
SAFOAM[®] USER'S GUIDE

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INTRODUCTION

SAFOAM[®] is produced from naturally occurring materials that are microencapsulated using sophisticated proprietary technology. Produced under food ingredient conditions with the highest levels of quality control, **SAFOAM**[®] is inherently safe to use and all components are *Generally Recognized As Safe (GRAS)* as prior sanctioned by the Federal Food and Drug Administration.

SAFOAM[®] is environmentally friendly. It has no photochemical reactivity or stratospheric ozone depletion potential. It leaves no residue and is free of the environmental concerns commonly associated with existing nucleating agents. **SAFOAM**[®] does not contain any transition metal salts as activators and does not generate cyanuric acid or ammonia, which are toxic and contribute to degradation of mold surfaces and extrusion equipment.

Reedy International Corp., in partnership with Genpak Corporation, has completed development of an advanced foam production process that meets current and future global emission requirements without major equipment changes or compromises in product quality, density or production rates.

This new technology is designed to replace chlorofluorocarbons (CFC's) and hydrochlorofluorocarbons (HCFC's) in the production of polystyrene foam food products. The system negates serious disadvantages of existing processes due to its ability to achieve very efficient production rates while improving the physical properties of the foamed materials.

Reedy International and Genpak Corporation have recently been awarded patents for producing foam sheets using **SAFOAM**[®] concentrates and a combination of atmospheric and organic gases as blowing agents. *Reedy International* currently holds six additional patents for using direct gas in a low-density polystyrene foam using CO₂, N₂, and/or any other gas.

SAFOAM[®] - ITS USE IN THERMOPLASTICS

SAFOAM[®] is an endothermic chemical foaming agent (CFA) used in thermoplastics with a wide variety of applications. Processors use it to produce foamed moldings or extrusions, or to eliminate other processing problems, such as sink marks, warpage or molded in stresses. Its use in structural plastics provides several advantages, including:

- Weight reduction
- Increased part rigidity
- Stress and sink mark elimination
- Cost savings
- Enhanced acoustical and insulation properties
- Warpage elimination

Plastic processing is a constantly evolving industry and new techniques and equipment are introduced regularly. Despite the wide variety of equipment and processes, they can be classified under two main groupings:

- Molding
- Extrusion

This User's Guide reviews physical and chemical foaming agents as well as the basic injection molding and extrusion processes. A glossary of terms and a list of common acronyms appear in the Appendix. **SAFOAM[®]** selection and use information can be found on the insides of the covers.

This **SAFOAM[®]** User's Guide is intended as a service to our customers. The information contained in this guide is based on our experience with **SAFOAM[®]** and the foaming processes that are discussed. We strongly recommend that **SAFOAM[®]** be thoroughly evaluated in your process equipment and application. We do not guarantee favorable results, and we assume no liability in connection with the use of **SAFOAM[®]**. This information is not intended as a license to operate under, or a recommendation to infringe any patent of *Reedy International Corporation* or others.

STRUCTURAL PLASTICS AND POLYMER SELECTION

The term “structural foam” is generally used to describe a plastic product having integral skins, a cellular core, and a high enough strength-to-weight ratio to be used in load-bearing applications. There are many systems used in the production of structural foam, with as many equipment manufacturers preparing machines to make the products. There are a wide variety of thermoset and thermoplastic resins used in structural foam, with many types of physical and chemical foaming agents being used to produce the cellular structure.

The real value of foam is the increase in strength-to-weight ratio and the reduction of sink marks in areas opposite thick sections. The structural integrity of a properly foamed part is greatly enhanced due to the reduction of stresses and a general increase in stiffness. Parts produced by the structural foam process are three to four times as rigid as injection moldings of the same weight. The density of a foamed part is generally 60-90% of the polymer or foaming agent.

Foamed plastic can be thermoset, thermoplastic or thermoplastic elastomer resins. Thermosets are generally foamed as a result of the vaporization of a foaming agent, caused by the exotherm in the thermosetting reaction. Foamed thermoplastics are typically produced by the addition of an inert gas or chemical foaming agent to a thermoplastic resin. The most significant quantities of foamed plastics are being produced in thermoplastics. More recently the term “structural plastics” has been adopted to describe polymers foamed by a variety of emerging technologies.

PROPERTIES OF AMORPHOUS POLYMERS

Amorphous polymers are those that are devoid of crystallinity or stratification. They do not have melting points but rather softening ranges. They are normally transparent, and undergo only small volume changes when solidifying from the melt, or when the solid softens and becomes fluid. Most plastics are amorphous at processing temperatures, with many retaining this state under all normal conditions. Common examples of amorphous thermoplastics include polycarbonate, acrylonitrile-butadiene-styrene (ABS) and polystyrene, and are very easy to foam using **SAFOAM**[®].

PROPERTIES OF CRYSTALLINE POLYMERS

Crystalline polymers contain solid crystals with a definite geometric form. Such structures are characterized by uniformity and compactness. Unlike amorphous polymers, crystalline polymers have considerable order to their molecules in a solid state. This indicates that many of the other atoms are regularly spaced, have a true melting point with a latent heat of fusion associated with the melting and freezing process, and have a relatively large volume change during the transition from melt to solid. It is these characteristics that cause a lack of melt tension and/or melt strength, which may make crystalline polymers more difficult to foam. Common examples of crystalline thermoplastics include polyethylene, polypropylene, nylon, and acetal.

PROPERTIES OF THERMOPLASTIC ELASTOMERS

Thermoplastic elastomers (TPE) represent a family of polymers that resemble elastomers in that they can be repeatedly stretched without distortion of the unstressed part shape. They are, however, true thermoplastics and as such do not require curing or vulcanization as do rubber-like elastomers. It is possible to foam TPEs if they are specifically designed for melt tension and strength.

The desirable performance properties of thermoplastic elastomers are derived from their chemistry and morphology. Thermoset rubber articles commonly contain a reinforcing agent such as carbon black. In TPEs, the polymer system itself provides this reinforcement, commonly due to two or more intermingled polymer systems, each with its own phase.

Chemical composition and morphology provide a rational, convenient means of categorizing the existing commercial thermoplastic elastomers. There are presently six generic categories of commercial TPEs:

- 1) Styrenic block copolymers
- 2) Rubber-polyolefin blends
- 3) Elastomeric alloys
 - a) Thermoplastic vulcanizates (TPVs)
 - b) Melt processible rubbers (MPRs)
- 4) Thermoplastic polyurethanes
- 5) Thermoplastic copolyesters
- 6) Thermoplastic polyamides (nylons)

STRUCTURAL PLASTICS AND POLYMER SELECTION

To compare the different classes of TPEs, locate them on the two-dimensional plot below, with the horizontal axis representing performance and the vertical axis representing cost. The cost and performance of the generic categories of TPEs increase as one proceeds in the order of styrenics, polyolefin blends, elastomeric alloys, polyurethanes, copolyesters, and polyamides. As a basis for comparison, Table 2 gives a plot of the different generic classes of thermoset rubbers. The thermoset rubbers also increase in both cost and performance as one proceeds from the lower left to the upper right portion of the plot. In comparing thermoplastic rubbers with the corresponding thermoset rubbers, it is important to remember the processing costs of the TPEs are significantly lower than those of the thermosets.

Thermoplastic Elastomers.

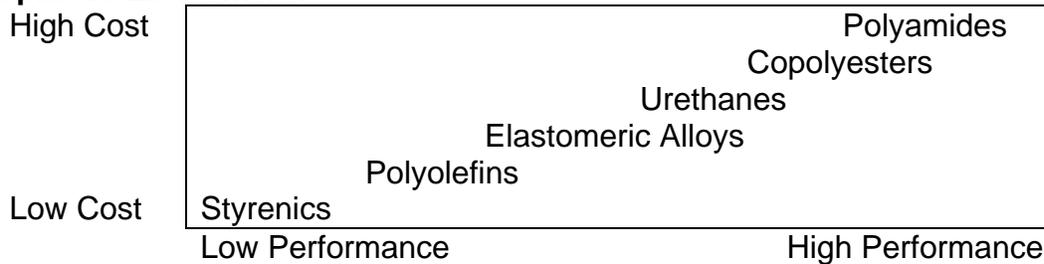


Table 1.

Thermoset Rubbers.

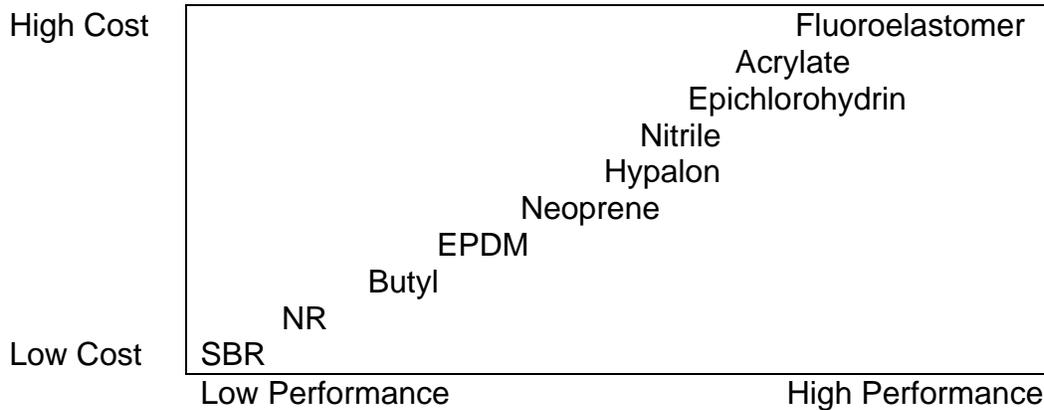


Table 2.

FOAMING AGENT SELECTION

Any substance capable of producing a cellular structure in a plastic or rubber mass, be it alone or in combination with other substances, is defined as a *foaming agent*. Thus, the term includes compressed gases that expand when pressure is released, soluble solids that leave pores when leached out, liquids that develop cells when they change to gases, and chemical agents that decompose or react under the influence of heat to form a gas. Liquid foaming agents include certain aliphatic and halogenated hydrocarbons, low boiling alcohols, ethers, ketones, and aromatic hydrocarbons. The chemical foaming agents range from simple salts such as ammonium or sodium bicarbonate to complex nitrogen releasing agents, of which azodicarbonamide is an important example. Foaming agents, also known as chemical blowing agents (CBAs), can be utilized in all conventional plastic processes including extrusion, calendaring, injection and compression molding, coating, expansion casting, and rotational molding. Regardless of type, a foaming agent should possess the following desirable qualities:

1. Long term storage stability under normal conditions.
2. Gas release over a controlled time and temperature range.
3. Low toxicity, odor, and color of both the foaming agent and its decomposition products.
4. No deleterious effects on the stability and processing characteristics of the polymer.
5. The ability to form cells of uniform size.
6. The ability to produce a stable foam, that is, the gas must not be lost from the cell, which causes collapse.
7. Good cost-performance relation and availability.

The quantity of gas contained in a foaming agent is not nearly as important as the rate at which that gas is released. Azodicarbonamides contain large volumes of gas, but are well known to give rise to foamed parts with voids and poor surface finish. **SAFOAM**[®] endothermic foaming agents contain less gas volume, but release that gas in a much more controlled fashion, giving rise to more uniform cell structures. **SAFOAM**[®] produces CO₂, which is a low-pressure, very soluble gas. Solubility improves the melt flow of most polymers and may lower processing temperatures. These foamed plastics have higher performance characteristics than those generated with other commonly available foaming agents.

Foaming agents are classified as physical or chemical. Chemical foaming agents (generally solids) undergo a chemical reaction when producing the gas, while liquid physical foaming agents undergo a reversible change of physical state: vaporization.

PHYSICAL FOAMING AGENTS

The two major categories of physical foaming agents are liquids and gases. The gas most often used is compressed nitrogen. In injection molding, the gas is injected under high pressure directly into the polymer during plastication, and the mixed polymer and gas are metered into the mold. When the pressure is relieved, the gas becomes less soluble in the polymer and expands, forming the cellular structure. Nucleating agents like **SAFOAM**[®], in the form of finely divided powders and chemical foaming agents, sometimes are used with the gas to yield a finer cell structure. The nitrogen is inert, nonflammable, leaves no residue in the polymer, and is not temperature restrictive; however, the use of the process in industry is limited. The specialized equipment that is needed is licensed, and there is a tendency for the process to produce foams with coarser cell structure and poorer surface appearance than those of polymer processes with nitrogen-producing chemical foaming agents.

Liquid physical foaming agents produce gas through vaporization. They are generally short-chain aliphatic hydrocarbons (in the C5 to C7 range) and their chlorinated and fluorinated analogs. Others used less frequently include cycloaliphatic and aromatic hydrocarbons, alcohols, ketones, and aldehydes. The liquid physical foaming agents are used over a wide temperature range in low pressure atmospheric processes. They are widely used to produce low density thermoplastics such as foamed polystyrene, and thermoset polymers such as polyester, epoxy, and polyurethane foam systems.

CHEMICAL FOAMING AGENTS

Chemical foaming agents produce gas by a chemical reaction, such as a thermal decomposition or a reaction between two or more components. They are selected for a specific application or process based on their decomposition or gas generation temperature. It is important to match the decomposition temperature with the processing temperature of the polymer to be foamed. If the polymer processes at temperatures below that of the chemical foaming agent, little or no foaming will occur. Additionally, if the process temperature is significantly above the foaming agent's decomposition or reaction temperature, poor (overblown, ruptured) cell structure and surface skin quality problems will likely result.

Chemical foaming agents may be either organic or inorganic chemicals. The thermodynamics of gas formation with chemical foaming agents are classified as either *exothermic* (heat releasing) or *endothermic* (heat absorbing). The most well known organic, exothermic chemical foaming agent is azodicarbonamide. The most common inorganic, endothermic foaming agent is sodium bicarbonate.

EXOTHERMIC CHEMICAL FOAMING AGENTS

Azodicarbonamide

One of the most widely used exothermic chemical foaming agents is azodicarbonamide. This chemical foaming agent is a yellow powder that decomposes at 383-421°F (195-216°C), depending on the method of preparation. It evolves 220 cc/gram of gas after decomposition. The decomposition rate of azodicarbonamide can be adjusted by activators, and a wide range of lower decomposition temperatures can be attained. This range of useful temperatures and high gas efficiency are the primary advantages of this type of chemical foaming agent. Suitable activators include transition metal salts, (especially those of lead, cadmium and zinc), polyols, urea, alcohol amines, and some organic acids. Unlike many other organic foaming agents, azodicarbonamide does not support combustion.

