part. Postmolding operations - such as trimming, drilling, bonding, sanding and painting - can add significant cost to a part. Designing a more complex mold may reduce overall cycle time and postmolding labor. While the mold may cost more initially, it could save money over the production life of the part, justifying the higher initial expense. Generally, molds for relatively flat parts with a minimum draw and without undercuts or special surface treatments have the lowest costs.

Finally, let your mold maker know which dimensions are critical and which have looser tolerances. Prioritize them from most critical to nominal. Specified dimensions can influence quotes from mold makers. Using standard fractional inches can be less expensive because a mold maker can use standard machining tools. Specifying decimal-numerical formats with high precision could significantly increase mold cost.

SHRINKAGE CONSIDERATIONS

All plastics, including polyurethane materials, shrink during cooling. Many factors influence the exact amount of shrinkage. Review BaySystems Product Information Bulletins (PIBs) for estimated shrinkage percentages for your selected system. Add the shrinkage dimension per inch to every nominal dimension of the part when designing molds. For example, if the shrinkage of a Baydur system is 0.7% and the part is 50 inches long, then the mold's length dimension should be increased 0.35 inches to 50.35.

Also, let your mold maker know which polyurethane system you have selected early in the mold-designing process. Different systems have different shrinkage values and therefore require different adjustments to mold dimensions to produce your final part. Changing systems or additives during or after mold construction can lead to an increase or decrease in final part dimensions.

DIMENSIONAL TOLERANCES

A number of environmental, processing and material variables determines a part's variation from specified size. Among the most-common variables affecting part-to-part reproducibility are:

- Part density
- Mold temperature
- Mold alignment
- Mold wear
- Injection rate
- Demolding time
- Component ratios and temperatures
- Ambient temperature and humidity
- Inhibited or uneven part curing
- Mold pressure
- Other production conditions

Because of CAD/CAM and other advances, mold precision has improved and should not be a major concern. Generally, expect a molder to guarantee a dimensional tolerance of 0.1% or less, but part tolerances can be greater.

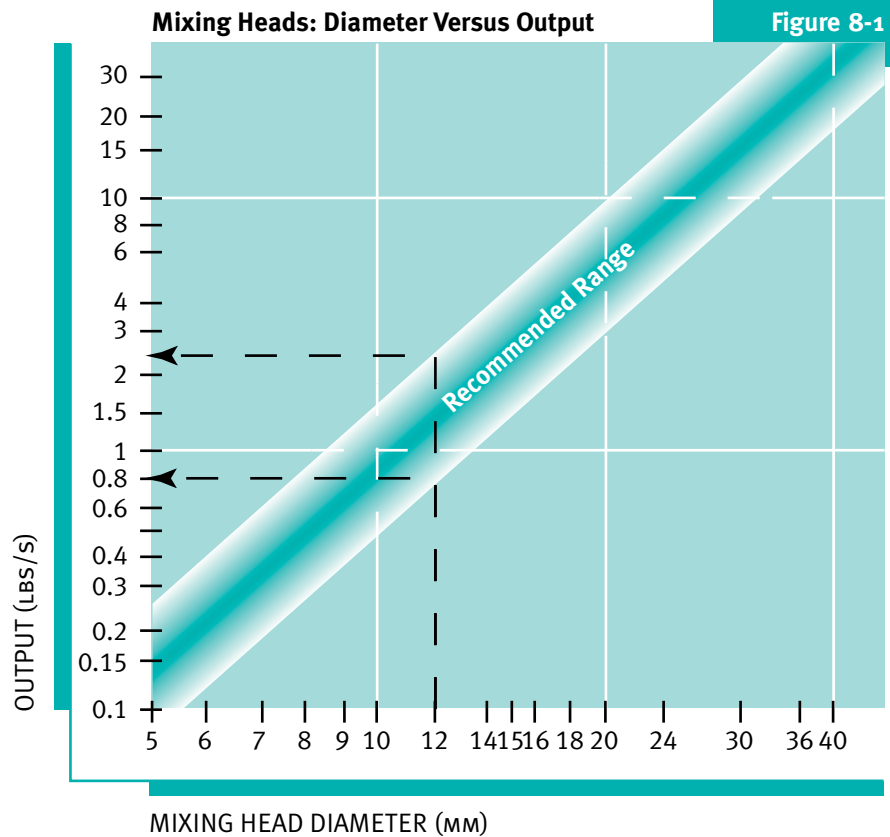
For best results, discuss all material selection and processing parameters with your mold maker before construction, so that the final tool accommodates your needs.

Often it is more important that your parts fit together properly than that they conform to absolute dimensions. Many times, molders make parts that fit with mating parts, even though both may be slightly out of tolerance. In most cases, this simple matching is functionally satisfactory. If your part must assemble exactly and be accurate to the drawing, explain this to your mold maker as early as possible. To save on costs, adapt your part design to fit within practical dimensional tolerances.



Polyurethane systems from BaySystems can be molded into very complex shapes ideal for hard-wearing, weathering applications.

Gating design is a major difference between thermoplastic injection molding and RIM polyurethane molding. Gating is the way the low-viscosity liquid transfers from the mixing head to the mold cavity. Typically there is only one gate per mold in polyurethane molding systems. Throughout this manual we use the word “gating” to refer to the combination of runners, aftermixer and the gate proper. This section discusses common design and placement parameters. For more information about gating placement, contact your BaySystems representative for a copy of our software, RIMgate@. This program helps you determine gate type, placement and size, as well as good runner and aftermixer design.



MIXING HEAD

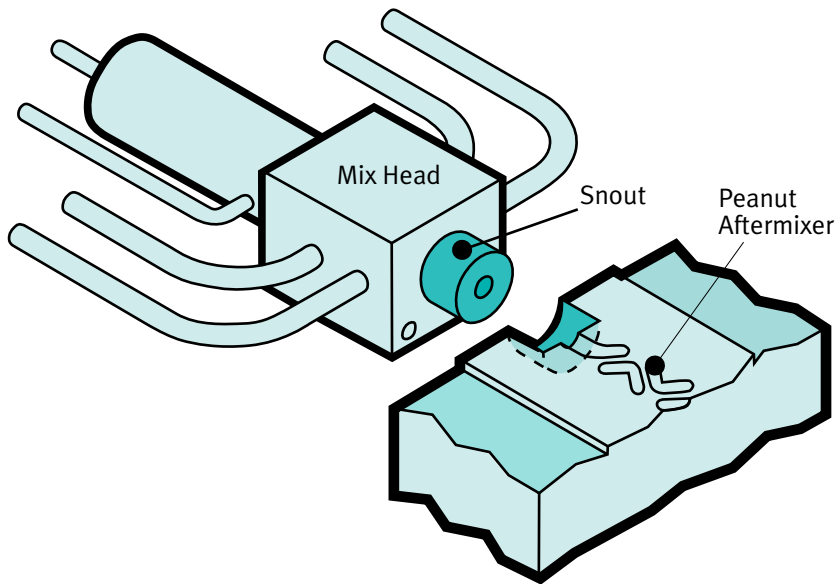
A critical part of molding, the mixing head is the area in which the isocyanate and polyol combine to form a liquid polyurethane material just prior to entering the mold. Self-cleaning mixing heads allow polyurethane materials to be used in large-scale, automated production runs. Mixing heads come in different sizes, each with a range of flow capacities (see figure 8-1). Material flows through opposing injector nozzles in these high-pressure heads, usually at impinging pressures of 1,500 to 3,000 psi (10 to 20 MPa). In the mixing chamber, material reaches ultra-high velocity prior to entering the aftermixer and mold cavity. Generally, the maximum output of a given mix

head equals three times its minimum. For example, a 12-mm mixing head (i.e., the inside diameter of the mixing chamber or outlet tube) can be used for material outputs between 0.8 and 2.4 lb/sec (0.4 to 1.1 kg/sec).

Various equipment suppliers make high-pressure impingement mixing heads. Because the mixing heads vary in size and have different bolt patterns to connect them to the mold, the equipment supplier should have the necessary dimensional information for the specific mixing head you are considering. For more information on mixing heads, contact Hennecke Machinery at 412 777-2000.

Cylindrical Mix-Head Snout, Flush with Mold

Figure 8-2



it can be used with any runner diameter. This design causes the mixture to churn as it passes through it, to ensure complete mixing. After the molding cycle, the molded peanut shape (sliced in half) visually indicates the quality of mixing, which can help to determine mixing problems.

When cutting a peanut aftermixer in both mold halves, make identical cutting patterns, not mirror images, to prevent blind alleys that can trap air. The aftermixer should be cut into the mold itself or cut into a plate which inserts into the mold. Keep it as close to the mixing head as possible to minimize gate waste. Because of factors concerning temperature control

Make sure that the mixing head is tightly fastened to the mold during filling. A loose-fitting mixing head may allow the high-velocity stream to bring air into the mold cavity, leading to defective parts.

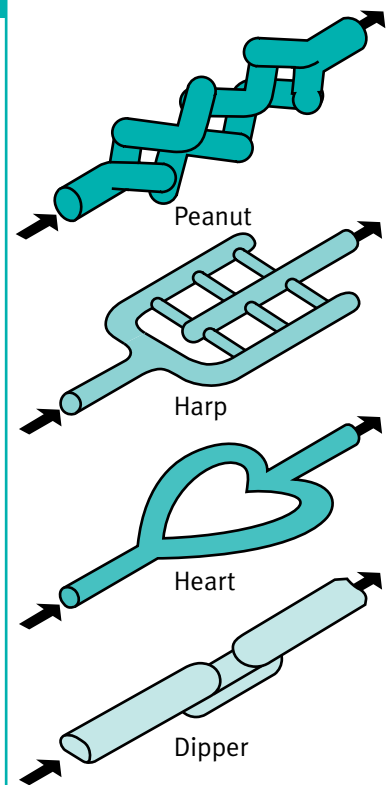
Most commonly, the head mounts to the side of the mold, parallel to the parting line. Mounting on the side of the mold gives you the greatest access to the mixing head, as well as more flexibility when determining its location. Always try to mount mixing heads on the stationary half of the mold to minimize hose movement. Side-mounted mixing heads are often the only choice for a press with closed platens and limited daylight. Usually, part and mold design and the available press determine the final position of the mixing head.

Most mixing heads have a cylindrical snout, which can be flush with the mold side at the parting line. When possible, design the mold so that the snout intrudes into the mold to create an additional sealing surface when the mold closes (see figure 8-2).

AFTERMIXERS

Any deviation in mix quality can cause imperfections. To ensure complete mixing, use an aftermixer. While many aftermixer designs are available, the “peanut” aftermixer has become the preferred choice (see figure 8-3). Because the mold designer can select the number of V-shapes in this aftermixer design, the peanut aftermixer complements mixhead performance. For instance, increasing the number of V-shapes will help mix difficult-to-mix materials. Additionally,

Figure 8-3
Types of Aftermixers



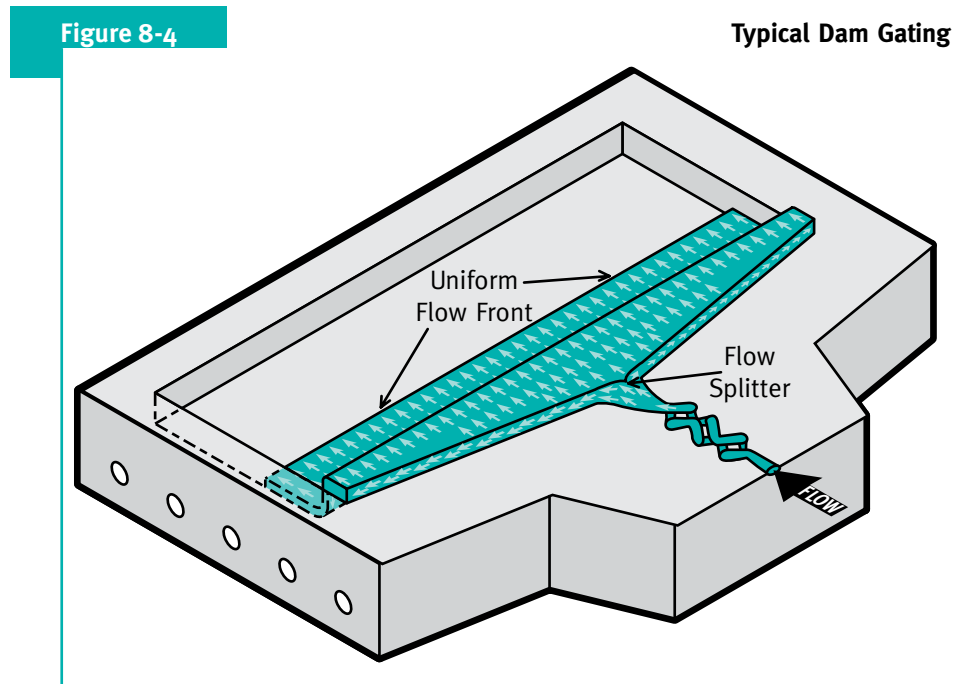
and sealing problems, do not use gate blocks, in which the aftermixer is cut into a separate block and externally attached to the mold. If your mold requires a separate block, place heating channels in the block to control temperature. To adequately seal the aftermixer assembly, the block should be fully supported in the mold.

Over the years, a wide variety of aftermixers have been developed. Although molders tend to have their own preferences, certain types of aftermixers have caused processing problems. The “harp” aftermixer, for example, may have blind areas which trap air. After filling, the trapped air may expand, causing bubbles in the stream, leading to defective parts.

EDGE GATING

Always edge gate molds for RIM polyurethane systems, unless you are using a Baydur STR composite, which should be center gated to prevent the glass mat from moving. The mixture should enter the mold cavity as a laminar stream, flowing onto the mold wall when entering the mold (see figure 8-4) to avoid air entrapment, the single largest cause of defective parts. It should not be directed into free space or perpendicular to a wall or other obstruction to avoid splashing and resulting air entrapments.

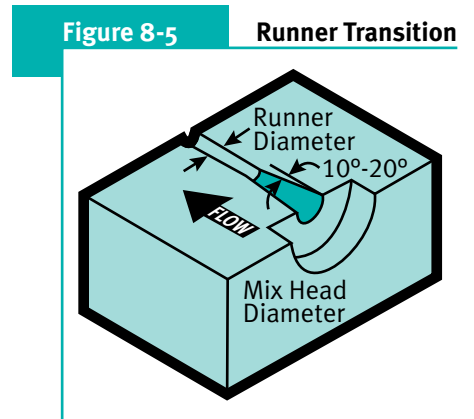
The runner that is adjacent to the mixing-head exit should have the same diameter as the mixing head. When reworking a mold, the runner diameter



may not match the new mixing-head diameter. To prevent bubbles and cavitation, make a smooth transition with no sharp edges (see figure 8-5).

The type of material (solid or foamed), mixing-metering machine output and available room at the parting line determine the gate dimensions. To determine the correct gating configuration, you must know the highest expected machine output. The speed at which material enters the mold must also be kept within limits.

- The upper limits for entrance speeds are 5 ft/sec for foamed systems and 25 ft/sec for solid systems.



- Determining lower-limit entrance velocities is difficult, because of the material's reactivity.
- If the injection rate is too low and the gate is too long, highly reactive materials may begin to gel before reaching the mold.

Gates can be designed as part of the mold or attached as a separate block. Again, these blocks can be difficult to seal, especially when the highest pressures are located in the block and are difficult to heat.

Fitting gate length to the part periphery and balancing flow lengths generally limit the choice of gate locations.

Considerations for gate placement include:

- Locate gates at the lowest possible point in the mold.
- Try to locate the gate on a straight parting line section.
- Try to locate the gate in a position that minimizes the longest flow length.
- Position the gate on non-aesthetic or less-noticeable area.
- Position the gate so that flow will be parallel to designed-in ribs.
- Place the gate closest to cutouts or most-detailed sections. This allows knit lines to form early in the flow.

Table 8-1

Sample Dam Gate Length Calculations for Solid and Foamed Systems

	Solid Systems	Foamed Systems
Known Variables		
Weight Output, O_w	3 lb/sec	3 lb/sec
Density, D	70 lb/ft ³	70 lb/ft ³
Maximum Injection Velocity, v	15 ft/sec	5 ft/sec
Gate Thickness, gt	0.1 in	0.08 in
Calculated Variables		
Volumetric Output, $O_v = O_w / D$	0.043ft ³ /sec	0.043ft ³ /sec
Minimum Cross-Sectional Area, $A = (O_v \bullet 144) / v$	0.41 in ²	1.23 in ²
Minimum Gate Length, $L = A / gt$	4.1 in	15.4 in

Foamed Systems

When using foamed, self-skinning materials, keep the gate thickness as thin as possible so that it can be easily removed from the demolded part. The material in a thin gate will cure to solid material. When it is removed, no foam core should be exposed.

For foamed systems, the rule of thumb for gate dimensions is 6 inches of gate length, with a gate thickness of 0.060 to 0.080 inches, for every pound-per-second output. Maximum stream velocity should not exceed 5 ft/sec. Table 8-1 shows calculations to determine gate lengths to produce a 10 pound part made of different polyurethane systems. Figures 8-6 and 8-7 show complete gate and runner dimensions for dam gates used with foamed systems.

Dam Gates

A dam gate equalizes material flow over its length (see figure 8-7). The gate has a splitting nose that divides the runner into two branches behind the dam. This triangular configuration ensures uniform distribution across the gate. Dam gates are strongly suggested for rigid RIM materials. Table 8-1 and figures 8-6 and 8-7 show a typical calculation for gate length.

Usually gate length and thickness are mutually adjusted to keep entrance velocity from exceeding specified limits.

Fan Gates

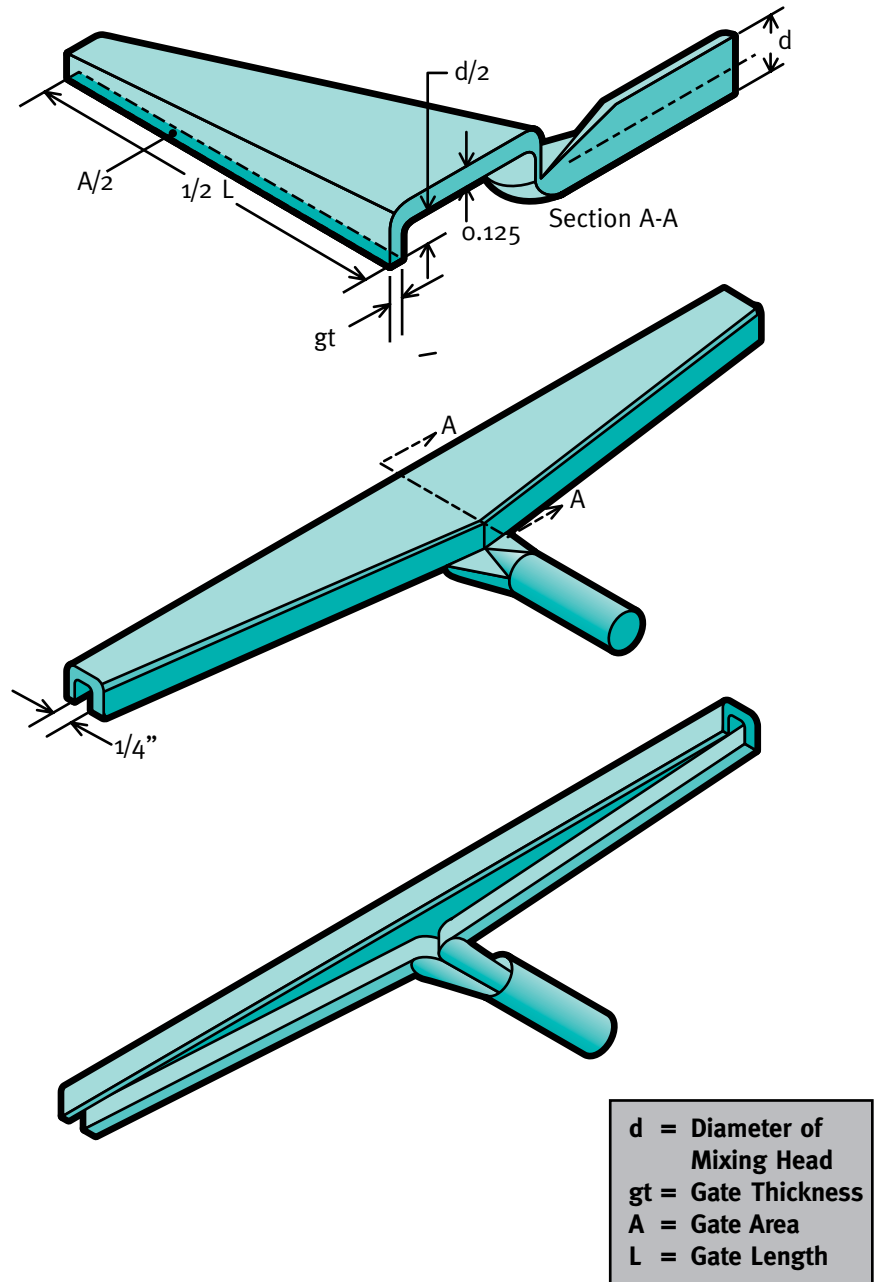
The two most-common types of fan gates (see figure 8-8) are the straight sided or triangular gate and the preferred quadratic gate, which has a parabolic profile. In fan gates, the runner gradually flattens and bends in the wall direction. The triangular gate's apex angle should not exceed 40° could generate bubbles. With this angle limitation, thin gates can become very long, particularly for large parts. Long gating can lead to excessive waste.

- As a rule of thumb: practical maximum gate length is 6 inches.
- Fan gates are recommended for solid elastomeric systems that have a fast curing time.

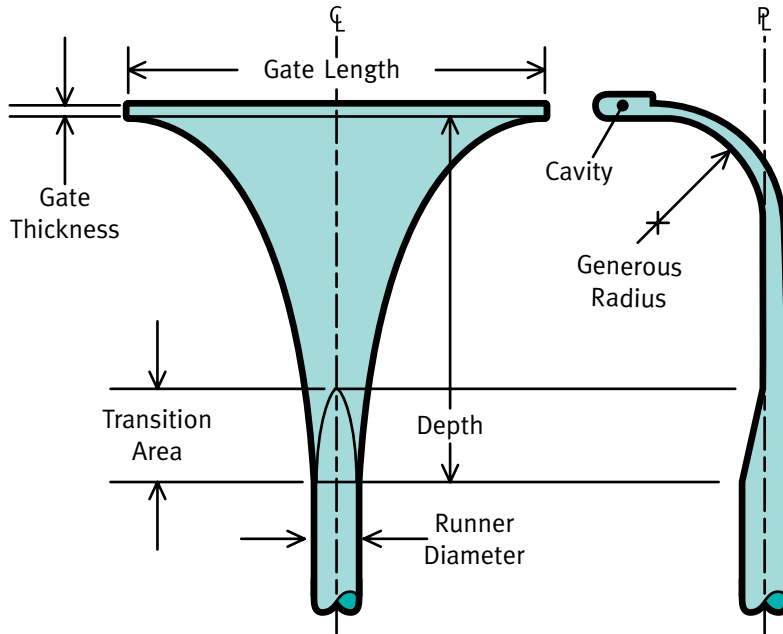
In practice, fan gate length averages four inches. Usually gate length and thickness are mutually adjusted to keep entrance velocity from exceeding specified limits. Table 8-2 and figure 8-9 show relationships for determining fan gate dimensions.