The thermal decomposition of azodicarbonamide is complex, giving rise to a variety of reaction products. The decomposition of azodicarbonamide at 374°F (190°C) produces gaseous products consisting of nitrogen (65%), carbon monoxide (31.5%), and carbon dioxide (3.5%). Ammonia has also been detected in some cases.

Exothermic chemical foaming agents are generally used for the following results:

- maximize total density reduction
- generate foam in high viscosity resins
- increase mold filling capability
- decompose at higher temperatures

Azodicarbonamides are capable of generating large quantities of gas at high foaming pressures. The exothermic reaction of this family of chemical foaming agents is hard to control in most foaming applications. This leads to coarser cell structures, voids, and poorer surface quality for the processed parts. The thermal decomposition of azodicarbonamide compounds is well known to generate cyanuric acid and isocyanurate, which contribute to plate out on mold surfaces and extrusion equipment.

FOAMING AGENT SELECTION

Exothermic azodicarbonamide chemical foaming agents should be used only when an endothermic chemical foaming agent is judged as unsuitable for your application.

A Differential Scanning Calorimetry curve for a common exothermic azodicarbonamide chemical foaming agent can be found in Figure 1.

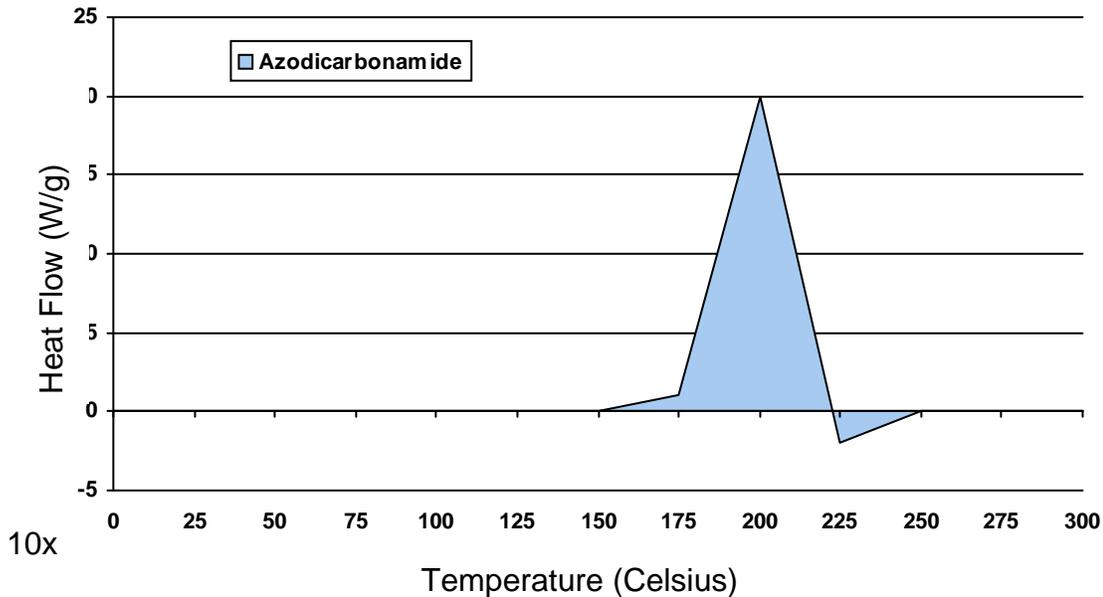


Figure 1. Differential Scanning Calorimetry curve for a common azodicarbonamide chemical foaming agent showing exothermic behavior.

ENDOTHERMIC CHEMICAL FOAMING AGENTS

Sodium Borohydride

Chemical foaming agents based on sodium borohydride produce gas as a result of a chemical reaction rather than thermal decomposition. Sodium borohydride foaming agents produce copious amounts of hydrogen gas upon reaction with water or when activated by a proton source. The decomposition of sodium borohydride is independent of processing temperatures.

Several products based on sodium borohydride exist in polyethylene and polystyrene carriers. Some grades are activated by special chemical additives. The sodium borohydride concentrates are typically 5-10% active. The sodium borohydride foaming agents are stable to moisture once compounded in the concentrate form.

Because the reaction decomposition product of sodium borohydride foaming agents is hydrogen gas, extreme care must be taken not to exceed the lower explosion limit of 4% volume of hydrogen in the air.

Traditional Acid/Carbonate Systems

The most well known endothermic chemical foaming agents are from the acid/carbonate family. These foaming agents take advantage of the chemical reactivity of inorganic carbonates with acidic species to evolve carbon dioxide gas. The most widely used acid/carbonate systems are based on sodium bicarbonate and citric acid derivatives.

The common acid/bicarbonate products are available as 100% powders or as concentrates in universal waxy-type carriers. The concentrate products are available in up to 70% active concentrates. The gas evolution of these acid/carbonate products depends on the level of their activity and in which form the product is used. The typical 100% active powder product produces about 100 cc/gram of carbon dioxide gas.

The acid/carbonate systems are typically safe for use in food contact applications. All components are Generally Recognized As Safe (GRAS). The carbon dioxide gas is non-flammable and poses no threat for explosion. It readily diffuses from the foamed products, allowing for shorter painting cycles. The universal waxy-type carriers have been known to cause screw slippage in certain applications. Poor dispersion is a common concern for the high percentage concentrates in many traditional material handling systems. Poor dispersion lends itself to variations in the foaming process, creating voids and thin skins that lead to mechanical failure in the final foamed products.

SAFOAM[®] ENDOTHERMIC CHEMICAL FOAMING AGENTS

A recent addition to the array of endothermic chemical foaming agents is the **SAFOAM[®]** family of products. The chemistry of **SAFOAM[®]** most closely resembles the traditional acid/carbonate systems, but is based on a buffered salt reaction chemistry. **SAFOAM[®]** products are not solely based on simple sodium bicarbonate, but take advantage of the controlled reaction of synthetic inorganic carbonate compounds with acidic species to generate carbon dioxide gas. Although the volume of evolved gas for **SAFOAM[®]** is somewhat lower than other acid/carbonate systems, the kinetics of gas release insures its superior performance.

SAFOAM[®] products are available as 100% active powders or as concentrates in functional polymer carriers. The concentrates are typically 40% active to insure a good dispersion in traditional material handling systems. **SAFOAM[®]** P, FP, RIC, and RPC will produce about 140 cc/grams and serve as the base material for the polyethylene and polystyrene concentrates.

A Differential Scanning Calorimetry curve of a common endothermic chemical foaming agent can be found in Figure 2.

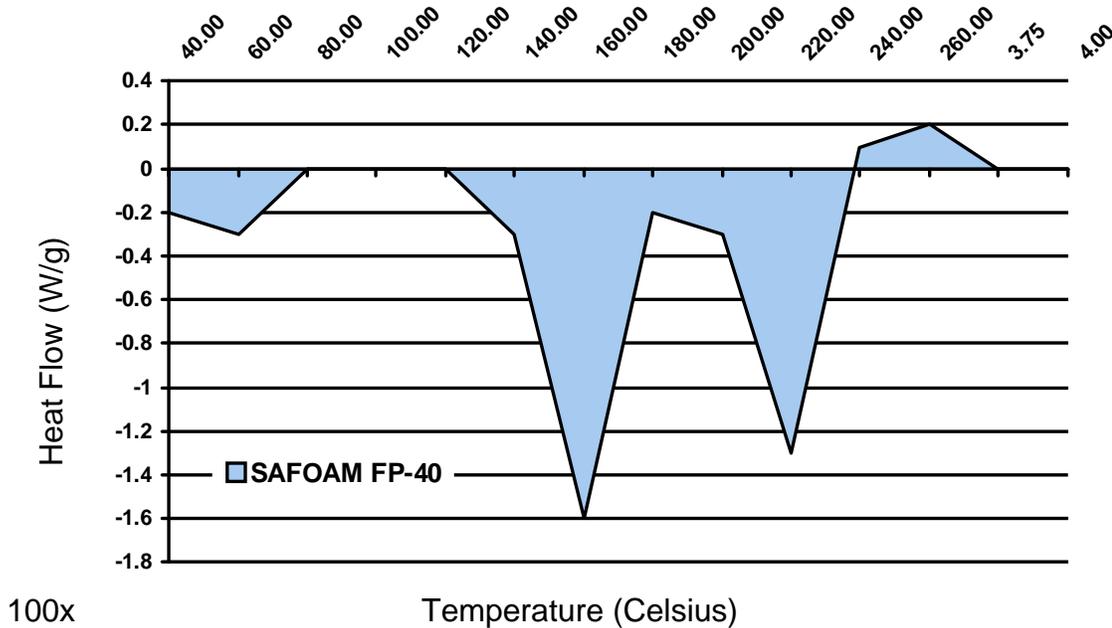


Figure 2. Differential Scanning Calorimetry curve for **SAFOAM**® FP-40 showing endothermic behavior.

The use of **SAFOAM**® endothermic chemical foaming agents gives rise to more uniform cell structures, thicker skins, better surface appearance, and more control as compared to other traditional chemical foaming agents. **SAFOAM**® affords significant weight reduction, sink mark elimination, shrinkage control, and warpage elimination. It produces parts that can be painted without significant degassing time.

SAFOAM® products are safe for use in food contact applications. The components of all **SAFOAM**® products are Generally Recognized As Safe (GRAS). **SAFOAM**® is manufactured within the confines of an FDA approved facility, adhering to strict Good Manufacturing Practices to insure the maximum product quality.

SAFOAM® products are generally used to:

- improve nucleation in tandem with nitrogen
- create a uniform cell structure
- reduce cycle time
- reduce surface swirl or splay appearance
- foam highly fluid polymers
- reduce physical property loss
- minimize part stresses
- increase weld line strengths

GAS EVOLUTION AND RATE

The enhanced performance of **SAFOAM**[®] endothermic chemical foaming agents is believed to be the result of a more uniform cell structure that is directly related to the controlled rate of gas release in the product. This rate of gas release is dependent on temperature, pressure and the composition of the foaming agent. The **SAFOAM**[®] family of endothermic chemical foaming agents is based upon modified citric acid/carbonate systems that vary significantly in their compositions from the traditional acid/carbonate systems.

The gas released by **SAFOAM**[®] FP can be seen in Figures 3 and 4, while figures 7 and 8 represent **SAFOAM**[®] FP-40. A typical azodicarbonamide was used as a reference in Figure 3. The gas volume data was generated by a linear temperature program. The thermal expansion of the air in the sample vessel is accounted for by the subtraction of a blank value (45.7cc) from the total gas volume measured. Figure 3 clearly shows that **SAFOAM**[®] FP generates 200 cc/gram of gas volume at 350°C. Figure 7 shows that **SAFOAM**[®] FP-40 generates 101 cc/gram at 375°C. Both the **SAFOAM**[®] FP and FP-40 generate significantly less gas than the typical azodicarbonamide, which generates 230 cc/grams at 350°C.

The first order kinetic factor of **SAFOAM**[®] RPC as compared to a typical azodicarbonamide can be found in Figure 6. The differential response of **SAFOAM**[®] RPC is significantly slower than the azodicarbonamide. The longer the foaming time (defined as the amount of time it takes to generate 63% of its gas capacity), the slower the kinetics of gas release. Slower gas release allows for a more controlled formation of the cell structure within the foamed plastic, which in turn allows for fewer voids and stresses, thicker skins, and higher quality surface finishes.

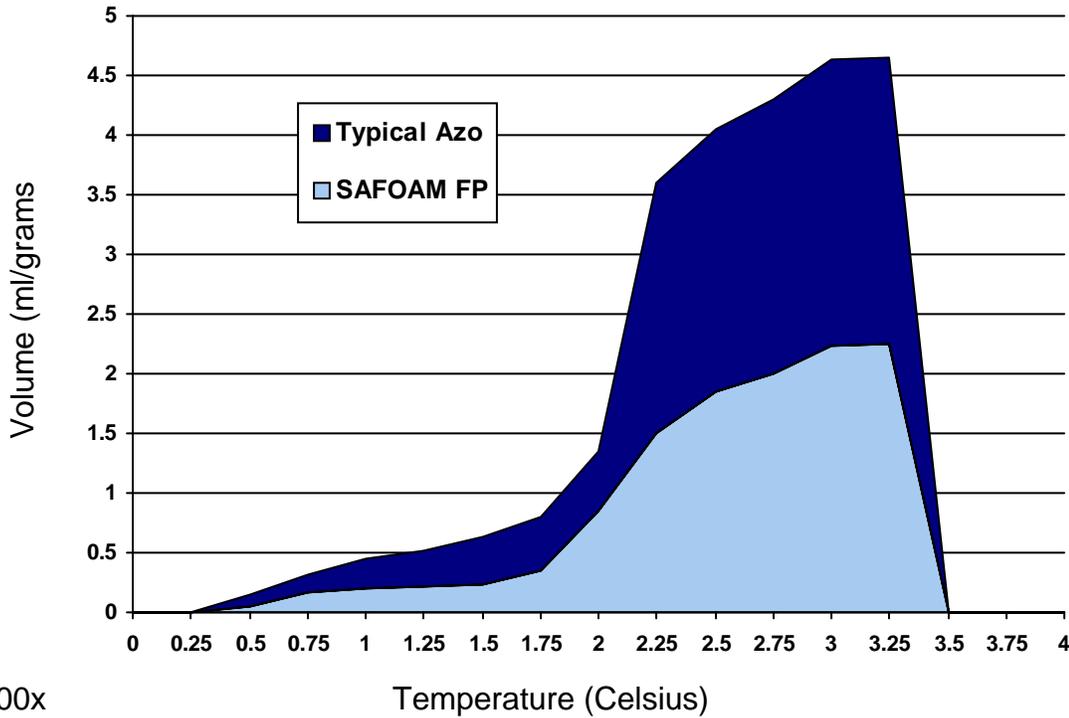


Figure 3. Comparison of gas volumes for SAFOAM® FP and a typical azo-dicarbonamide.