Figure 8-7

Dam Gate Dimensions (Option 1)

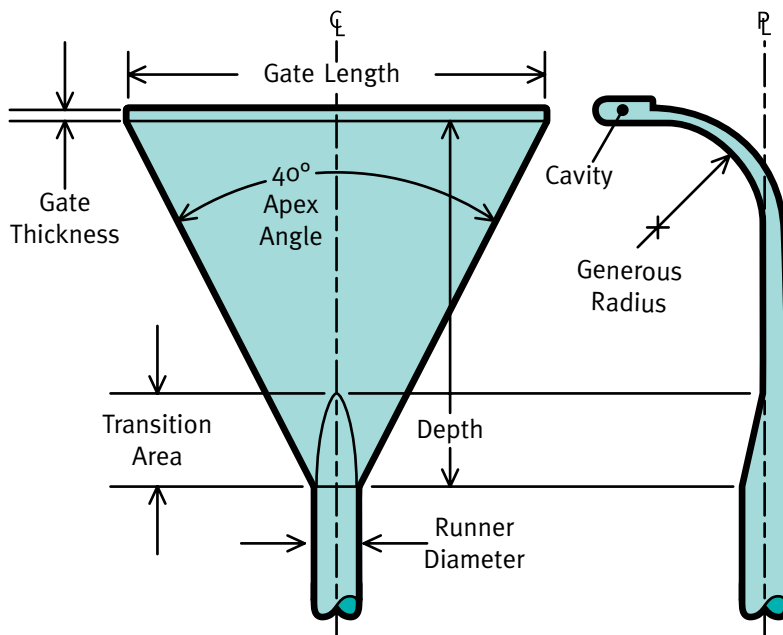


Fan Gates



Quadratic Fan Gate

Gate thickness decreases quadratically from the transition area to the entrance of the cavity



Triangular Fan Gate

Gate thickness decreases linearly from the transition area to the entrance of the cavity

Figure 8-8

Table 8-2

Calculation of Typical Fan Gate Dimensions

O_w = Weight Output, lb/sec
O_w = Part Weight/Shot Time
D = Liquid Density, lb/ft ³
O_v = Volume Output, ft ³ /sec
$O_v = O_w / D$
v = Velocity, 5 ft/sec Foam 25 ft/sec Solid
A_f = Final Fan Area = $[O_v/v] \cdot 144$, in ²
gl = Gate Length (Specify) Typically, gate length depends on the available space along the parting line at the gate location
$gt = A_f / gl$, in
A_o = Initial Fan Area, in ²
$A_o = \pi d^2 / 4$
$t_o = d / 2$
$L_o = A_o / t_o$
A_m = Mid-Fan Area, in ²
$A_m = (A_f + A_o) / 2$
$t_m = (t_o + gt) / 2$
$L_m = A_m / t_m$
$D_A = gl - (2\pi r / 4) + r$

BALL CHECK

In cases where the mixing head is not attached to the mold, use a ball check to prevent the mixture from running out of the mold before gelling (see figure 8-10). Typically, ball checks are suggested when using hand-held mixing heads, also known as “handguns,” for filling multiple molds mounted on a carousel, or when molds are positioned in a half-circle.

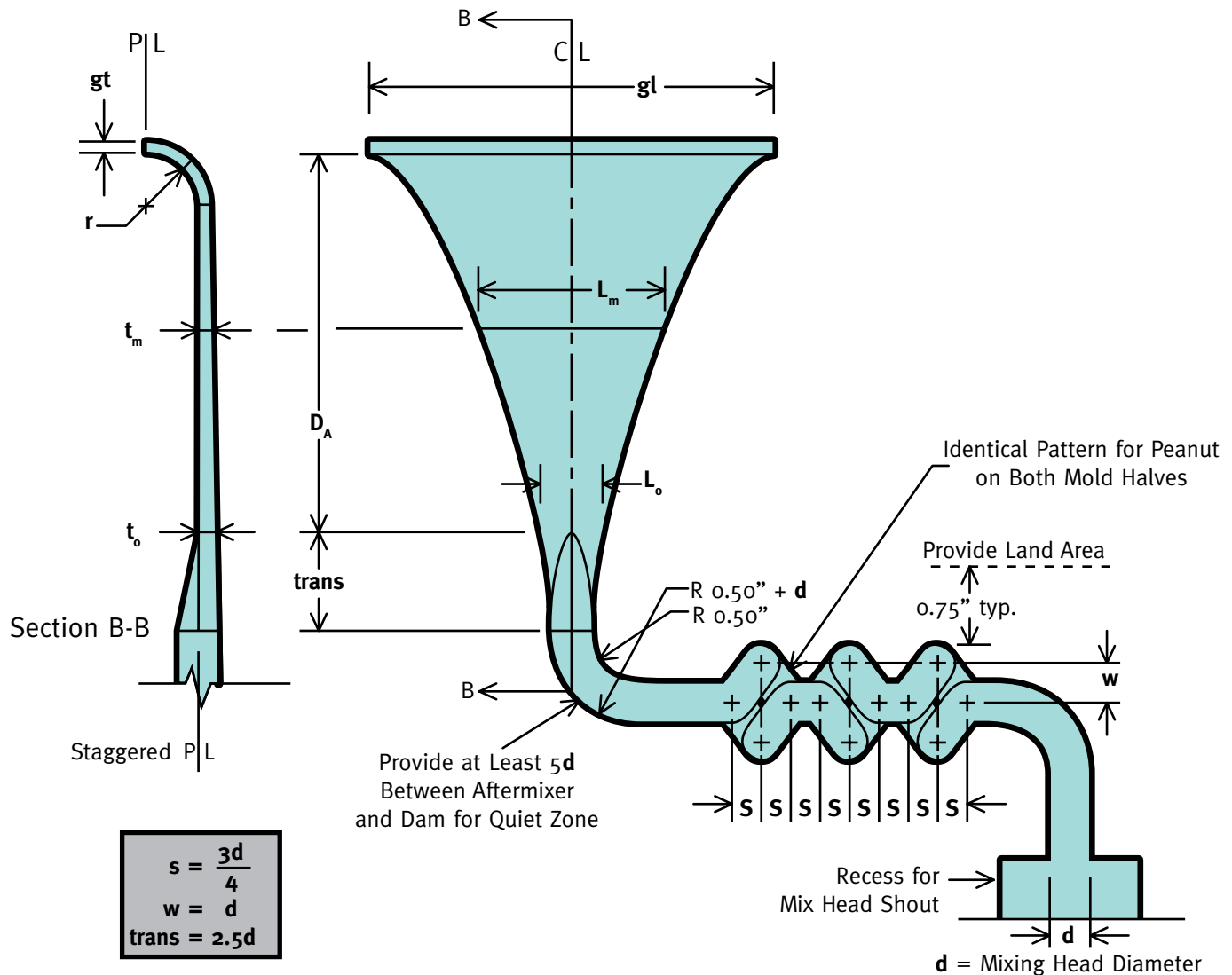
The ball-check design allows flow in one direction only. In this design, a rubber ball can freely move in a channel, with one end of this channel having bypasses to allow the liquid to flow around the ball. When filling from ends, internal pressure pushes the ball to the other end of the widened section where there are no bypasses. The ball then seals the channel, effectively preventing back flow.

CENTER-GATED DIRECT FILL

When designing molds for use with structural RIM materials, always plan on direct fill. Centering the gate prevents the liquid from pushing the glass mat out of position and allows for uniform flow in all directions. In this filling method, the mixing head attaches directly to the mold wall, creating an airtight seal.

Fan Gate Dimensions

Figure 8-9



Ball Check

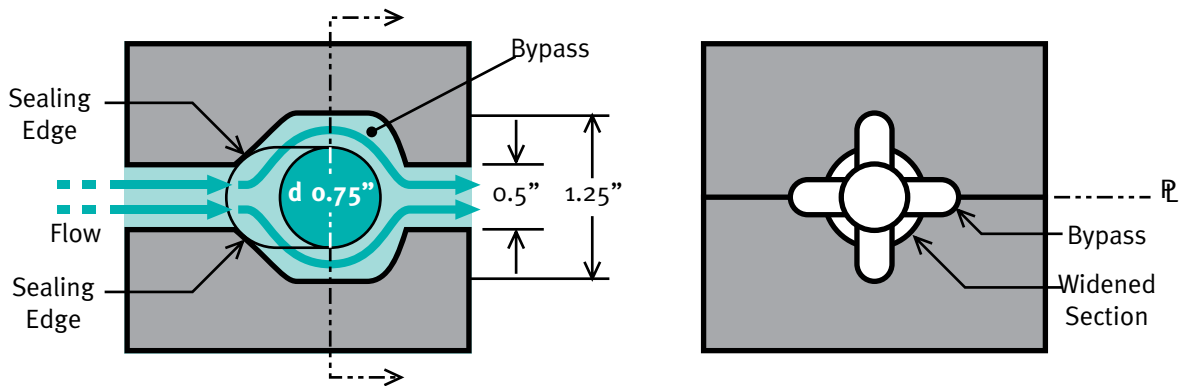
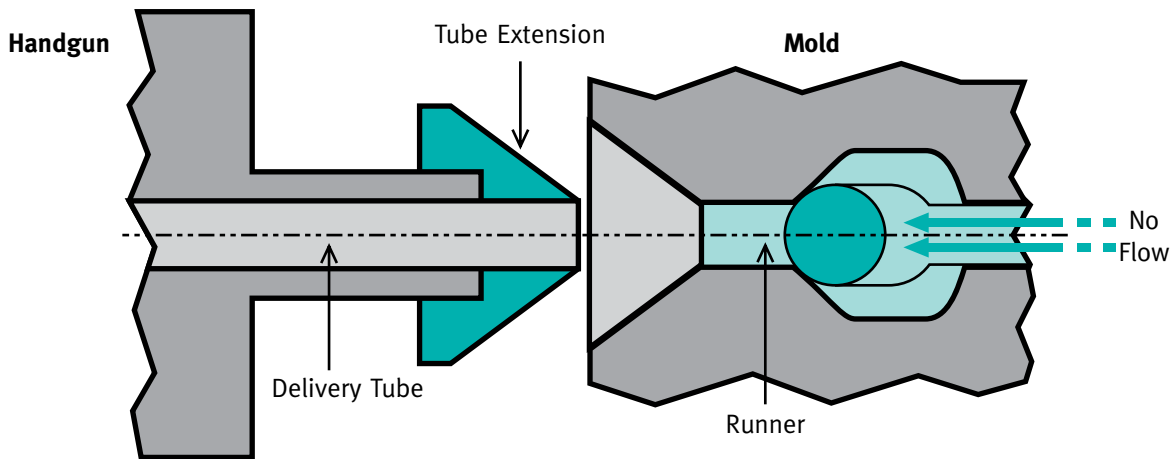


Figure 8-10

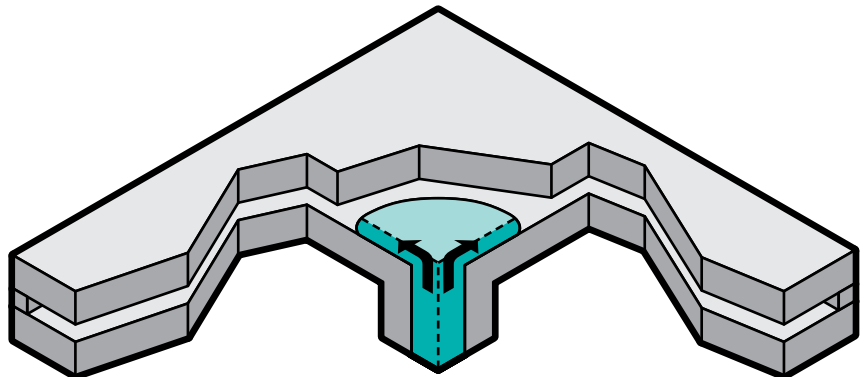
Proper Connection of Mixing Head to Mold



A center gate is particularly important in parts made of structural RIM systems, such as Baydur STR composite, where back pressure is more likely. For this type of system, center-gated direct fill offers the simplest, cheapest and most straightforward type of gating. It minimizes flow lengths and gives more uniform flow inside the cavity (see figure 8-11). Additionally, with a self-cleaning mixing head mounted flush in the cavity wall, gating waste is minimized, if not eliminated. Because the mix head is located in the center of the mold, leaking is also minimized.