100x

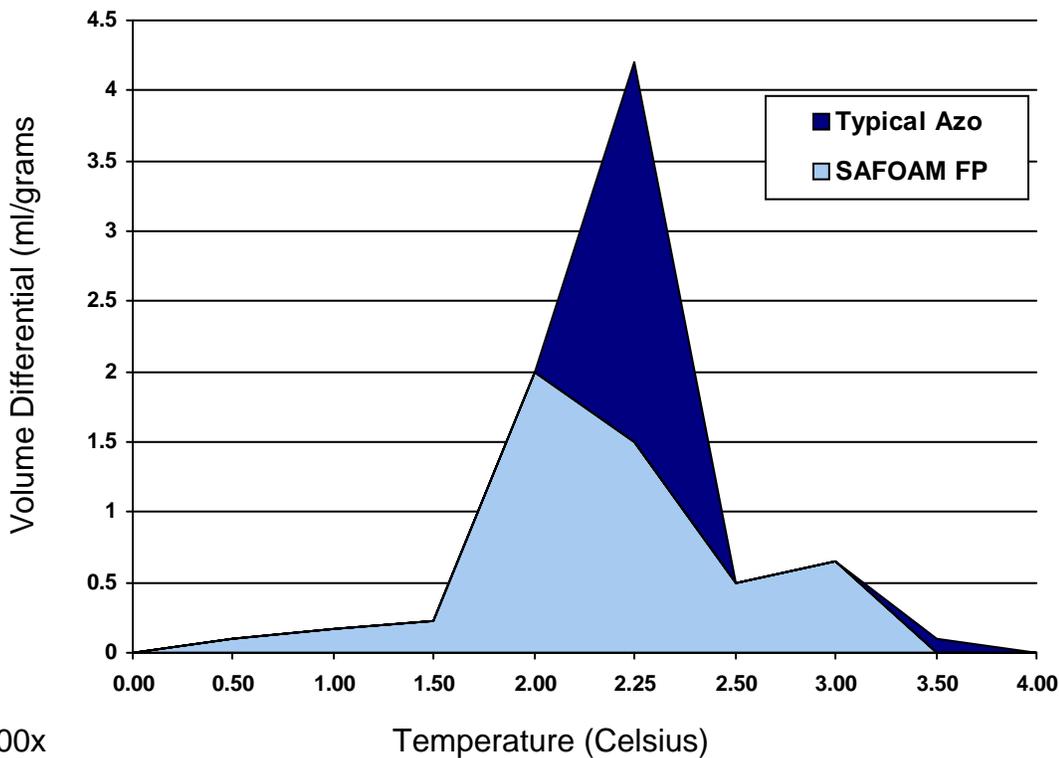


Figure 4. Differential response for SAFOAM® FP and a typical azodicarbonamide showing rate of gas release.

100x

FOAMING AGENT SELECTION

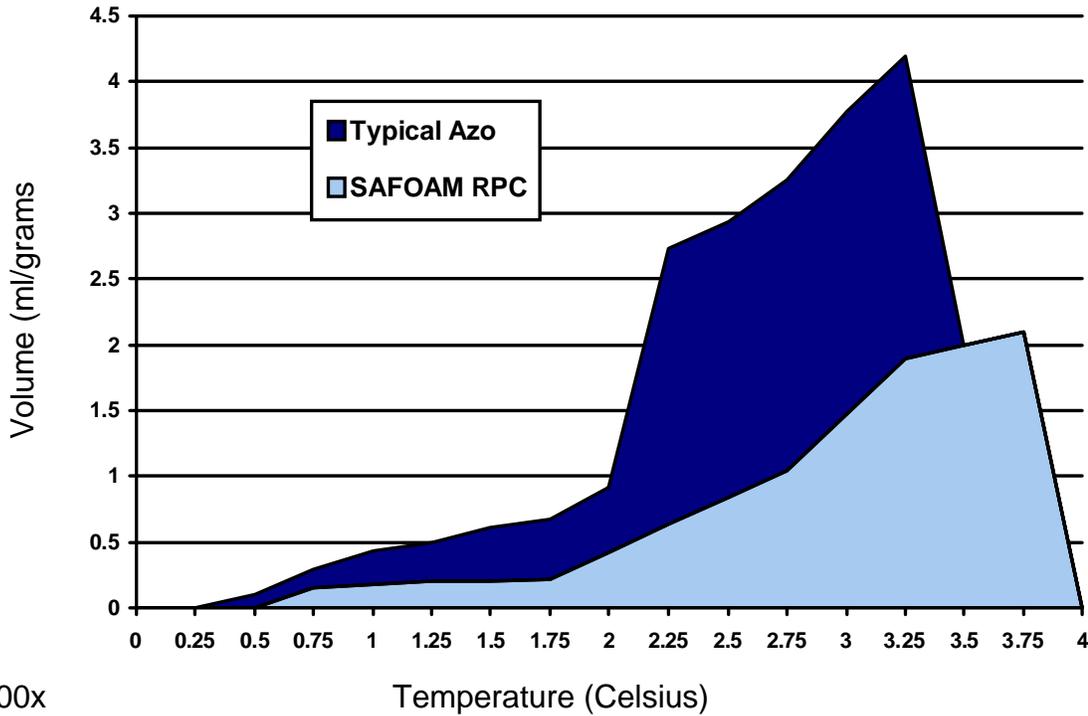


Figure 5. Comparison of gas volumes for SAFOAM® RPC and a typical azodicarbonamide.

100x

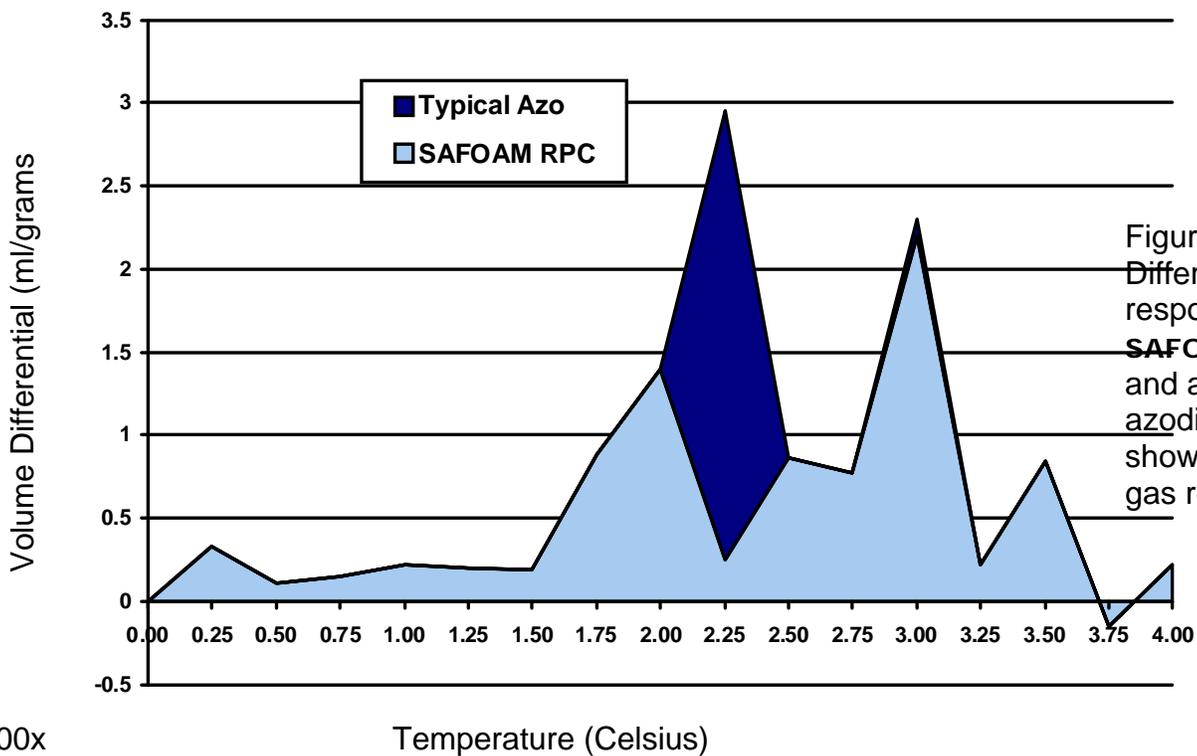


Figure 6. Differential response for SAFOAM® RPC and a typical azodicarbonamide showing rate of gas release.

100x

FOAMING AGENT SELECTION

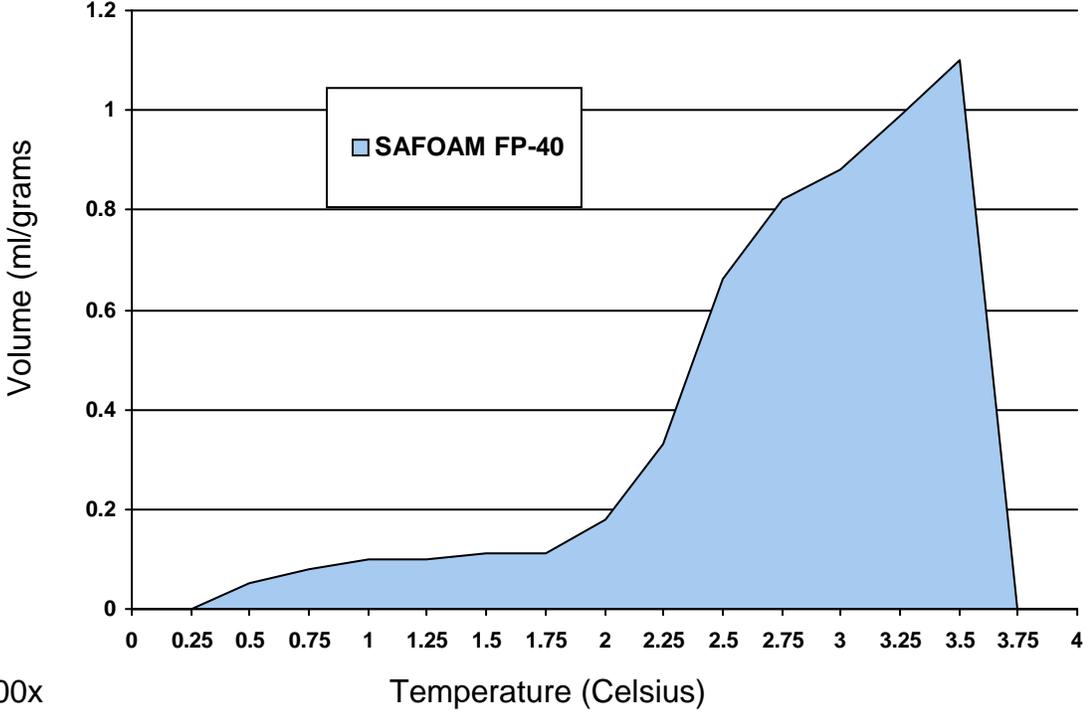


Figure 7. Gas volume for SAFOAM® FP-40.

100x

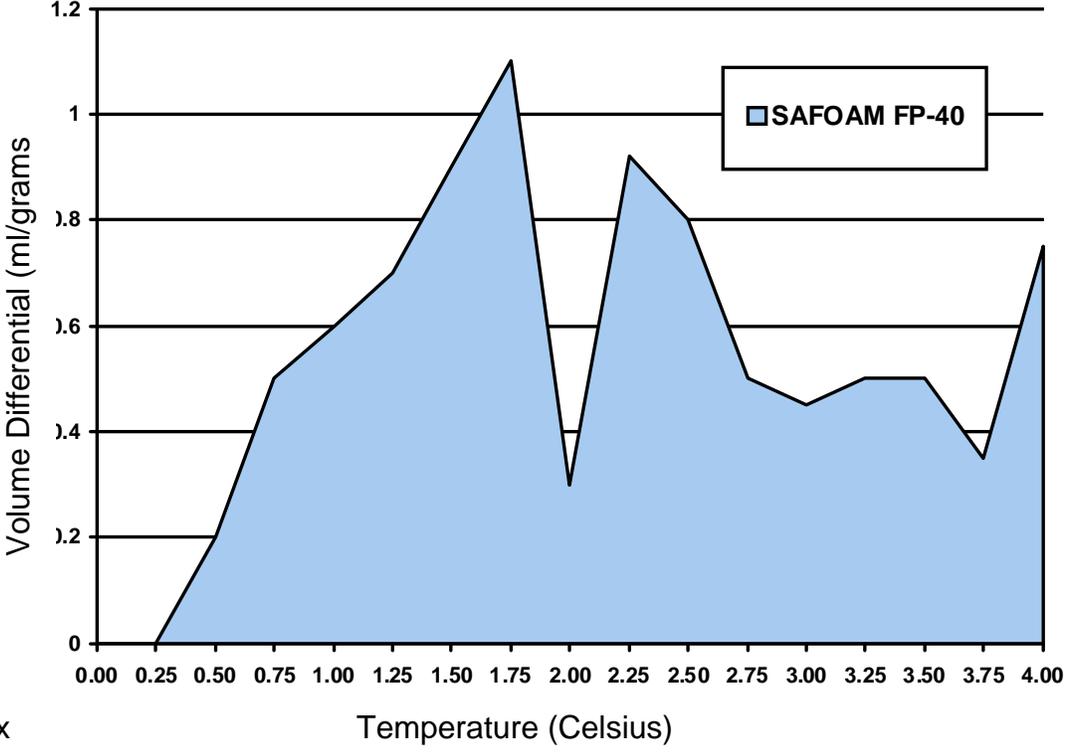


Figure 8. Differential response for SAFOAM® FP-40 showing rate of gas release.

100x

SAFOAM® is used in the production of injection molded parts requiring a cellular structure and for the elimination of sink marks and stress in solid parts. **SAFOAM®** is used in all types of injection molding equipment, including low and high pressure specialized structural foam machines, and conventional machines modified for structural foam.

SAFOAM® is used in the following foam structures:

- Structural Foam Molding (SFM) - usually parts of 1/4 inch (6.35 mm) thickness or more, with a 10-40% weight reduction compared to solid molding.
- Thin wall parts - generally 1/8 - 3/16 inch (3.18 - 4.76 mm) thickness with a 1-20% reduction in weight compared to solid molding.

SAFOAM® is also used to eliminate sink marks and to reduce warp and molding stresses: it is used at low levels (up to 0.20% active **SAFOAM®**) and is not intended to produce any significant weight reduction.

INTRODUCTION TO STRUCTURAL FOAM

Structural Foam is a plastic product having walls with a solid skin around a cellular core. Density is usually 65-90% of the solid polymer and varies according to material, fillers, blowing agent, wall thickness, processing conditions and required physical properties of the part. The term “structural” is applied because the principle behind foaming is that strength is obtainable by properly designed structure (using the wall thickness). The flexural strength (S) of a supported beam can be defined by:

$$S = K_o \frac{EI}{Wl^3} \quad \text{or} \quad S = K_1 Ea^3 \quad \text{Figure 9.}$$

for any two identical loading conditions. “E” is the flex modulus of the material, “K₁” is a constant for that particular beam and load, and “a” is the beam height. From this it is obvious that the wall height is much more important than the flex modulus. If we were to take the material required for a solid beam with a wall 0.160” thick and foam it to 80% of solid, we would now have enough volume to generate a 0.200” thick beam at the same width. The flex modulus may decrease by 25% for the foamed resin, but the results are:

$$\begin{array}{ccc}
 \text{SOLID} & & \text{FOAMED} \\
 S_1 = K_1 E (.160)^3 & \text{and} & S_2 = K_1 (.75E) (.200)^3 \\
 = K_1 (.0041E) & & = K_1 (.0060E)
 \end{array}$$

Figure 10.

dividing S_2 by S_1 and solving:

$$S_2 / S_1 = \frac{K_1 (.0060E)}{K_1 (.0041E)} = \frac{.0060}{.0041} = 1.463$$

Thus, the same quantity of resin foamed is nearly 50% stiffer than its unfoamed counterpart. With similar manipulations, we would see that equal strength could be obtained with only 88% of the resin at 20% weight reduction.

The ability to obtain strength with structural foam caused the initial push to develop around cheaper commodity resins. As the end-use requirements have become more demanding, however, the materials used have become more sophisticated. There are now well over 200 million pounds of engineering plastics being foamed each year.

Density reduction up to 40% can be achieved in SFM. The density reduction obtained is dependent upon part thickness, flow length of the resin, amount of filler, and part design. Foaming a polymer should not change its chemical resistance or chemical structure, provided the proper processing conditions are used.

SFM parts have increased stiffness because they are usually thicker than solid moldings. Their lower density gives a higher strength-to-weight ratio compared to solid moldings. Because of the cellular structure within the parts, acoustic or insulation properties can be enhanced.

Thermal Conductivity. Engineering Structural Foam is also a good heat insulator, significantly better than solid plastics as seen from its lower thermal conductivity. In business machine housing design, for instance, higher operating temperatures can be tolerated without exposure of the machine operator to a hot surface, as would be the case with metal.

It should also be noted that as densities decrease, thermal conductivity also decreases. This is true because in the cellular core there is an increased content of air, which has lower thermal conductivity than the base resin.

Acoustical Properties. Engineering Structural Foam can offer distinct advantages versus metal in noise reduction since they dampen vibrations much more rapidly.

It should be noted that the manner in which structural foam is used to reduce noise plays an important role in its effectiveness. If the method of noise reduction is merely to enclose the sound source (sound attenuation), metal will suffice. However, if the actual source of noise can be made out of foam, the noise will dissipate up to 16 times faster than with metal. Moreover, if the source continuously generates noise, as is the case with a printer housing, the use of structural foam decreases the amplitude of vibration for an over-all reduction in noise level.

In many cases, to eliminate unwanted vibration or noise it is necessary to add dampening to the system, or to design it so that the forcing frequency is well below the natural frequency. This is done by either increasing stiffness or reducing mass, usually accomplished by the addition of ribs.

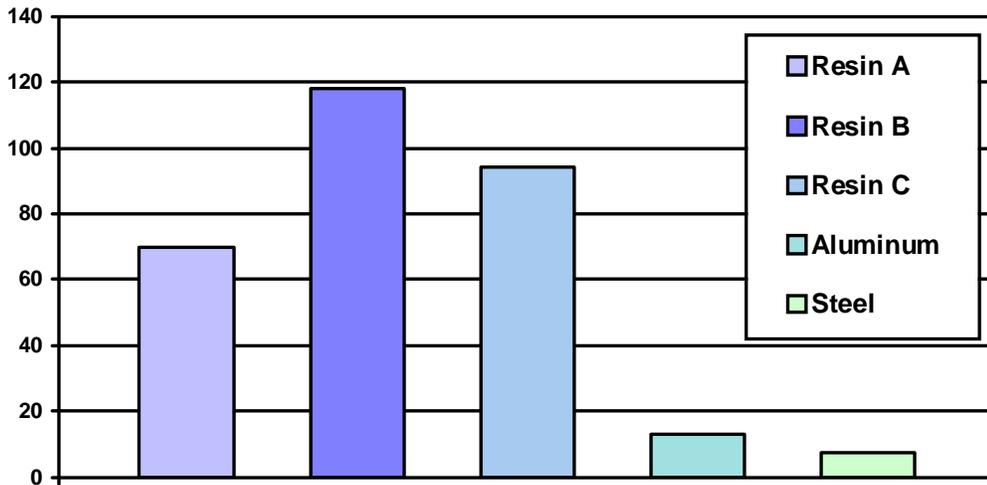


Figure 11.
Sound Dampening
Characteristics

Physical properties such as impact resistance or tensile strength will depend on the amount of weight reduction and the thickness of the skins surrounding the cellular core. The thicker skins achieved with **SAFOAM®**, compared to other foaming agents, produce parts with better physical properties.

BENEFITS OF FOAMING

Although increased strength from designing thick wall sections is a major benefit of structural foam, there are several other key advantages obtained from foaming. Some of these are: enhanced processability, reduced part stresses, large part sizes, lower costs, and a large variety of processing techniques. These topics will be overviewed in this section and will be discussed in more detail throughout this guide.

Structural Design Flexibility

Density. The level of foam that can be achieved varies with each individual resin and is further affected by solids loading, processing conditions, foaming agent, and part design. When density is matched with the designed wall thickness, a multitude of combinations can be used to achieve a given flexural requirement or other property. For example, a 0.150" wall at 10% weight reduction might provide the same impact strength as a 0.180" wall at 25% weight reduction with both options requiring the same amount of resin. The part's flexural strength would most likely be higher with the thicker wall, thus allowing the designer an additional design parameter not available in solid injection molding.

Weld Lines. The occurrence of weld lines (knit lines) is very common with specific configurations and causes weak areas in the part. Consequently, a part must be designed with that in mind, since typically only 50% of the solid wall strength is retained. In a foamed part, however, the melt merges more uniformly and achieves about 70% of the part's wall strength. While not perfect, the superior bonding does allow for greater overall part strength and permits more freedom in allowing weld lines when necessary. By further masking the weld line in a slightly thicker wall, a designer may produce a part having a weld line, but not a weakness.

Knit Lines. Improved melt flow can cause more distinct knit lines. Reducing injection speed should correct this.

Improvements in Processing

The presence of gas in the polymer provides a slight lubricating effect which increases typical flow lengths by about 2-5%. Similarly, the viscosity responds as if it was lower and requires lower injection pressures to fill. In most cases, the expansion of the dissolved gasses in the molten polymer provides the force that fills the part, eliminating the need to maintain a packing pressure during molding. The force exerted on the mold is substantially smaller during filling/packing, usually less than 1,000 psi, as compared with 12,000+ psi in injection molding. Typical values for estimation are 20-25 tons of clamp required per square foot of surface area of the part.

Lower Internal Stresses

Two major characteristics of the structural foam process are the low pressures required during injection and the fact that the mold is filled by rapid expansion of the gas dissolved in the polymer. Both features, plus the presence of the cell structure, permit much greater relaxation of the polymer chains and more randomization of any fillers. The mild, continuing pressure of the gas exerts enough force on the walls of a part to eliminate sink marks. The randomization of fillers, the shortening of polymer length and the low stress levels from gas expansion substantially increase the uniformity of shrinkage. These same characteristics result in less stress cracks and weld-line strength loss in the finished part. This is due to the deformable nature of the gas cells. An internal stress in solid plastic is frozen in place and the latent energy can manifest itself as a crack or other external stress, during an impact or otherwise. With a foam structure, however, the gas cells become stress-energy absorbers, leaving little residual forces to cause problems. In a similar manner, warpage can often be eliminated. In all these situations, however, improper molding with foam or the need for high pressure (force) can offset the effects of the gas cells to some degree.

Large Complex Parts

Compared to injection molding, much larger parts are achievable in foam molding. Both structural foam and injection molding processes are comparable and since the same kinds of resins are used, similar detail and complexity are possible in a part. The major difference is the low pressure required for foam molding. This changes economics significantly so that a low pressure structural foam machine could be built with only a 400-ton clamp but have an 8-foot x 8-foot platen and a 100 lb. shot capacity. A similar size machine for injection molding would likely have a 4,000-ton clamp and a 25 lb. shot to go with such a large platen. Large parts lend themselves to structural foam, particularly since wall sections tend to be bigger and will permit adequate foaming to take place. Small parts (1 oz. or less), on the other hand, usually need all the physical properties associated with a solid wall and should not be foamed. Parts in the mid-range should be foamed if there are specific advantages provided by the process. The key advantage to consider is the effectiveness of structural foam in both cost and processing when making a large part that is too complex for extrusion, compression molding, or thermoforming.

Lower Costs

Several of the peculiarities of structural foam molding can have significant impact on cost savings. In the majority of cases, if the physical disadvantages of foamed parts are not prohibitive in end use, structural foam processing will be more cost effective than injection molding. Each cost saving area, though related, is generally autonomous so that any application could use one or all of the benefits. Resin savings and tool costs are obvious ones, but the biggest contributor to cost is the option on the type of machine that can be used for the foam process. Whether using a low pressure structural foam machine or a high pressure injection molding machine, the machine selected will dictate the type of product, several of the part's characteristics and, most importantly, the cost savings options that can be included.

Resin Usage. Using less resin is the obvious area of cost improvement for foam. The greater the density reduction, the higher the savings in resin cost will be. If a chemical foaming agent (CFA) is used, there will be an added cost for the chemical. In most resin/blowing agent mixtures, a minimum level of chemical is needed to produce measurable density reduction. This weight can usually be reduced further by an increase in the CFA concentration. Generally a point is reached, however, where additional foaming agent will produce little or no additional weight reduction. A typical example appears below in Table 3. Use of a physical foaming agent, such as nitrogen or carbon dioxide, is cheaper but requires different types of machines or machine modifications and produces coarser cell structure. Wall thickness and flow length will impose a physical limitation on the reduction in density and physical end-use requirements may solidify that limit.

Part Wt. lbs	% Density	Resin Cost \$	% SAFOAM®	SAFOAM® Cost \$	Total Cost \$
5.00	100	10.00	0.0	0.0	10.00
4.75	95	9.50	0.5	0.13	9.63
4.50	90	9.00	1.0	0.26	9.26
4.25	85	8.50	1.5	0.39	8.89
4.00	80	8.00	2.0	0.52	8.52
3.75	75	7.50	2.5	0.65	8.15
3.50	70	7.00	3.0	0.78	7.78
3.25	65	6.50	3.5	0.91	7.41
3.00	60	6.00	4.0	1.04	7.04

Table 3. Comparative cost chart based on an average resin price of \$2.00 and an average SAFOAM® price of \$5.20.

Tooling Expenses. The mold cost is a variable influenced by many parameters, particularly the design of the part. Most of these parameters are identical for tools in structural foam; however due to the lower pressure of the foaming process, the physical strength required for withstanding injection and clamp pressures is much less. As such, aluminum tools are the standard material of construction. This generally means that the cost of the mold is around 25% less than that of a steel tool, and of course, much lighter and easier to handle. If the mold will see a great deal of activity (over 200,000 parts), then tool wear will be a key factor and hardened steel might be the better choice.

Processing Charges. The substantial decrease in clamp tonnage necessary to make a foamed part is the reason that machine (or operation) charges are reduced. Since platen dimensions and shot size become the new limiting factors, any typical injection molding machine would be capable of producing much larger parts in foam. If a 30 ounce part with a large surface area required a 700 ton machine for injection molding, it is probable that a 300 ton machine would be adequate to produce a foamed part, assuming sufficient shot capacity and adequate platen area. The cost of operating smaller machines is significant, and if only larger machines are available, then 2 or 3 parts could be made with multiple-cavity molds. In one case there are lower operating costs per part; in the other case, more parts are made for about the same operating cost.

Flexibility in Part Production

The structural foam process presents several alternatives in producing parts. Since low pressures are generally used, an injection molding machine has a much higher limit on surface area that can be successfully molded. Consequently, multi-cavity molds are generally quite common and a family of parts can be produced with one shot, assuming shot capacity is adequate. On a structural foam machine (a variety of injection molding machines) there is generally the presence of a multi-nozzle manifold. The stationary platen has a pattern of holes from which the nozzles on the manifold can be matched up. These are often on a 6"x6" grid which means that a large part could be filled by using a nozzle at any of the 6" spacings or that a different part could be shot every 6 inches (or multiples thereof). This allows maximization of the machine's shot capacity and/or permits overall cycle time per part to be greatly reduced.

PART DESIGN

Designing parts in Engineering Structural Foam requires the same careful consideration of load, modulus, fatigue and stress conditions as any product design cycle.

Load Considerations

The mechanical properties of Engineering Structural Foam resins are relatively stable over a wide range of conditions and are predictable over a range of temperatures. Like all thermoplastics, structural foam resins exhibit visco-elastic behavior. Therefore, the properties of strength and rigidity depend on the amount of stress, the rate of loading, and the length of time that the stress is applied, as well as the temperature and environment in which it is applied. In structural foam, unlike injection molding, the type of process, the degree of density reduction and the wall thickness will have an effect on the properties of the molded part.

Stress-Strain Curves

The stress-strain curves, exemplified in Figure 12, illustrate the capability of Engineering Structural Foam resins to withstand short-term loading and the effects of density on tensile properties, measured by ASTM D638. Tensile properties and proportional limits increase as density increases. On this basis, the designer can determine a specific gravity of a part appropriate to fulfill performance requirements.

(.250" Wall Thickness)

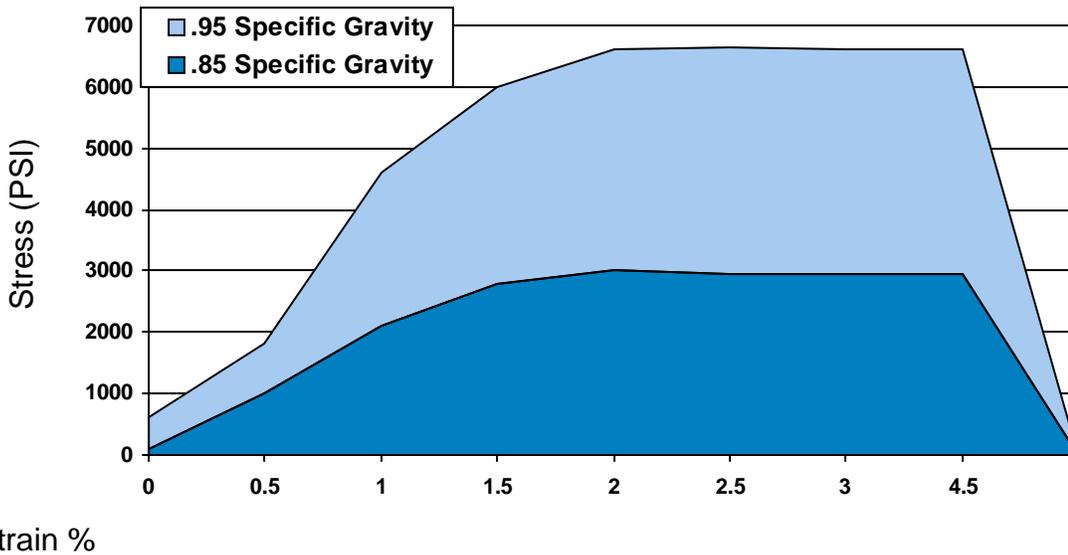


Figure 12.
Stress-Strain
Curve @73°F.