Figure 8-11

Direct Fill into the Center of Mold



Direct fill also has disadvantages: it may cause a blemish opposite the entry location in the part because the mixture makes a 90 degree turn over a sharp edge (see figure 8-12). This extremely unfavorable flow could cause bubbles and scarring.

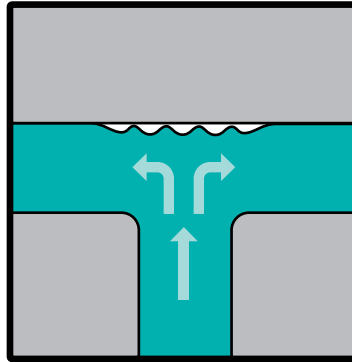
- Research shows that the mixture will be bubble-free only if the wall thickness at the entry point is less than one-eighth of the entrance-area diameter (see figure 8-13).

For example, a 16 mm entrance diameter should not have a wall thickness larger than 2 mm (0.08 in). Because most parts are thicker than this, redesign the wall thickness near the entrance, narrowing it to this value (see figure 8-13).

If the mixing head cannot be flush mounted, use a short sprue. Keep it as short as possible, so that mold release can be sprayed into the sprue cavity.

Figure 8-12

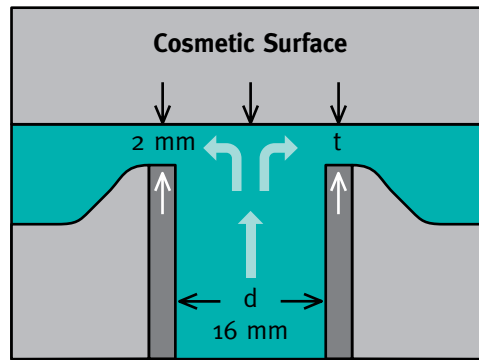
Gate Marks



Caused by Poor Gate Dimensioning

Figure 8-13

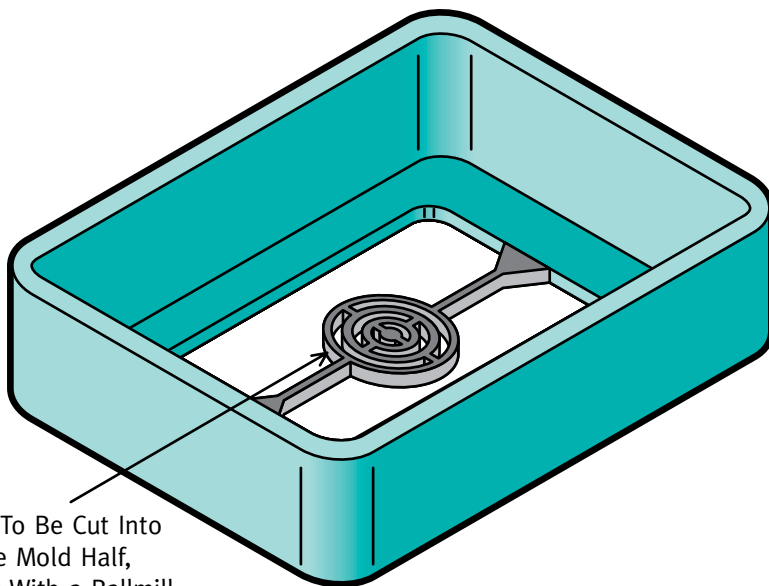
Ratio of Wall Thickness to Mixing-Head Diameter for Direct Fill



d = Mixing-Head Diameter
 t = Wall Thickness
 $t \leq d/8$

Typical Circular Aftermixer

Figure 8-14



Note: To Be Cut Into One Mold Half, Usually With a Ballmill

For noncomposite systems, the center-gate position makes using aftermixers difficult. When the part has cutouts large enough for an aftermixer and edge gate – such as a picture frame – an aftermixer can be used. Use a peanut aftermixer or one made of concentric channels with a staggered “spoke” design to provide a labyrinth. This configuration splits and reimpinges incoming material before it enters the mold cavity (see figure 8-14).

PARTING-LINE CONSIDERATIONS

Many times, part configuration limits parting-line location. However, the position of the parting line directly influences many other mold features, including gate position, mold tilting and venting (see figure 9-1). Preferably, molds should fill from the lowest point to the highest, with the parting line as high as possible to accommodate vents and prevent air entrapment (see figure 9-2). Try to design parts so that a simple two-part mold can be used. If the parting line cannot be located in the highest position in the mold cavity, use a drag plate to create a secondary parting line (see figure 9-3).

Mold makers or BaySystems personnel can help determine venting areas from part drawings or models.

Figure 9-1

Mold in Tilttable Press

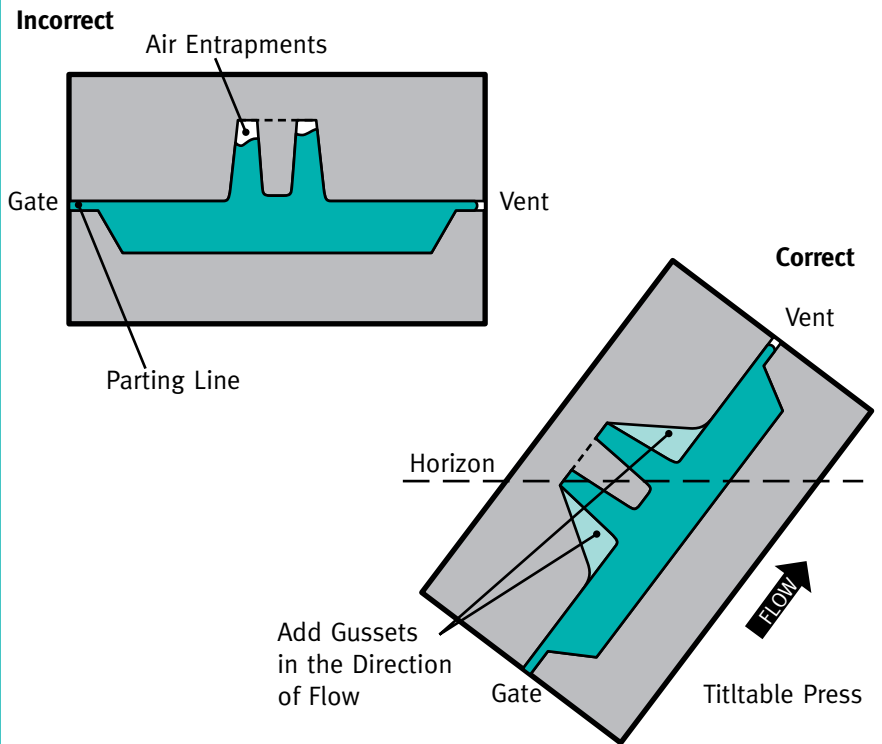
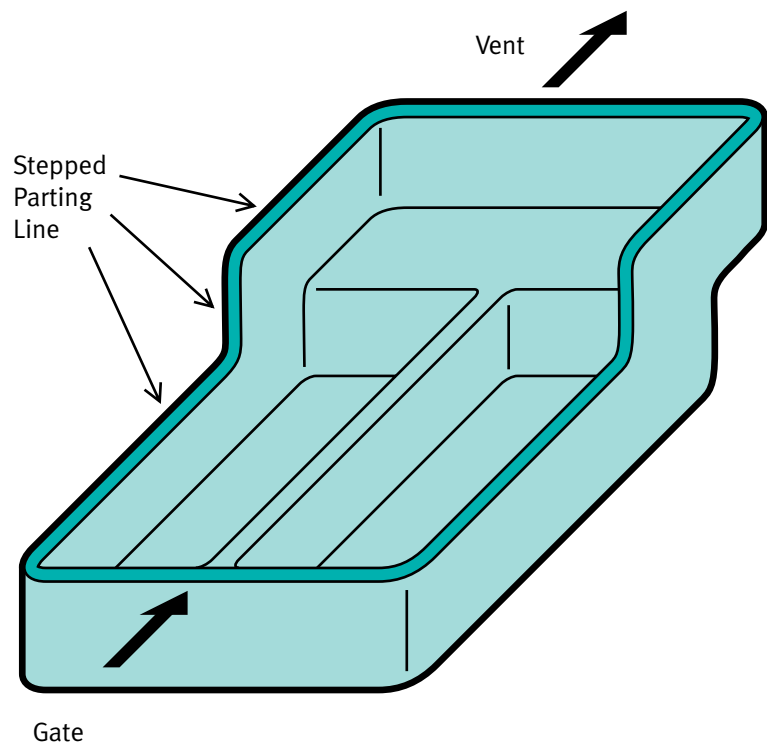


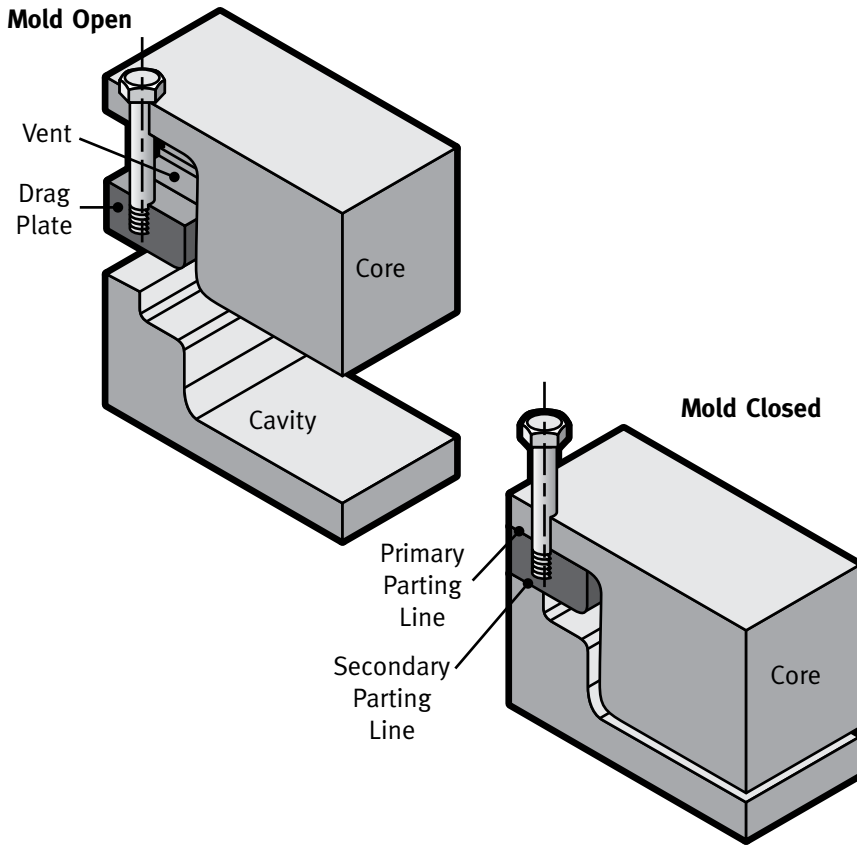
Figure 9-2

Gate Low, Vent High



Secondary Parting Line Via Drag Plate

Figure 9-3



MOLD SEALING

When molding parts made of RIM polyurethane materials, the molds must be adequately sealed to ensure part density and minimize flash (see figure 9-4), the excess material that occasionally forms along the parting line. Sometimes flash is intentionally created in select areas to help fill the mold cavity. In these cases, the mold will have a dump well to collect excess material (see figure 9-5).