Apparent Modulus and Creep

Following the immediate elastic deformation caused by a load, a slower deformation occurs which gradually approaches a nearly constant rate of flow. This time-dependent behavior is called *creep*.

The rate of creep in a part will vary with the temperature of the environment and stress in the part. The stress level where creep becomes negligible is called the *creep limit* of the material.

The simplest method to compensate for the visco-elastic behavior of Engineering Structural Foam is to work with the apparent modulus rather than the instantaneous modulus. The *apparent modulus* is used to predict part performance at given points in time after initial application of external loads. It is expressed as:

$$E = \frac{S}{e_1 + e_2}$$

Figure 13.

Where:

- S = Induced stress (psi)**
- e₁ = Initial strain (in/in)**
- e₂ = Strain due to creep of the material at a given stress and time (in/in)**
- e₁ = e₂ + Total strain**

Fatigue Properties

When parts are subject to cyclic loading, fatigue failure can occur below the yield point of a particular structural foam material. Figure 14 shows the results of fatigue testing conducted at 1800 CPM for two foamable resins. To determine the fatigue life of a part, the maximum stress of the part is calculated and compared to the fatigue endurance curve. Stress concentrations should be considered when calculating the maximum stress level. Since fatigue endurance in thermoplastic materials is dependent on cyclic frequency, this curve can be used as a guide. For critical applications, prototype testing or computer-aided methods are recommended to assure satisfactory reliability.

Fatigue strength can be expected to increase with decreasing wall thickness, due to the higher density seen in thinner wall parts.

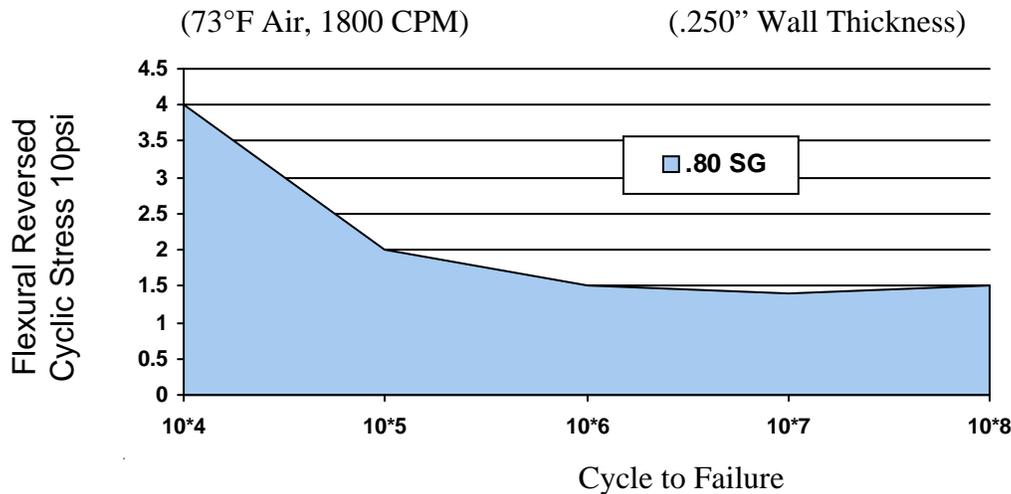


Figure 14.
Flexural Fatigue-
Fatigue-Endurance.

Recommended Maximum Working Stress

Temperature, fatigue and chemical environment are the three critical factors that limit the load bearing capabilities of structural foam. Actual design limits of foam applications should be determined only after careful evaluation of each of these factors.

Thermal Stress/Coefficient of Thermal Expansion

Thermal stress, caused by the thermal expansion and contraction of a material, can often be the cause of unexpected part failure. When two materials with greatly dissimilar coefficients of thermal expansion are combined in assembly, thermal stress is of the greatest concern. Differences in the thermal movement of the materials may cause problems in tight tolerance and close fit areas, particularly when press fits are used or inserts are molded-in. Thermal stress can be approximated using the equation:

$$\sigma_t = (\alpha_1 - \alpha_2) E \Delta T$$

Figure 15.

Where:

- α_1, α_2 are the coefficients of thermal expansion for respective materials
- E = Modulus of Material
- ΔT = Temperature Change

Structural Design

Unlike most commodity thermoplastic foams, which are not linearly elastic, Engineering Structural Foam resins enable the designer to accurately predict stresses and deflections resulting from external loads, enhancing the reliability of short- and long-term performance.

Stresses, strains and deflections can be determined using classical engineering methods. The structure of the cellular core and solid skin may be considered to be a composite, and the stress analysis performed accordingly in the composite analysis. An equivalent I-beam section of solid material serves as the cross-section for the foam part. (See figure 16.)

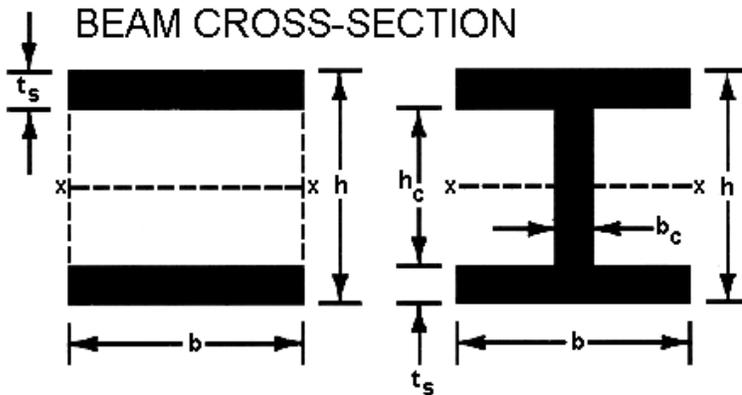


Figure 16.
Beam
Cross-Section.

The Moment of Inertia of the equivalent I-beam is then formulated as:

$$I_x = \frac{bh^3 - (b - b_c)(h - 2t_s)^3}{12}$$

Figure 17.

Where:
$$bc = \frac{b E_c}{E_s}$$

E_c = Modulus of Core
E_s = Modulus of Skin
t_s = Thickness of Skin
h_c = Height of Equivalent Core

This approach is technically correct, but there are difficulties in measuring the core modulus and the as-molded variations in skin thickness. Incorrect assumptions in these areas can result in erroneous solutions.

A more conservative approach to analyzing a structural foam part in a load-bearing environment would be to model the cross-section as two outer skins with no cellular core. (See Figure 18).

TWO SKINS WITH NO CORE - CROSS-SECTION

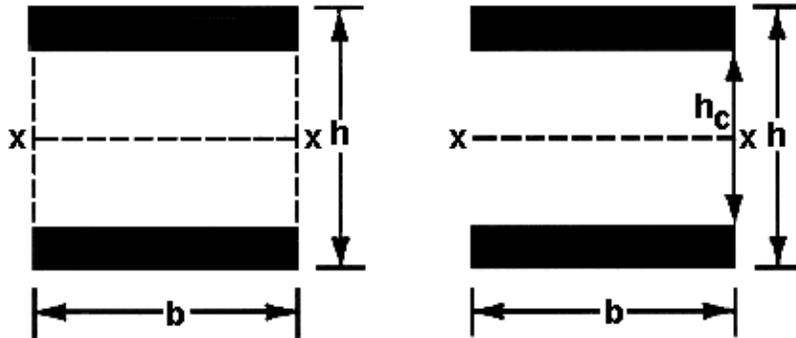


Figure 18.
Two Skins with
No Core --
Cross-Section.

The equivalent Moment of Inertia is equal to:

$$I_x = \frac{b(h^3 - h_c^3)}{12}$$

Figure 19.

Since the cellular core does provide some stress-absorbing characteristics, this analysis should provide a safety factor. When time or costs do not permit a more detailed analysis, the structural foam cross-section can be considered to be homogeneous. (See figure 20.)

HOMOGENEOUS CROSS-SECTION

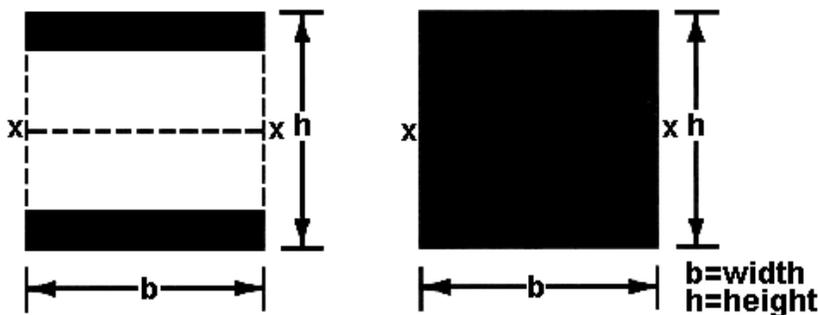


Figure 20.
Homogeneous
Cross-Section.

(All mechanical properties reported in this manual were determined with the test material being homogeneous materials -- not composites. Therefore, the reader should assume homogeneity when computing stresses or deflections, or when referencing this data. The section modulus or moment of inertia of a part's cross-section is then determined solely by the exterior dimensions of the part. The property values as a function of the environment can be obtained from the graphs shown).

Bending

The efficient distribution of material in a structural foam cross-section contributes to its excellent flexural properties. The flexural strength of a structural foam material is significantly higher than its tensile strength, even though failure in bending is a result of tensile rupture, because the maximum tensile stresses occur in the outer fiber of the part, which is solid polymer or skin (Figures 21 and 22).

When designing for ultimate failure of a part in bending, the engineer should be cautioned that flexural failure can occur at the tensile strength limits of the foam. The governing factor is the maximum tensile stress in the cellular core under flexure. If the distance from the neutral axis to the outer-most cellular core exceeds one-half inch, failure will occur approximately at the tensile strength of the material. The cellular core will yield and a stress crack will propagate through the adjoining skin. If that distance is kept under a half inch, flexural failure will result closer to the reported flexural strength for a standard test specimen.

When optimizing structural members for bending, the designer should select a non-symmetrical cross-section to allow the placement of the neutral axis so that the maximum bending stresses occur in compression.

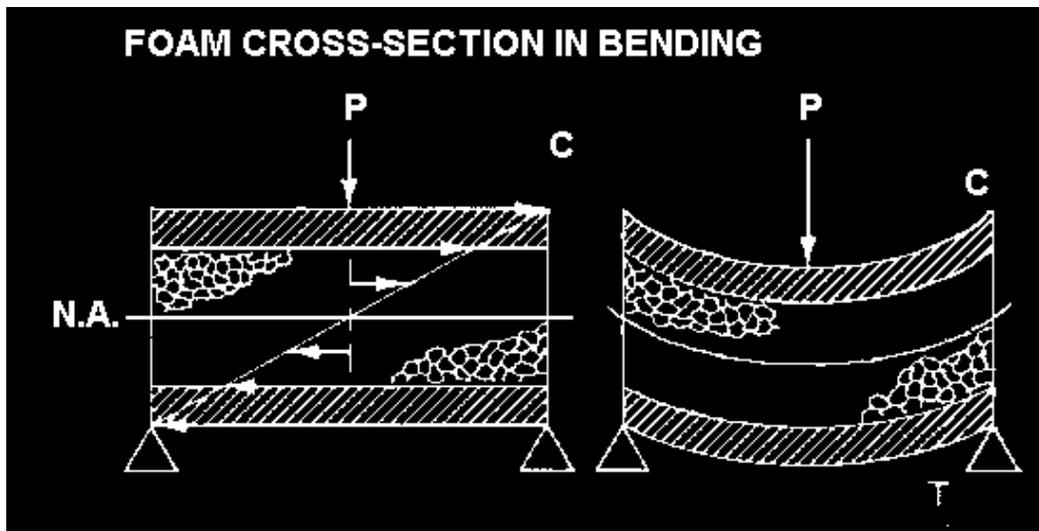


Figure 21.
Foam Cross-
Section in
Bending.

E=flexural modulus
I=moment of inertia
P=external force
L=length of beam
w=load per unit length

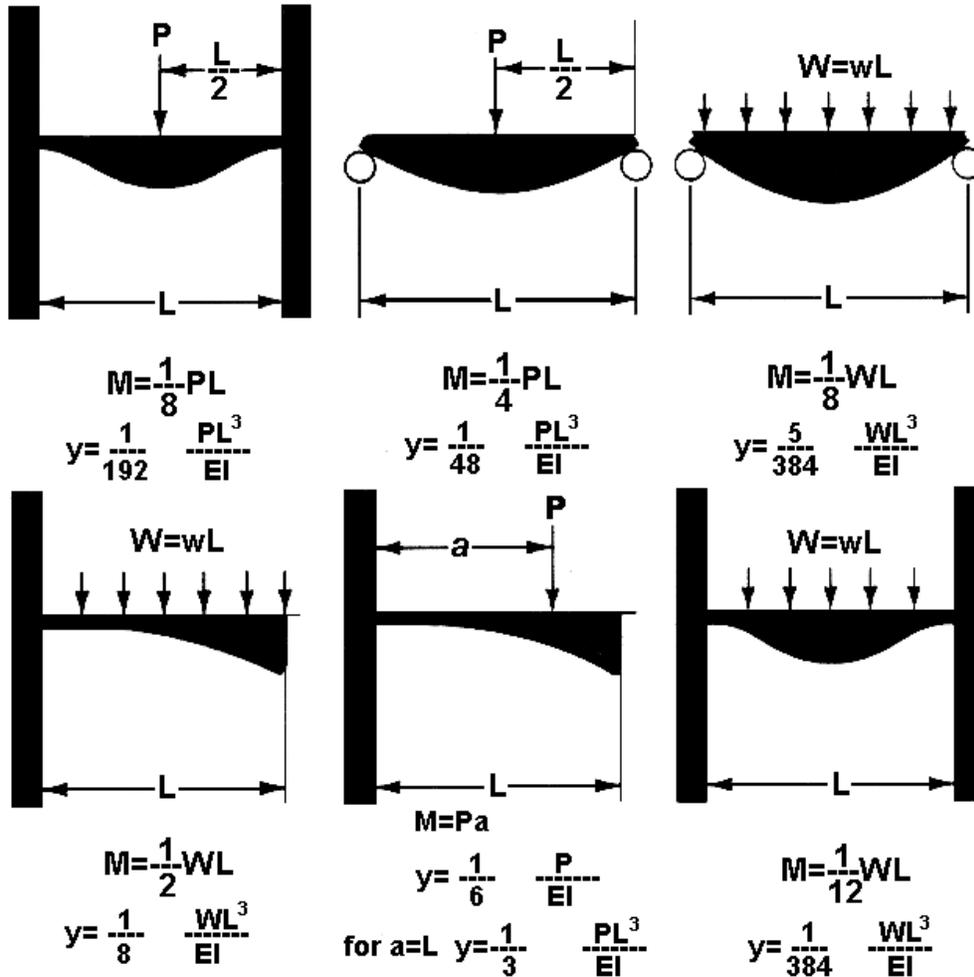


Figure 22.
Beam
Cross-Section.