- Make sure that flash does not get into the knockout mechanism. Flash can bind the knockout plate, leading to torn, deformed parts.

Mold seals must be “liquid tight.” To achieve this seal, internal mold pressures must not exceed clamping pressures. The sealing edge around the cavity and the runner should be as small as possible to reduce contact area and provide a good seal (see table 9-1).

Mold Sealing- Land Area

Figure 9-4

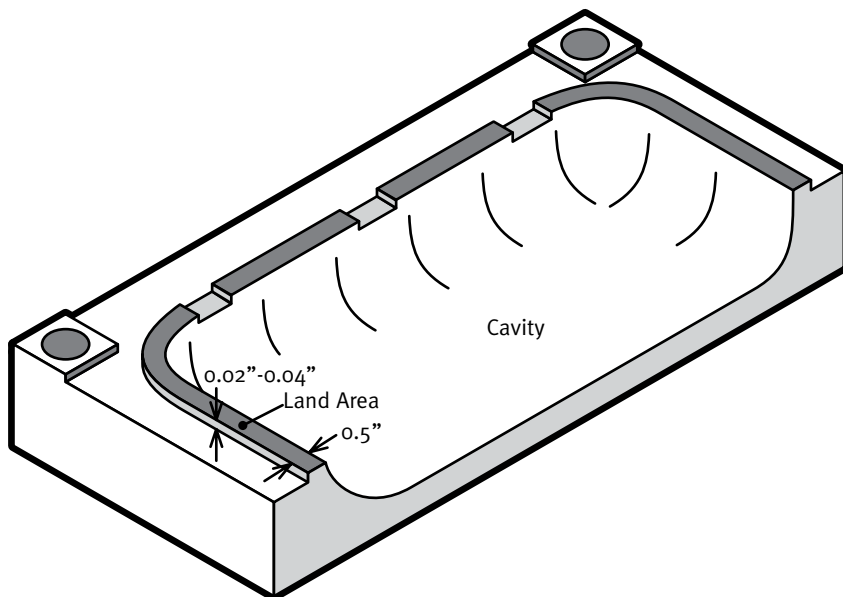


Table 9-1

Approximate Sealing edge Widths

Mold Material	Approximate Sealing Edge Width (Inches)
Steel	1/2
Aluminum	3-4
Kirksite	3-4
Nickel Shell	1-2
Epoxy	1

MOLD VENTING

All molds used with RIM polyurethane systems must have vents to ensure the air in the cavity can escape during the filling processes. New molds should be provided without vents. Vents can be cut into the mold where needed. Initial shots will indicate where the vents are required.

- Make vents wide and shallow; not narrow and deep.
- As a rule of thumb, design mold vents that are 1 inch wide, 0.010 inch deep and 3 to 4 inches apart, edge-to-edge (see figure 9-6).

Design ribs and bosses to allow for air displacement. Consider connecting them to a part wall or placing a tiny, tapered hole in or through the mold wall to help venting (see figure 9-7). If a hole is used, it must be accessible from the mold exterior so that it can be cleaned as needed. If necessary, use vent pins that are part of a knockout mechanism to vent bosses. All protrusions above the parting line must be vented separately.

Figure 9-5

Mold Dump Well

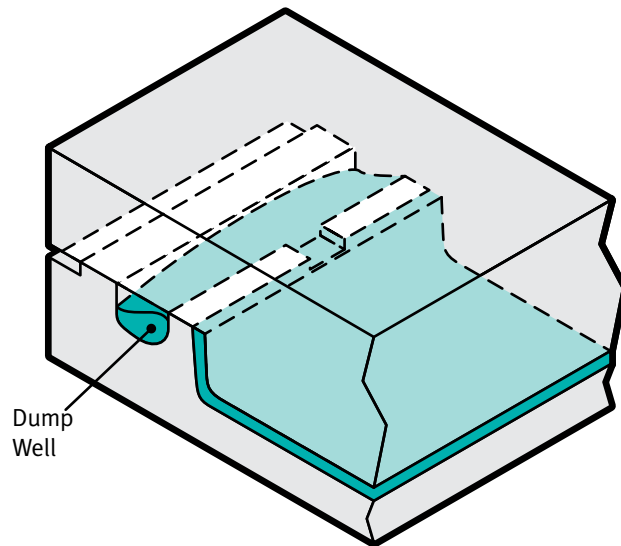
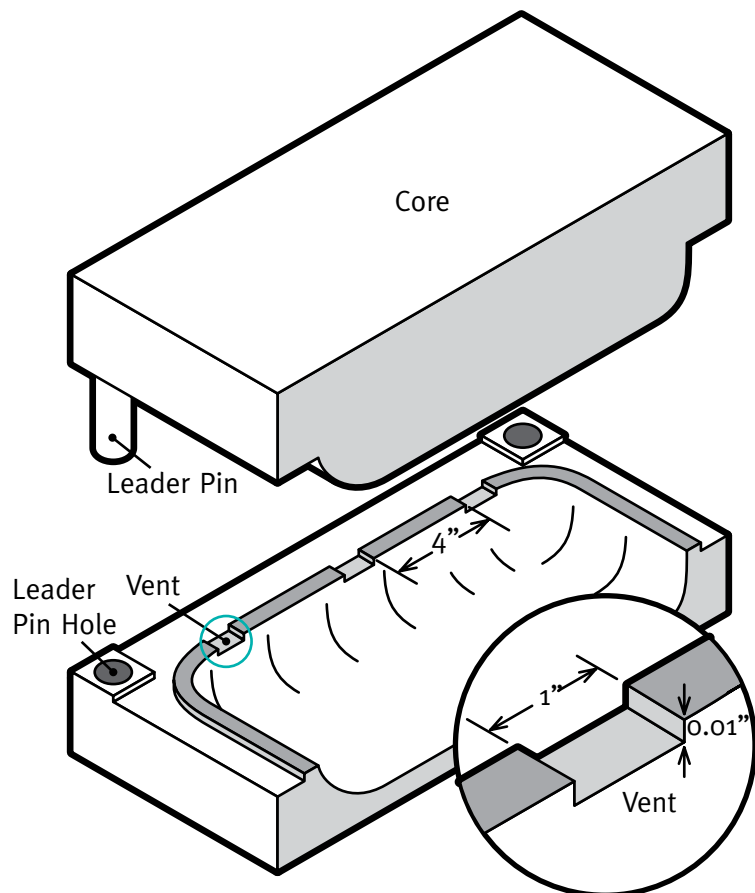


Figure 9-6

Typical Mold Venting



Typical mold venting using 4-inch spacing. Vents on high side of mold.

MOLD FILLING

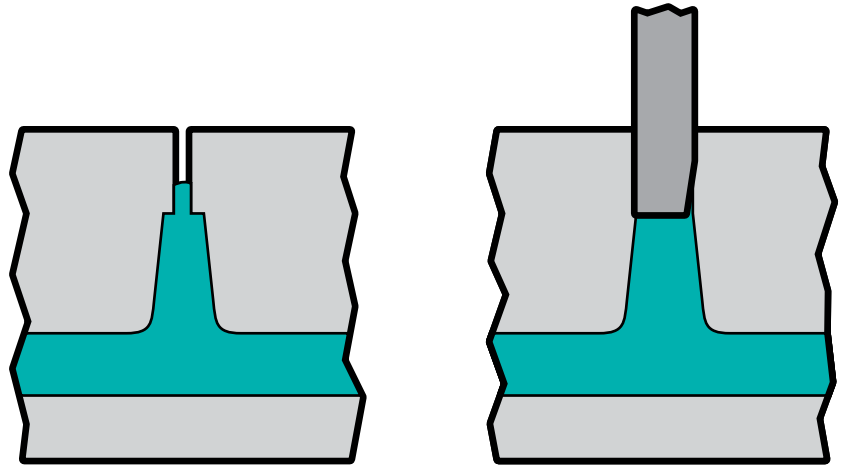
Filling levels vary with systems and specified density. Solid systems fill the mold completely. In contrast, foamed systems usually fill 40 to 80% of the mold cavity, depending upon final part density required.

When planning for proper material flow, consider any obstructions in the mold cavity, such as cores. To reduce the effect of weld or knit lines, liquid polyurethane systems must flow around such obstructions and rejoin. If flow fronts join early in the filling process, weld lines will be unnoticeable and show very little, if any, loss in properties.

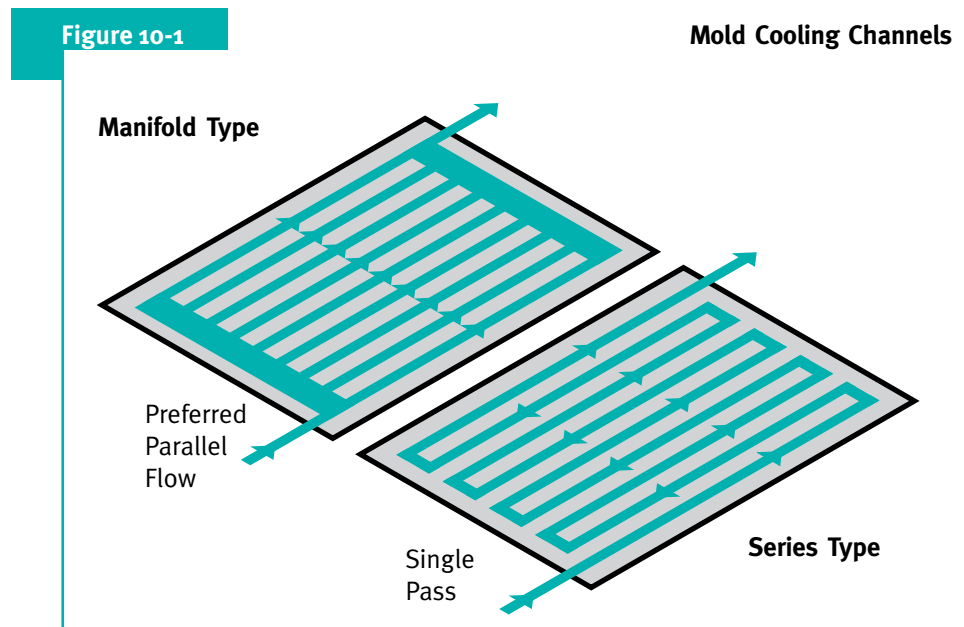
Weld-line formation is particularly important in short-fiber, reinforced materials, because fibers tend to align with flow direction. Where the flow fronts join, fiber crossover and homogeneity will not occur. With faster reaction and gelling times, this problem intensifies. To minimize this condition, consider a different gating position closest to the largest obstruction. Computerized mold-flow analysis can help determine where problems may occur. Contact BaySystems for more information on filling analysis.

Figure 9-7

Vent Solutions for Field Problems Using a Tapered Hole or Knockout Pin



When designing molds, you must account for mold temperature control and cooling line placement. Additionally, this section addresses demolding methods and any special inserts or movable cores in the mold.



MOLD TEMPERATURE CONTROL

Mold cooling directly affects the quality of your finished part. When the “A” and “B” components in a RIM polyurethane system react, they generate heat, as much as 150 BTUs per pound of metered material, depending upon the system used. Mold temperature must be kept at a constant, specified level, usually between 120° and 180°F, again depending upon the system used. To maintain a controlled temperature in the mold, this heat must be conducted through the mold walls, away from the curing part. Cooling channels with circulating water is the typical method for maintaining and controlling mold temperature.

Generally manifold-type cooling lines are preferred. They offer more-even cooling, minimize hot spots, are more efficient and use more water at a lower pumping-head pressure than single-pass systems (see figure 10-1).

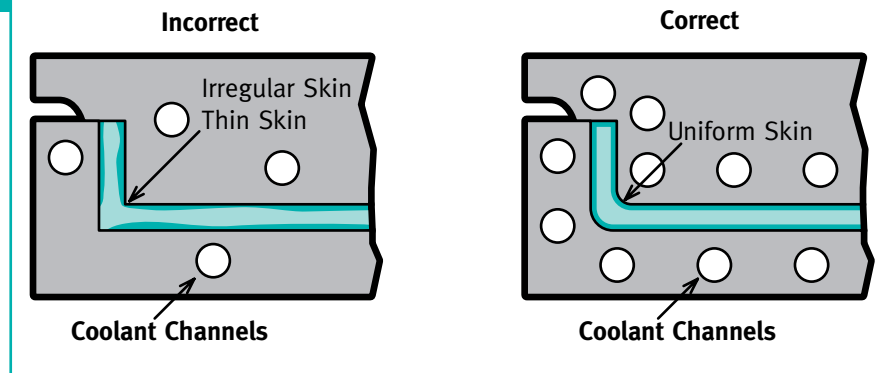
The selected polyurethane system, mold-making material, mold size and mold complexity determine the placement and number of cooling channels. For best results, cooling channels should be located 1-1/2 to 2 channel diameters from the mold surface and a maximum of 2 inches apart (see figure 10-2). Channels typically have a diameter of 3/8 inch. Pipe or tube fittings on cooling lines should have diameters equal to the diameters of the lines to prevent blockages. Remember to incorporate cooling lines adjacent to inside corners, gate blocks and other slow-to-cool areas to produce good parts (see figure 10-3). Proper cooling is especially important when using Baydur structural foams which need adequate cooling to form rugged skins.

DEMOLDING METHODS

To help remove parts, use demolding techniques in strategic locations. The three most-common demolding methods are:

- **Mechanical or Hydraulic Knockouts** – have pins in strategic locations to push out parts (see figure 10-4);
- **Air Assists** – have proven sufficient with simple, flat parts (see figure 10-5);
- **Vacuum Cups** – are applied to parts for manual removal, but are rarely used.

Figure 10-3



The most-common demolding device, **mechanical knockout pins**, are rods that are flush with the wall during molding and protrude when the mold opens

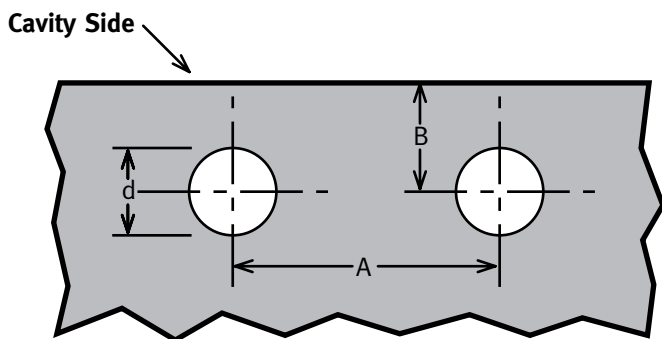
Knockouts should not be actuated until the part has achieved sufficient “green strength” or when the part has solidified enough to maintain its shape and be removed from the mold without knockout marks or tears. The part’s limited compressive strength at the demolding time requires a large contact area for these devices. Whenever possible, have pins actuate against a rib, corner, or boss to distribute their forces over a wider area of the part.

Small-diameter pins can damage parts made of foamed systems during demolding. Use large pins, with a minimum diameter of 3/8 inch. For flat areas, 1/2 inch pins are recommended. In contrast, solid rigid parts, such as those made of PRISM polyurethane, can withstand actuation by 1/8 inch pins, particularly in areas where ribs or walls intersect.

Pins in a knockout plate are usually positioned in the moving half of the mold. Mechanical stops in the press

Typical Cooling Channel Placement

Figure 10-2



	Aluminum Mold	Steel Mold
Diameter Of Channel (d)	3/8 – 1/2 inch	3/8 – 1/2 inch
Maximum Depth (B)	3/4 inches	3/8 – 1/2 inch
Maximum Distance	2 inches	1 – 1/2 inches

actuate the plate when the mold opens (see figure 10-4). The press usually has four stops: large screws that must be adjusted so that all four touch the knockout plate at the same time to ensure uniform knockout action to help prevent part binding.

If knockouts are located in the stationary mold half, hydraulic cylinders move the knockout plate. Alternatively, chain-activated knockout plates can be used. Return pins push the knockout pins back to their flush position when the mold closes.

Unconnected knockout pins can occasionally be used if they are actuated with double-acting hydraulic cylinders. Do not use cylinders with spring returns as they may not retract completely when the mold closes.

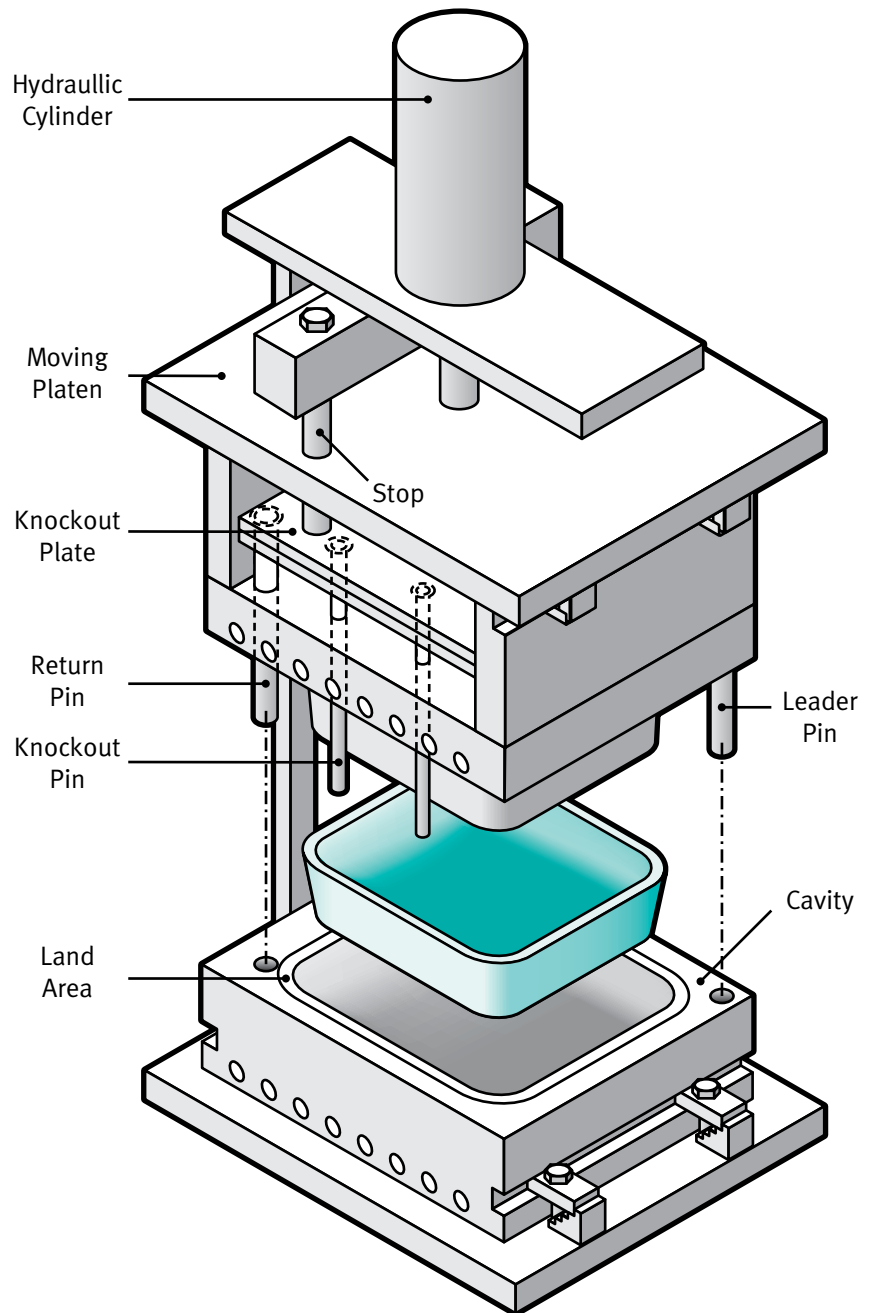
A combination of mechanical knockout pins and **air assists** is another common demolding technique. A vacuum may develop between the core and a part as the knockout pins activate. Compressed air blown into this vacuum releases the part (see figure 10-5). The air valve must seal perfectly and be flush with the mold so that air cannot escape and create bubbles during mold filling.

Vacuum cups can be used to remove parts from core sections. Rules of thumb for using vacuum cups include:

- Distribute large vacuum cups uniformly over the part surface.
- Use a quick motion to remove parts, rather than a long pulling motion with slowly increasing force.

Figure 10-4

Typical Mold Arrangement



MOVABLE CORES AND INSERTS

Use movable cores for parts with undercuts - snap fits, holes, or cutouts - located perpendicular to the direction of draw. Movable cores must be liquid-tight to prevent material flashing into the actuators and locking the slides (see figure 10-6). Consider using O-rings on the pins and actuator shafts to prevent leakage.

Removable inserts are another method for making undercuts (see figure 10-7). Generally molders do not like to use these inserts, as they are labor-intensive, can fall out of position and may damage the mold. Pins aligned in the direction of draw hold inserts in position, allowing the insert to be removed with the part. Discuss any movable cores and inserts with your mold maker during the mold design process.