Tension

The apparent tensile strength of any foam material is less than that of the same material in a solid configuration. Strength is reduced considerably because of the density reduction and stress concentrations caused by each individual cell. Therefore, tensile stresses should not exceed the proportional limit of the material.

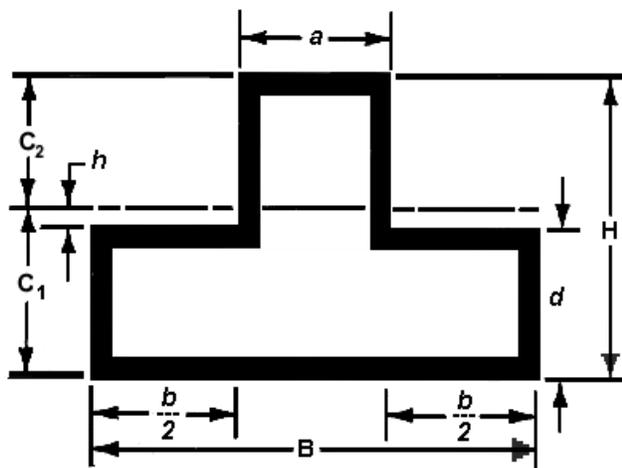
Compression

The compressive strength of a foam material is higher than its tensile strength. In bending, a compressive failure, although extremely rare, normally involves buckling of the skin and collapse of the cellular core. When pure compressive stresses are applied, structural foam parts will fail because of a crushed cellular core rather than from induced tensile stresses resulting from volumetric changes.

The distribution of material in a foam cross-section helps optimize the torsional stiffness-to-weight ratio. In this case, the cross-section can be thought of as a hollow shaft similar to the analogy of the I-beam effect in bending. A foam part will have less torsional stiffness than a solid part of the same dimensions. But as weight is reduced with the introduction of a cellular core, the polar moment of inertia is only decreased a fraction of that same amount. This is because the inertia is a function of the fourth power of the ratio of the inner diameter to the outer diameter.

Twisting and racking of structural foam parts can be offset with the use of molded-in ribs. For example, a square plate would resist torsion if diagonal ribs were molded-in to help avoid deflections. In this case, the ribs would be put into tension and compression, and strains would be significantly reduced because of the increased polar moment of inertia.

UNIT "T" FROM RIB CROSS-SECTION



Moment of Inertia,

$$I = \frac{1}{3} (BC_1^3 - bh^3 + aC_2^3)$$

$$C_1 = \frac{1}{2} \frac{aH^2 + bd^2}{aH + bd}$$

$$C_2 = H - C_1$$

Determine the thickness (T) of an equivalently rigid rectangular section

$$T = \left(\frac{12I}{B} \right)^{1/3}$$

Figure 23.
Rib
Cross-Section.

Very often a plate analysis is required for a foam structural design. As with beams, plates can be analyzed using standard engineering methods. However, a foam structure requiring rigidity will normally consist of a cross-pattern of ribs rather than a uniformly thick wall. Since handbooks will give plate equations in terms of uniform thickness, ribbed plate design thickness must be calculated, and is based on equivalent moments of inertia between the flat and ribbed sections. (See figure 23).

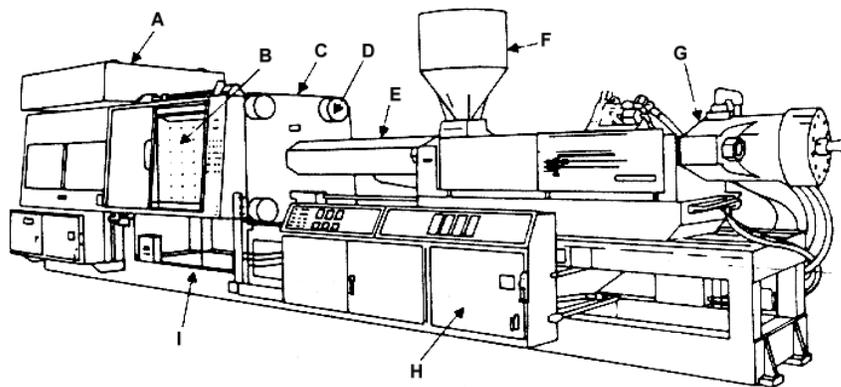
- Straight Injection Molding
- Low Pressure Structural Foam Molding
- High Pressure Structural Foam Molding
- Gas Counter Pressure Structural Foam Molding
- Nitrogen Injection Structural Foam Molding
- Gas Co-Injection Structural Foam Molding
- Gas-Assist Molding
- Chemical Gas Assist
- CoralFoam®
- Over Molding Structural Foam Molding

PROCESSING METHODS

SFM parts may be made by low or high pressure processes. Pressure refers to the mold cavity pressure. Low pressure SFM is produced by incorporating **SAFOAM®** with a resin and injecting a “*short shot*” (less than the mold cavity volume) into the mold. The screw must be allowed to *bottom out*, that is, no pad or cushion should exist for the forward movement of the screw. This allows the gas to expand and evolve in the polymer melt while in the mold. The gas released by **SAFOAM®** expands the resin to fill the cavity. Since the mold cavity is not completely filled with resin, the pressure in the mold is only that generated by the **SAFOAM®**. Low pressure SFM is produced in a variety of equipment.

SFM on conventional machines (Figure 24) is possible, but some modifications are recommended if good quality parts are to be produced. The most important modification is the use of a positive nozzle shut-off valve to prevent drooling of the resin which causes variation in part weight and nozzle freeze-up. The shut-off nozzle may be spring, mechanically, or hydraulically operated.

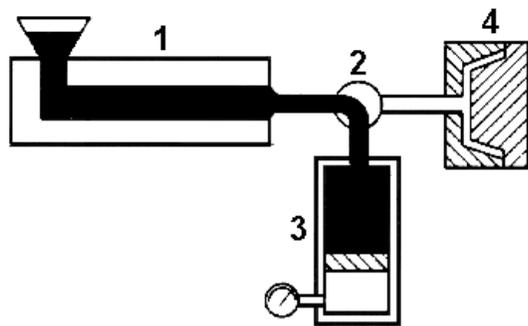
Conventional Injection Molding Machine



- | | | |
|-------------------|-----------------------|--------------------|
| A. Oil reservoir | D. The rod | G. Hydraulic drive |
| B. Movable platen | E. Injection cylinder | H. Control cabinet |
| C. Fixed platen | F. Hopper | I. Base with pumps |

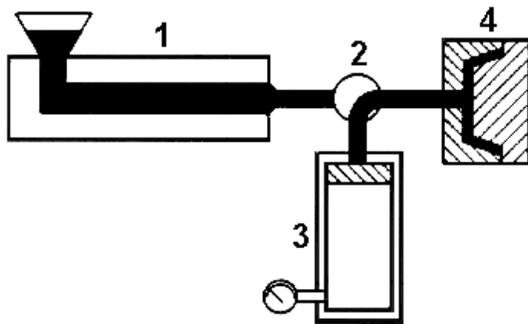
Figure 24.
A typical
injection
molding
machine
with major
elements
identified.

Specialized Low Pressure SFM Machines



1. Screw plasticator
2. Distributing valve
3. Accumulating cylinder with injection ram
4. Injection mold

Figure 25. Schematic illustration of low-pressure injection molding.



There are machines that are specifically built for the production of low pressure SFM. These machines offer the advantages of fast injection speed, large shot capacity and platens. Because lower clamp tonnages are used, the tooling is less expensive. Reciprocating screw, or two-stage screw, plasticating/ram-injection machines are available.

Low Pressure Process with Chemical Blowing Agents

In this type of process, a chemical blowing agent such as **SAFOAM®** is first blended with plastic pellets, and the mix is then introduced at the feed point of the molding machine. During processing, the blowing agent is exposed to sufficient heat to cause its decomposition, thus giving off the gas necessary to achieve the foaming process.

The equipment used for a low pressure structural foam process with chemical blowing agents is very similar to that used in injection molding. In fact, standard injection molding machines are used in many cases, giving the injection molder the flexibility of processing structural foam.

Low Pressure SFM parts generally show characteristic surface splay (or swirl marks) caused by gas bubbles escaping from the leading edge of the molten plastic and being smeared due to the laminar flow. **SAFOAM®** normally produces smoother surfaces than other chemical foaming agents, and techniques such as increased mold temperatures and fast injection speeds with increased mold pressure can reduce surface splay.

Co-Injection Machine

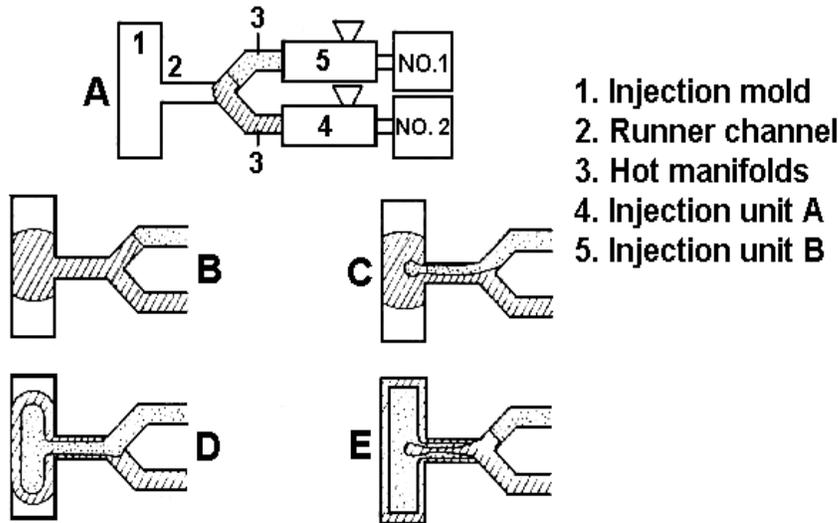


Figure 26. Schematic illustration of two-component molding:
 A. initial position
 B. injection of skin material
 C. transition phase
 D. injection of core material
 E. additional injection of skin material.

Co-Injection (Sandwich) SFM Machines

Co-injection (or sandwich) molding machines are capable of injecting both solid and foamed resins simultaneously through specially designed nozzle systems. This results in a solid outer layer covering a foamed core. Different resins can be used for skin and core, and since the skin is solid, the parts have an excellent surface quality. The ability to use a different resin for the core can also reduce costs.

Gas Counter-Pressure SFM

In the gas counter-pressure method, inert gas charged in molten polymer is contained until the entire shot is injected into the cavity. This prevents simultaneous expansion and produces a molded part with a smooth comparable to a solid part

Gas counter-pressure SFM utilizes a sealed mold and sequencing valves to pressurize the mold from a gas (e.g., nitrogen) pressure source. The purpose for the sealed mold is to control the gas pressure during injection. Use of SAFOAM® means that low gas counter pressure (40-60 psi) can be used. Sealing the mold usually involves machining an O-ring groove around the parting line to accept sealing material such as neoprene. Recommended groove dimensions are .170" deep by .182" wide (.432 x .463 cm), for a .188" (.476 cm) O-ring. It may also be necessary to seal ejector pins, the sprue bushing and moving slides or cores to maintain a seal adequate to hold 35-300 psi counter-pressure. Thus, the process should be considered as a tooling modification rather than one that requires specialized molding equipment.

The steps in the process are as follows: clamping the mold, pressurizing the cavity, injecting the resin, depressurizing and ejecting the part. This sequence has no significant effect on either cycle or cure time.

Just before the injection stroke begins, the mold is pressurized, and this pressure is maintained during about 75% of the injection stroke. Pressurization is accomplished by connecting the mold to a supply of filtered, dry

compressed air, or, more frequently, nitrogen. At this point the sequencing valves isolate the pressure source and also release the pressure from the mold. Solenoid-controlled valves regulate both gas intake and venting to depressurize the cavity. The gas pressure prevents escape of the foaming gas while the mold is almost filled and a solid skin is formed. The amount of gas is controlled by pressure transducers or regulators. Release of the mold pressure permits the gas to expand to fill the mold completely. (Figure 27)

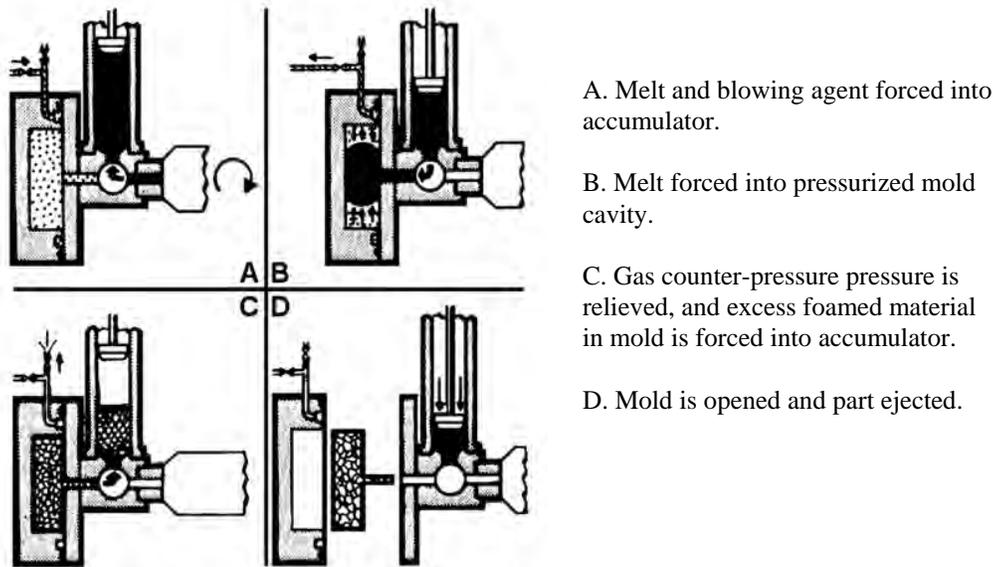


Figure 27.
Steps of
SFM
process.