Figure 10-5

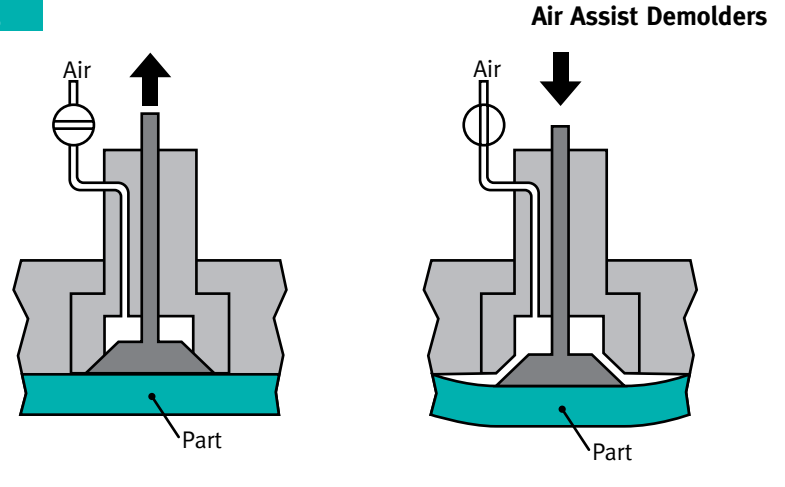


Figure 10-6

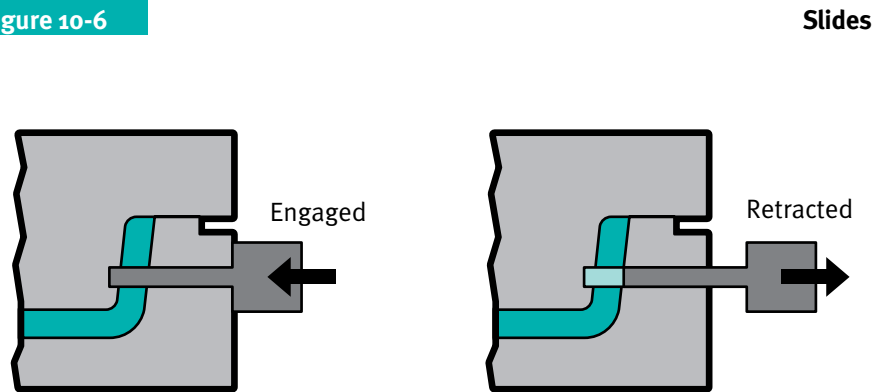
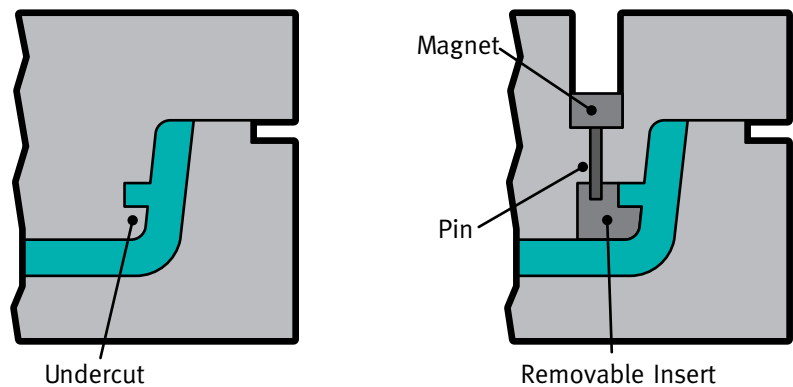


Figure 10-7

Undercut Molded With a Removable Insert



MOLD DESIGN FOR SLOTS

When designing for a part with slots, do not design a mold such that the cores just touch the opposite wall; rather, seat them approximately 1/8 inch into the wall (see figure 10-8). This design practice will facilitate flash removal, because the flash will be perpendicular to the part's surface. If possible, design a mold with a stepped parting line for slots (see figure 10-9).

SHEAR EDGES

Fiberglass mat, used in parts made of Baydur STR composite systems, should fill the entire mold cavity, leaving no empty areas between the mat and mold wall. To meet this requirement, the mat needs to be slightly oversized. The mold will need a renewable-steel

shear edge to cut away any glass-fiber overhang, a pocket to hold this excess and a mold seal external to the shear edge (see figure 10-10). Because glass fibers can erode softer metal molds, we strongly suggest using steel molds for structural RIM.

Recommended Shut-Off for Slots

Figure 10-8

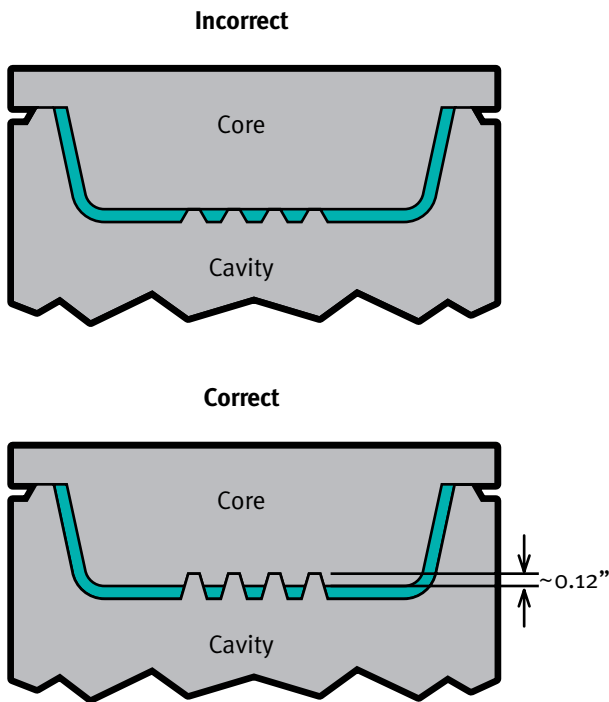


Figure 10-9

Mold for Louvers Without Side Pulls

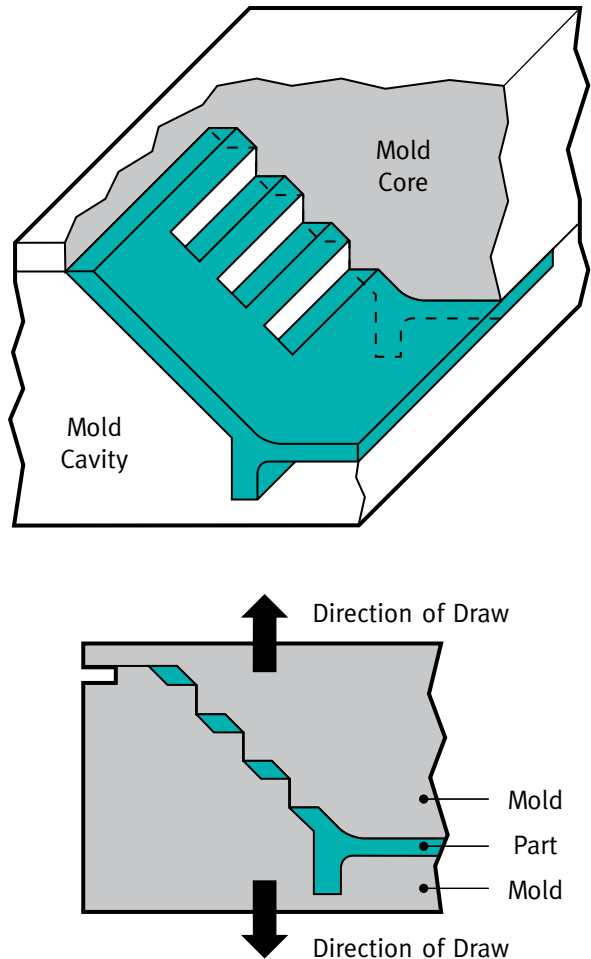
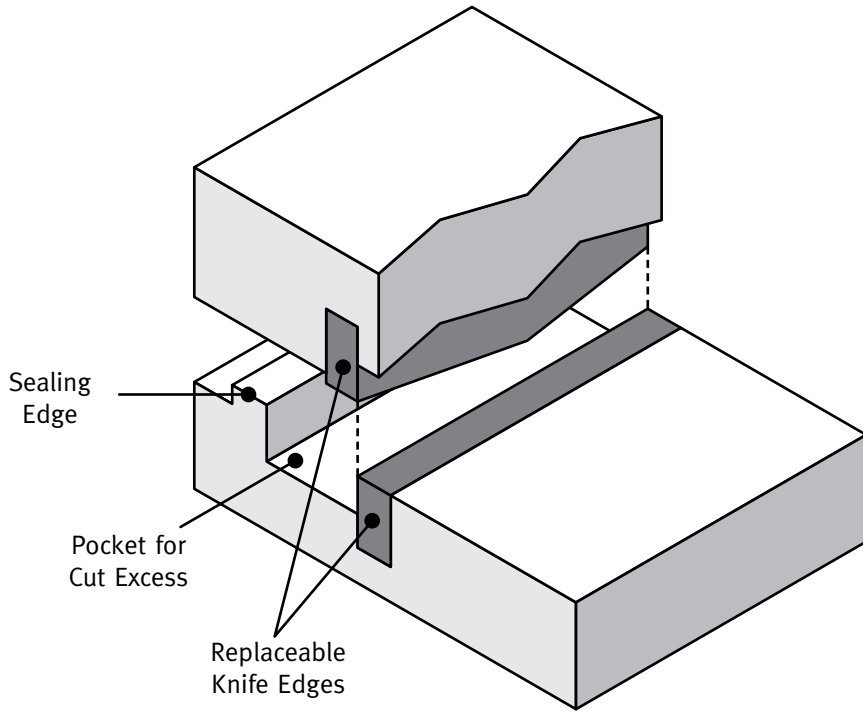


Figure 10-10

Mold Shear Edge



Occasionally, a multiple-cavity or self-contained mold is used for economic or processing considerations. These special molds have unique requirements, which are discussed in this section.

MULTIPLE CAVITY MOLDS

Molds can be designed with multiple cavities to produce several parts simultaneously (see photo). Multiple-cavity molds rarely have more than four cavities, with a two-cavity mold being more common. A special type of multiple-cavity mold - called a “family mold” - produces mating parts of an assembly. Typically, multiple-cavity molds are economical for larger production runs. While the tooling may be more expensive than single-cavity molds, production time and costs can be lower with multiple-cavity molds.

In a typical multiple-cavity mold, the reaction mixture enters the mold through a centrally located edge-gating system. The fill time for all cavities

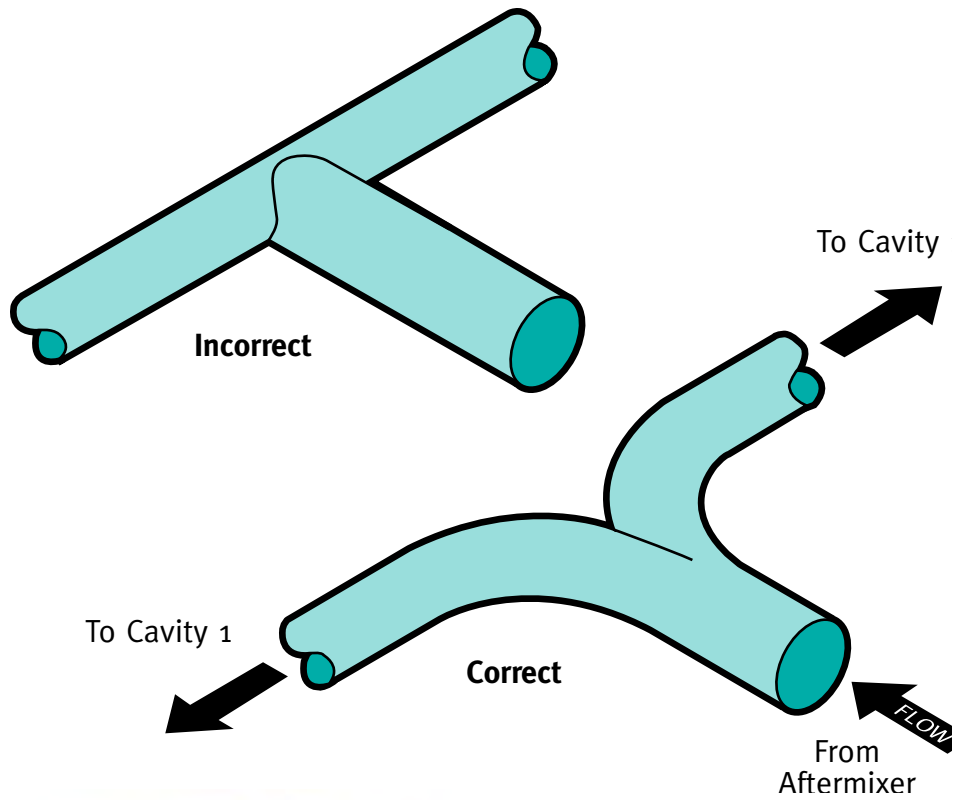
should be identical. Maintain an equal pressure drop through all gates to ensure acceptable parts. Use Y-splits instead of T-splits to help prevent bubbles in your part (see figure 11-1). A multiple-cavity mold having different-sized cavities may be filled through a single mix-head system with balanced runners.