The more blowing agent used, the higher the counter-pressure required to contain bubble growth, although 300 psi is usually sufficient. Table 4 shows the relationship of wall thickness and counter-pressure requirements.

Normal Counter-Pressure Range		
Wall Thickness	% Blowing Agent	Pressure Required
.150	5	400-500
.500	5	300-400
.250	5	200-300
.300	5	300-500

Table 4.

With a tightly sealed mold, gas counter-pressure processing produces a part with a cellular core and a smooth surface. Although a Class A surface is achievable, slight imperfections may occur, but are easily masked with a mist coat of paint. Density reduction is normally less than that of a similar part molded with the low pressure foam process. The exact amount of density will be determined by wall thickness, flow length, part configuration and processing conditions.

The gas counter-pressure method does offer a number of advantages. Because expansion of the polymer does not occur until the entire shot is injected, cell structure is evenly distributed throughout the part. This provides a predictable, uniform mechanical property profile and reduces the possibility of over-packed and over-stressed

sections that can result in poor dimensional control and warping. Counter-pressure produces a much thicker and non-porous skin, sealing in the gases that usually permeate the porous skin of conventional foam parts.

The addition of **SAFOAM®** to the mix allows parts to be painted directly from the mold without blistering. In addition, volatiles that sometimes rise to the surface of parts are kept in solution, greatly reducing liquid build-up in vent areas and on the parting line.

Direct-gassed Nitrogen SFM

The physical or nitrogen process requires specialized foam molding equipment in which nitrogen gas is metered directly into the polymer melt. The extruder section of the machine then mixes and meters the gas-containing polymer melt into a holding container called an *accumulator*. Here, the melt is held under pressure to prevent premature expansion. When the predetermined shot size is attained in the accumulator, a valve opens and a plunger forces the melt into the mold - only partially filling it to allow for expansion. It should be noted that one or more nozzles are used for filling the mold cavity, and that the number and location of these nozzles is determined after considering resin flow characteristics, part configuration, and other requirements of the application.

The mild foaming nature of **SAFOAM®**, an endothermic product, imparts a much higher level of control to the structural foam process. Use of **SAFOAM®** as a nucleating agent, which produces smaller bubbles, (up to 0.5% of 100% active **SAFOAM®** or **SAFOAM®** concentrate up to 2%) will give smoother surfaces and fewer voids, because it allows better dispersion of gas into small, numerous, uniform cells. This improved gas dispersion is essential in thin walls to obtain a significant weight reduction. A reduction of 10% or more is possible with **SAFOAM®** that is not possible with nitrogen alone.

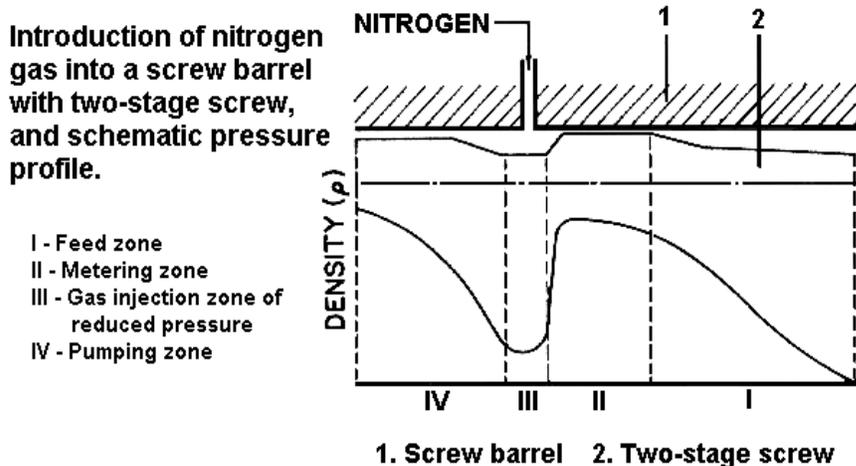


Figure 28.

Foaming Agent	Weight, ozs.	% Weight Reduction
Nitrogen	52.2	16.8
Exothermic	53.5	14.7
Endothermic (SAFOAM®)	53.5	14.7
Nitrogen + Exothermic	50.3	19.8
Nitrogen + SAFOAM®	48.1	23.3

Table 5.

High Pressure SFM

Specialized machines are used for high pressure SFM. A full shot of foamable resin is injected at pressures normal for the resin used. The mold cooling forms a solid skin and then the expansion of the melt occurs by retracting a platen or platens, core or slide activation, or a combination of the techniques, to enlarge the mold cavity.

The high pressure SFM process provides a better reproduction of mold cavity detail and a surface essentially free of surface splay, which often eliminates post molding finishing operations, if the correct processing conditions are used. It is also possible to vary density by controlling the mold expansion so that weight reduction is restricted to non-critical areas. Areas where high strength is required can essentially be solid resin.

Guidelines for high pressure foam molding regarding clamp requirements, material flow, and basic mold configuration are quite similar to those for injection molding. However, the increased complexity of expansion molds results in higher tooling costs than in low pressure molding.

Gas Co-Injection is a two-component molding technique. One component completely encapsulates the other, thereby allowing us to call the outside component the “skin”, and the inner component the “core”. No shuttling or rotating of tools or machine platens takes place, as in some other two-component processes. Both material components are shot through a common nozzle assembly. The two resin components are delivered from independent in-line reciprocating screw-type barrels, each with its own profile of temperature, pressure, and injection velocity. The two barrels share a common nozzle assembly, which is the backbone of the process. This nozzle assembly provides two concentric flow chambers for the respective resins.

Gas Assist Molding is being realized as a method that can offer significant cost reductions over other processes by taking certain operations out of the manufacturing sequence. Gas assist injection molding offers most of the manufacturing and design advantages that a customer looks for. These include good surface finish, good structure, and a shorter cycle time - all of which add up to a notable cost reduction.

Chemical Gas Assist Molding will enable designers to produce molding with thin and thick sections without processing problems, built in stresses or sink marks. To produce molded products that have wall sections between 0.04 inches and 0.4 inches or more in a single molding with ease, it is necessary to add only .1% to .5% active level of an endothermic blowing agent, such as SAFOAM®.

CoralFoam® is a process with selective foaming ability done outside the tool and is capable of achieving a Class A surface.

Over Molding is a process consisting of two shells molded in separate cavities. This technique allows uniform wall thickness and, if required, interior ribs or bosses as well as inserts. The shells are then temporarily attached by simple snap or press fits and installed into a second tool for overmolding. For best results in sealing, the flange temperature should be elevated prior to injecting the overmold material. In contrast to encapsulation, the surface temperature of the flanges allow the overmold material to adhere, creating a better seal. The best time for the seam to be injected is directly after the halves have been molded.

PROCESSING EQUIPMENT

Standard Injection Machines

Very satisfactory results can be obtained by processing *Reedy International's* foaming agents with foamable resins on standard injection machines. Quality parts can be produced as long as the machine and process limitations are recognized and considered in part/process design. These limitations include:

- Distance of flow from the nozzle, or single point of entry, to the most distant edge of the part. This shortcoming of flow can, in many cases, be overcome by increasing part thickness or improving runner design.
- Platen size, when inadequate, requires that molds be centered rather than placed for optimum results.
- Shot size is limited to the free area inside the barrel in front of the injection screw.
- Injection speed is limited to the design of the hydraulic system of the injection machine.

Chemical Structural Foam Machines

Like standard injection machines, chemical structural foam machines are designed for flow from a single point of entry into the mold. This, however, is where the similarity ends. The primary advantages of foam machines include:

- Oversized platens relative to clamp tonnage, enabling the use of large molds and the placement of these molds for optimum processing.
- Extremely high injection speeds in the range of 1,000 cubic inches per second.
- Large shot capacity. With these machines, material is "stored" in an accumulator and then injected into the mold. Since the size of the accumulator is virtually the only limitation on shot size, this is a considerable advantage over single-nozzle machines, which in reality are also limited by resin flow length, hydraulic system design and other process variables.

Physical or Inert Gas Machines

Designed specifically for processing structural foam resins, these machines utilize inert gas, usually nitrogen. A very long extruder charges a plastic accumulator, and the resin/gas mix is then injected through a manifold system feeding one or more nozzles.

Machines of this type, suitable for very large parts and multiple-mold production, require adequate temperature control, as well as streamlined flow in transfer tubes, manifold and nozzles, to properly process engineering structural foam.

Machine Settings

To achieve optimum results when foam molding resins, certain basic criteria must be maintained and monitored:

- sufficient clamping pressures
- proper mold temperatures
- proper melt temperatures
- proper injection, hold and back pressures
- proper injection speed

Each application may require independent determination of optimal machine settings within the ranges described for each material.

Clamping Force

A number of variables affect correct clamping, including projected surface area, thickness of the part, length of flow from the gate, injection pressure and injection speed. Figure 29 illustrates typical clamp requirements.

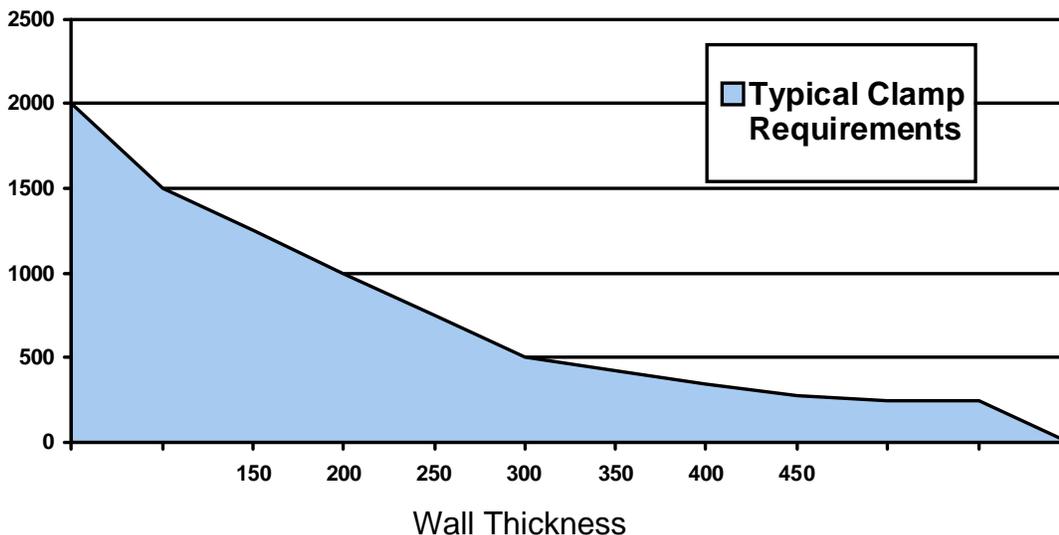


Figure 29.
Typical Clamp
Requirements.

Melt Temperatures

Although the flexibility of foamable resins allows them to be processed at relatively wide temperature ranges, the optimum temperature for a given part depends on the machine used, the part's geometry and complexity, the flow lengths required, and other considerations. *Reedy International* has technical help available at your request. Please find our contact information on www.reedyintl.com for support and assistance.

Mold Temperatures

Although it is possible to use molds without temperature controls, controlled molds are recommended for foamable resins, as they can substantially influence the following parameters:

- surface appearance
- molded-in stresses
- shrinkage/release
- dimensions
- juicing

Cooling

Efficient cooling is essential in SFM to minimize cycle times. It is defined as the time between the end of injection and the opening of the mold. The actual cooling time required may vary depending upon part size and complexity. It is very important where the part has thick sections, because that will determine the cycle. Cooling efficiency is much poorer when using epoxy molds. The benefits of **SAFOAM®** in this area are: 1) reduction in cycle times of 3-50%, 2) lower clamp forces, 3) improved filling due to lower viscosity, 4) lower internal stresses, 5) more molecular disorientation, and 6) lower filling temperatures.

Mold Cooling

To produce uniform, high quality Engineering Structural Foam Parts, mold temperature control is of utmost importance. Temperature differentials in the mold can cause unpredictable thermal expansion of large molds, creating alignment problems. Difficult-to-cool areas, such as high cores, should receive special attention so as to avoid hot spots. Water channels should be designed to maintain uniform temperature and avoid cold spots.

Proper mold temperature, aided by **SAFOAM®**, contributes to good surface finish, low molded-in stresses, uniform predictable flow, proper cell structure and uniform skin thickness.

Pressure Settings

Injection Pressure. Pressure should be sufficient to maintain constant injection speed. Pressure levels depend on:

- the type and grade of material
- material viscosity
- complexity of the part
- quality of the mold
- type of gating

Hold Pressure. Although usually not necessary, hold pressure can be utilized to delay screw drive, resulting in shorter residence time.

Injection Speed

The most efficient method of figuring injection speed is by measuring with a stopwatch or electronic device. The ideal injection speed is determined by several factors:

- part weight
- flow length
- wall thickness
- gate and runner design
- part configuration
- density and surface requirements

Functional Design

The structural foam process permits molded parts with sections thicker than can be realized in injection molding without sink marks and warpage problems. Traditionally, structural foam parts were designed with .250" (6.35mm) wall thickness. Now with engineering resins, parts can be designed with wall sections as low as .04" (1mm) and up to .4" (10mm) or higher with as little as .1% to .5% active level of an endothermic blowing agent such as **SAFOAM®**. The design criteria of a structural foam part must be considered before choosing the optimum wall thickness and material for an application. The main considerations are impact strength, rib design, boss design, and the strengths and moduli required for a properly functioning part. Flexural strength, flexural modulus, and tensile strength increase with decreasing wall thickness. This is due to lower density reductions and higher skin-to-core ratios seen more in thinner walls than in thicker ones.

Rigidity, load-bearing ability, and impact strength decrease with decreasing wall thickness, since they are more dependent on part cross-section than density reduction. The effect of wall thickness on rib and boss design will be covered later in this section.