When using foamed systems in a multiple-cavity mold, pay special attention to the mold tilt. You may also have to use adjustable restrictors in the runner branches to control the degree of filling in individual cavities to ensure equivalent filling levels. Contact your BaySystems representative for assistance on your specific application.



SELF-CONTAINED MOLDS

Self-contained molds do not require a press. Typically, these molds are more expensive than the mold in a mold-and-press setup, but generally cost less than a traditional mold and press. They are often used for simply shaped parts requiring low molding pressure. Contact your BaySystems representative for more information on self-contained molds.



When designing a mold, pay special attention to mold-construction materials, mold-surface treatments and any textures or finishes to be applied to the mold. These topics are discussed in this section.

MOLD CONSTRUCTION MATERIALS AND FABRICATION TECHNIQUES

Because RIM polyurethanes generate heat when they react, you should choose a mold material that is conductive, to dissipate heat from the molding part. For this reason, metal molds are strongly suggested. Consider epoxy and spray-metal molds only for prototyping or low-volume production where cycle time and surface quality are of less importance. For high-volume runs, particularly those using reinforcing fillers, steel is usually the mold material of choice. If your mold needs mechanical or hydraulic knockouts, metal molds can accommodate these actuators much better than epoxy ones.

Generally, molds should be able to withstand 200 psi of pressure as a safety measure, even though typical molding pressures do not exceed 100 psi. Any number of materials can be used to make molds, including steel, aluminum, zinc alloys, copper alloys and nickel. Determining which material is the best for your particular mold depends upon several parameters, such as:

- Number of parts to be made
- Surface finish requirements
- Time available for mold construction
- Part tolerances, dimensions and shape
- Single- or multiple-cavity molds
- Mold cycle time and heat conduction
- Quality of parts to be made

MATERIAL SELECTION

Because surface textures will be closely duplicated, nonporous mold surfaces are essential. A smooth mold surface greatly improves part release. Pits, gouges and other surface imperfections in the mold can lead to poor part release and breakage. As rules of thumb:

- The RIM system and production parameters influence the mold-construction material.
- Part geometry influences the mold-construction technique.

Steel

Because of their high degree of production reliability, machined steel molds are especially advantageous for mass-produced parts. They offer long mold life, can be outfitted with elaborate automated ejection systems and are less likely to be scratched or damaged than softer materials. Widely used for automotive parts which require long production runs, steel molds last longer and may be costly. Typically, steel molds are used for parts made of short-fiber-filled materials or composites, as steel resists abrasion.

Aluminum

Offering lighter weight, good heat conductivity and lower machining costs than steel, aluminum has long been the material of choice for mold makers specializing in polyurethane molds. It is softer than steel and may not be suitable for very long runs or for use with composite systems.

Zinc Alloys (Kirksite)

High-quality cast zinc molds offer excellent, nonporous surfaces. They are relatively heavy and require closely spaced cooling lines for accurate temperature control, because they are not as heat conductive as aluminum.

Nickel Shells

For high-quality surface reproductions, consider using nickel shells. These shells have a high surface hardness and offer good release characteristics. Small molds may not need back support for the shell. Mount larger molds in a steel or aluminum support frame and backfill with a casting material for structural rigidity. Cooling lines can be attached or plated onto the backside of the shell prior to mounting.

Epoxy Molds

Used mostly for short-run, prototype parts, epoxy molds have poor temperature control, are fragile and can have surface roughness. They are poor heat conductors, sometimes causing parts to stick. Epoxy should be used only for short runs of prototype parts, when quality is not important and low cost is a primary concern. Foamed parts made in epoxy molds tend to have thin, nonuniform skin. Applying a spray-metal surface to an epoxy mold can eliminate some of these shortcomings.

Before filling an epoxy mold with a polyurethane system, carefully condition the surface with a reactant such as isocyanate. Before using any reactant, please check appropriate literature on proper use, storage and personal safety equipment. This cleaning should remove any amine catalysts in the mold cavities. Waxing all cavity surfaces before the first molding may help the demolding process. If any reactive material remains on the mold surface, you may have difficulty removing your first prototype part.

MOLD CONSTRUCTION TECHNIQUES

As previously mentioned, final part geometry generally influences the mold-construction technique. This section discusses several of the most-common construction methods.

Milled Block

In this construction technique, the mold cavity is machined directly into a metal block. Although it may be more costly, a milled-block mold gives the most accurate representation of the part, does not show lines where the mold parts meet and incorporates cooling lines easily; however, they are more difficult to modify.

Structural Components

Milled metal plates are joined with screws or pins, or welded in this construction technique. Joined plate and bar is the method of choice for large, flat parts.

Cast

Widely used in mold making, cast molds are relatively inexpensive. They make excellent molds and are used particularly for curved parts. Steel molds are not normally cast. Surface porosity, often just under the skin, can cause difficulties when polishing cast aluminum molds. To make a mold casting, a positive pattern with a predetermined parting line is made. This pattern is then cast. Afterwards, the surface is conditioned to remove bubbles and imperfections. Cooling lines can be cast into the mold.

Extruded Aluminum Profiles

Used for both solid and foamed systems, extruded profiles find special application in building inexpensive molds for profile geometries such as window frames or door sashings.

Nickel Plating

Nickel plating can be formed either electrolytically or by electroless deposition. In this latter technique, a 0.04 to 0.08 inch layer of nickel is deposited on a positive pattern, with a 3/8 to 1/2 inch copper backup layer electrolytically deposited onto the nickel. Cooling lines can also be plated onto this backup layer.

SURFACE TREATMENTS FOR MOLDS

Because RIM polyurethane systems reproduce fine surface details, the type of finish on a mold surface is critical. Consider using plastic-industry standards such as the SPI-SPE Mold Finish Comparison Kit, available from the Society of Plastics Industry, as a guideline.

Chrome and nickel plating, excellent surface treatments for molds, improve the mold's scratch resistance and reduce necessary demolding forces.

Chrome plating gives better results. Before plating any mold surface, closely examine it to ensure that it is smooth and nonporous.

Other treatments such as Teflon coating or a nickel-polymer coating are used to improve mold release properties. Surface hardening methods – such as nitride minimize minor damage and the effects of abuse during production operations.

Depending upon your part's surface specifications, consider using the following finishes:

- No. 2 Grit (#15 micron range)
- No. 3 320 Emery Cloth
- No.4 280 Stone

For cosmetic surfaces, consider using a finish between No. 2 and 3; for non-cosmetic surfaces, a finish between 3 and 4 should suffice.

TEXTURES AND FINISHES

Lettering, textures and graphics can be molded into a part. Typically these visual elements are milled into the mold resulting in a raised appearance on the finished part. For large areas of fine text, consider using decals.

Textures enlarge the effective surface area, requiring increased demolding forces. Surfaces parallel to the direction of draw have lower limits on texture depth.

Nickel shells offer high surface hardness and good release characteristics for high-quality surface reproductions of textures, such as leather or wood grain.

Photo-etching and mechanical texturing offer a wide variety of finishes. In photo-etching, chemicals etch mold surfaces in a given pattern. Some mold makers have examples with different textures to help you select one. In mechanical texturing, small metal balls are placed in the mold, which is then shaken, to achieve a pebble finish.

Before applying any texture to a mold surface, ensure that the mold is to final dimensions, because these dimensions cannot be changed after texturizing. Textures in molds must be very accurate, as the parts cannot be retouched after molding. These molds are very sensitive to nicks and scratches, requiring special care during demolding.

HEALTH AND SAFETY INFORMATION

Appropriate literature has been assembled which provides information concerning the health and safety precautions that must be observed when handling BaySystems thermosetting resins mentioned in this publication. Before working with any of these products, you must read and become familiar with the available information on their hazards, proper use and handling. This cannot be overemphasized. Information is available in several forms, e.g., material safety data sheets and product labels. Consult your local BaySystems representative or contact the Product Safety Manager in Pittsburgh, PA.

DESIGN AND ENGINEERING EXPERTISE

To get material selection and/or design assistance, just write or call your BaySystems representative in the regional offices listed on the back cover of this brochure. To best help you, we will need to know the following information:

- Physical description of your part(s) and engineering drawings, if possible
- Current material being used
- Service requirements, such as mechanical stress and/or strain, peak and continual service temperature, types and concentrations of chemicals to which the part(s) may be exposed, stiffness required to support the part itself or another item, impact resistance and assembly techniques
- Applicable government or regulatory agency test standards
- Tolerances that must be held in the functioning environment of the part(s)
- Any other restrictive factors or pertinent information of which we should be aware

Upon request, BaySystems will furnish such technical advice or assistance it deems to be appropriate in reference to your use of our products. It is expressly understood and agreed that because all such technical advice or assistance is rendered without compensation and is based upon information believed to be reliable, the customer assumes and hereby releases BaySystems from all liability and obligation for any advice or assistance given or results obtained. Moreover, it is your responsibility to conduct end-use testing and to otherwise determine to your own satisfaction whether BaySystems's products and information are suitable for your intended uses and applications.

TECHNICAL SUPPORT

We provide our customers with design and engineering information in several ways: Applications and processing advice, available by phone, at 412 777-2000; processing assistance, through a nationwide network or regional field technical service representative (see list on back cover); technical product literature; and periodic presentations and seminars. The types of expertise you can obtain from BaySystems include those listed in this section.

Design Review Assistance

- Concept development
- Product/part review
- Mold design review
- Part failure analysis
- Finite element stress analysis
- Mold filling analysis
- Experimental stress analysis
- Shrinkage and warpage analysis

Application Development Assistance

- Product development
- Part cost estimates
- Color matching
- Prototyping
- Material selection
- Molding trials
- Physical testing
- Secondary operation advice

Product Support Assistance

- On-site processing audits
- Start-up assistance
- On-time material delivery
- Troubleshooting
- Processing/SPCS eminars
- Productivity audits

REGULATORY COMPLIANCE

Some of the end uses of the products described in this publication must comply with applicable regulations, such as the FDA, USDA, NSF and CPSC. If you have any questions on the regulatory status of these products, contact your local BaySystems representative or the Regulatory Affairs Manager in Pittsburgh, PA.

RIM PLASTICS RECYCLING

Polyurethanes are now being recycled. Recycled polyurethanes have practical uses, like housings for electronic equipment and exterior body parts for transportation vehicles.

- **Regrinding**– This technology allows for a “second life” for many types of polyurethane parts such as business machines and bumpers, which are then ground into a granulate or powder for use as a filler.
- **Adhesive Pressing**– Polyurethane granulate is surface treated with a binder, then cured under heat and pressure. The resulting materials can be reinforced and molded.
- **Compression Molding**– This technique allows for 100% reuse of RIM polyurethane elastomers in which no virgin material needs to be added. Can retain up to 50% of tensile properties.

- **Energy Recovery**– Technology exists to pyrolyze polyurethane polymers cleanly and the combustion products can meet EPA standards. One pound of RIM polyurethane contains between 12,000 and 15,000 BTUs, about the same energy potential as oil or coal.
- **Injection Molding**– This process is suitable for composite components, such as instrument panels that contain a thermoplastic support, foam and decorative skin. The entire module can be ground and injection molded.
- **Glycolysis**– This is a chemical recycling process in which the polymer is broken down into a mixture of liquid polyols. Many different kinds of polyurethane parts can be used.

Polyurethanes. They do a world of good when you use them. And when you reuse them.

FOR MORE INFORMATION

The data presented in this brochure are for general information only. They are approximate values and do not necessarily represent the performance of any of our materials in your specific application. For more detailed information, contact MaterialScience Marketing Communications at 412 777-2000, or your nearest district office.

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