Wall Thickness and Material Flow Lengths

In order to achieve thicker wall sections than injection molding with lower stresses and no sinks, it is important to maintain a good and consistent density reduction throughout the part. To obtain these characteristics, the part must be designed so the material can flow and readily fill the mold.

As all section thickness and ram pressure increase, the flow length of foamable resins increases. Higher melt and mold temperatures also add to flow length and the ability to lower density. **SAFOAM®** converts to liquid CO₂, which acts as a lubricant, improving flow and mold filling.

Figure 30 shows the relationship of wall thickness and flow for various resins.

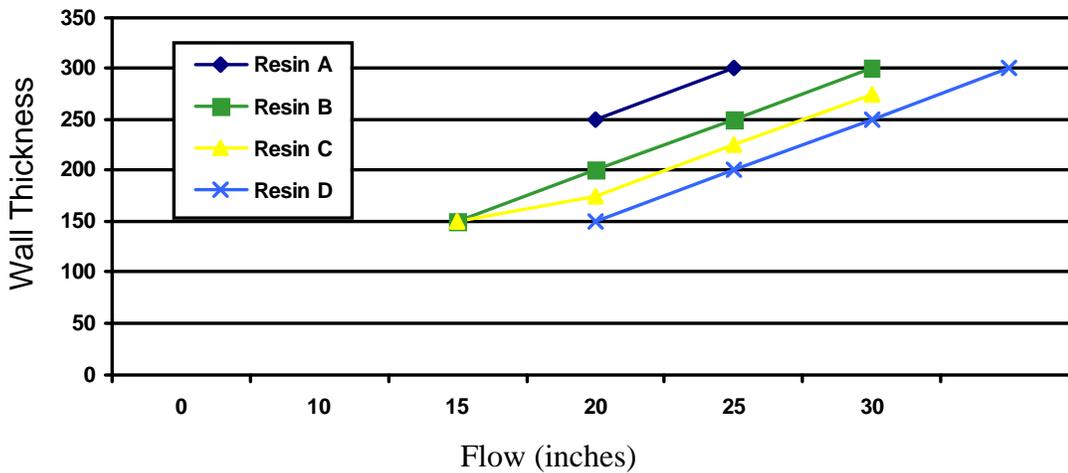


Figure 30.
Wall Thickness
vs. Flow.

In molding wall thicknesses below .250" (6.35mm), there is a higher resistance to flow which must be overcome by increasing injection pressure. Wall sections above .250" (6.35mm) have minimal opposition to flow. These variations in resistance to flow could result in lower achievable density reductions and shorter flow lengths in thinner walls than thicker ones.

However, recommended melt temperatures yield optimum physical properties. Exceeding these melt temperatures produces lower physical properties with little or no increase in flow length. If flow lengths for the chosen material exceed the recommended values, two methods can be employed to increase flow capability:

1. The cross-section-to-material flow can be increased by adding flow ribs or runners. These should not become too large or the material will flow down the rib and have trouble filling the flat sections and part cycle time may be increased.
2. By slightly increasing wall thickness by .030" - .0500", material flow capabilities may be enhanced to alleviate molding problems in difficult-to-fill areas such as between louvers, where a flow runner is not sufficient.

Transition Sections

Transition sections from thick to thin walls are more easily achievable without sink marks in structural foam than in injection molding. Still, uniform wall thickness should be maintained whenever possible to minimize restrictions to material flow.

Transition from thick to thin walls should be tapered for proper processing of the structural foam part. In molding parts with wall sections of varying thicknesses, it is often better to gate the part in the thin section and allow the material to flow into the thicker area.

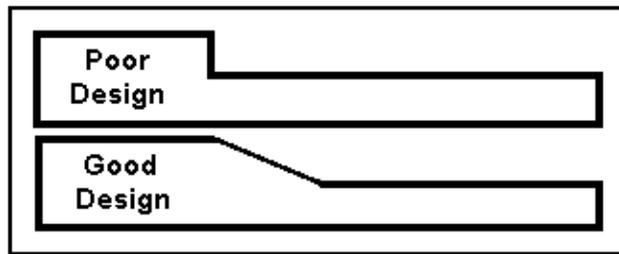


Figure 31.
Wall
Thickness
Transition.

Fillets and Radii

Sharp corners create points of stress concentration and restrict material flow in a structural foam part. They are often a major cause of part failure. The effect of fillet radius on stress concentration is shown in Figure 32.

K_t is the concentration factor and should be included in the equation for stress calculations. R/T is the ratio of the fillet radius to the part section thickness. Use as large a radius as possible on inside and outside corners to minimize this stress concentration and aid in mold filling. In most parts, the minimum inside radius should be .060". If the section is under load or subject to impact, a minimum radius of .125" should be adopted.

A radius equal to 0.6 times the wall thickness will provide a desirable fillet for practical purposes.

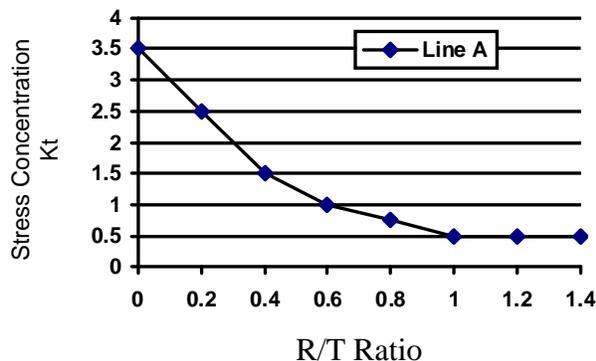
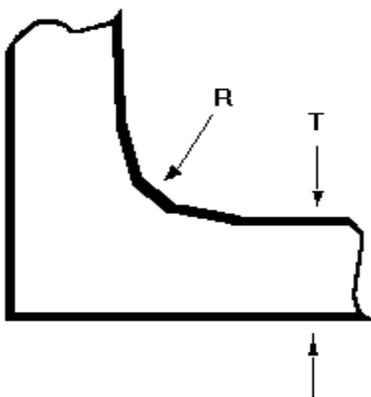


Figure 32.
Stress-
Concentration
Factors.

Tolerances/Warpage Control

Tolerance specification is extremely important in product design as it can directly affect both part cost and the ability to perform properly. The practice of blanket tolerancing on a drawing can result in unnecessary cost, both in the part and the tool.

The final dimensions on a part are affected by:

- thermal expansion and contraction
- processing conditions
- mold dimensions and design
- part configuration
- material selection

The key to tolerance and warpage control in a structural foam part is to achieve a good and consistent density reduction throughout the part. Some general guidelines for obtaining this density reduction and subsequent flatness are:

- Maintain uniform wall thickness throughout the part. Thick sections will not only cause increased cycle times, but may contribute to part warpage.
- Minimize restrictions to material flow. Omit ribs unless absolutely necessary and orient louvers in the direction of the flow.
- Remain within the flow length of a material to reduce the chances of part overpacking. Add flow ribs or gates close to openings to minimize overpacking.

Tighter tolerance and flatter parts can be realized by means of the structural foam process rather than injection molding, since lower induced stresses result from lower cavity pressures.

Draft Angles

As in injection molding, draft angles are necessary in structural foam molding. Because of the lower pressures involved in foam molding, smaller draft angles can be tolerated in certain cases. The wall thickness of a part will influence the amount of draft necessary to release a part. As wall thickness decreases, larger draft angles will be required. This is due to the higher cavity pressures in the mold which will make the part more difficult to release from the tool. Generally, an angle of 0.5 to 3° will provide sufficient draft to release a part. (Figures 33 and 34 show the result and taper per inch for varying draft angles.) On very deep draws such as tall standoffs and ribs, the increase in base width due to draft must be considered. A base that is too thick can result in sink marks, postblow conditions, or increased part cycle time. In certain situations, zero degree draft can be incorporated, depending on part configuration, material shrinkage, wall thickness, mold design, and mold material.

Textured surfaces generally require an additional 1° draft per 0.001 inch depth of texture. For best results, consult your engraver for depth versus pattern before specifying the draft requirements.

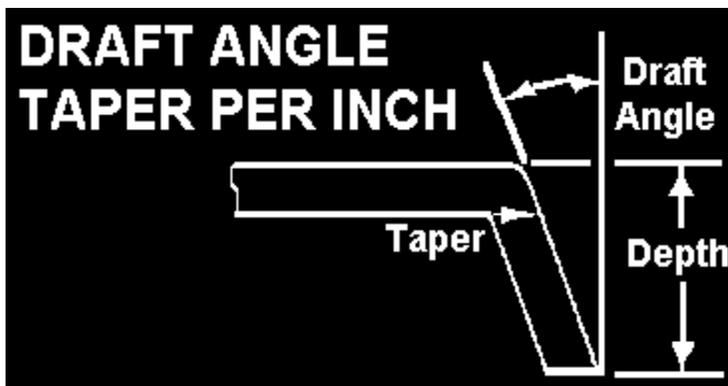


Figure 33.
Draft Angle
Taper Per
Inch.

	DRAFT ANGLES, Degrees						
	1/8°	1/4°	1/2°	1°	2°	3°	4°
Taper per inch	.0022	.0044	.0087	.0175	.0349	.0524	.0699



Figure 34.
Draft Angle
Taper Per
Inch.

Snap-fits

The superior rigidity and strength of structural foam parts permit increased utilization of snap-fits for assembly and for mounting heavy components in bases. A quick and extremely economical assembly method, snap-fitting eliminates the need for added screws, brackets, and fasteners, significantly reducing labor and assembly costs.

Stress, deflection, and strain are the primary criteria in determining the stiffness and assembly force required for optimum performance of snap-fits. Equations for a cantilevered beam with constant cross-section are used as models when designing snap-fits in structural foam parts:

$$\sigma = \frac{FLC}{I} \quad y = \frac{FL^3}{3EI} \quad \xi = \frac{3yC}{L^2}$$

Figure 35.

Where:

σ = stress	F = Load
y = deflection	L = Length of Beam
ξ = strain	E = Modulus of material
I = Moment of inertia of cross-section	C = Distance from neutral axis to extreme fiber

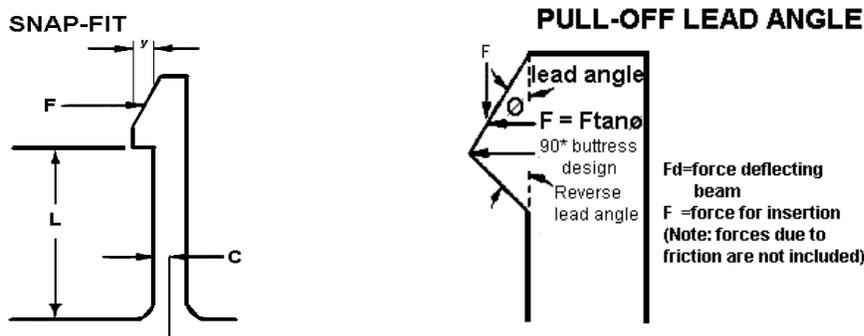


Figure 36.
Snap-Fit and
Pull-Off Lead
Angle.

To facilitate pull-off, an angled lead can be designed to function in the same way as the push-on lead angle. To stay within the maximum allowable strain, the height of the lead ramp should never exceed the calculated deflection.

If the snap-fit is designed as a tapered beam, a separate set of beam equations must be used. The primary design criteria in this analysis are given by the following equations:

$$y_t = \frac{-6F}{Eb} \left[\frac{LR}{h(1-R)} \right]^3 [2LnR + 3 + R^2 - 4R] \text{ Where } R = \frac{h}{b}$$

$$\sigma = \frac{6FL}{bh^2} \qquad \xi = \frac{3yh_s}{2K_s L^2}$$

Figure 37.

Where

- b = Beam width
- h_o = Height of tapered beam at tip
- h_s = Height of tapered beam at base
- K_s = Proportionality Constant = (y_t/y_c)

y_t = Deflection of tapered beam
 y_c = Deflection of constant thickness beam

The above analysis considers the theoretical perpendicular force required to deflect the beam a specified distance. In actual performance the force is applied via a lead-in angle. Thus the actual force required to bend the beam is a function of the tangent of the lead angle (i.e., F_{insertion} = F_{bending} tanØ). A small lead angle gives a lower assembly force. For example, changing the lead angle from 45° to 30° decreases the lead-in force by 42%.

The maximum stress level can be varied by changing the required deflection for insertion (y), the length of the beam (L), the thickness of the beam (h), or a combination of all three.

Hinges

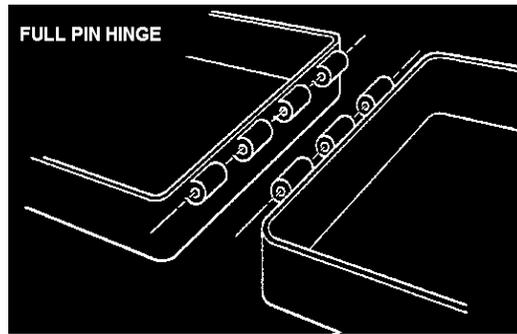
Properly designed, integral structural foam hinges offer fatigue strength comparable to metal, while eliminating costly bracketry and assembly time. Hinges can be designed to be either hidden or visible, depending on their location in the part. A number of basic hinge designs are practical for structural foam parts, several of which are discussed below.

Full Pin Hinge

Design. The full pin hinge usually consists of barrels molded on each mating piece. Each of these barrels is cored through and a metal pin is extended the full length of the part. Since disassembly requires removal of the pin, the lift-off feature is not practical with this type of hinge.

The length of the hinge and the diameter of the metal pin are the determining factors in whether the full pin hinge can be molded. When the length of the hinge is restricted by the permissible length of the side pull, a partial pin hinge may be necessary.

Figure 38.
 Full Pin
 Hinge.



Load Bearing Ability. The full pin hinge has the highest load-bearing ability of any of the types discussed, because the metal pin distributes the loading the full length of the part.

Cost. This type of hinge also has the highest tooling cost. Both mating pieces require side pulls to produce a through-hole the entire length of the part.

Partial Pin Hinge

Design. The design of the partial pin hinge is similar to the full pin hinge except that the center barrels are cored to produce a U-shaped section, and pins are inserted from each end. This type of design permits long hinges to be molded with side pulls only at each end. The partial pin hinge does not allow a lift-off door.

Load-Bearing Ability. When the hinge is in the open position, the U-shaped sections assist in load bearing and provide a uniform appearance along the length of the hinge.

Cost. The tooling cost for this design is less than for the full pin hinge because only the two barrels at the ends require side pulls. The central barrels can be molded with straight pull tooling.

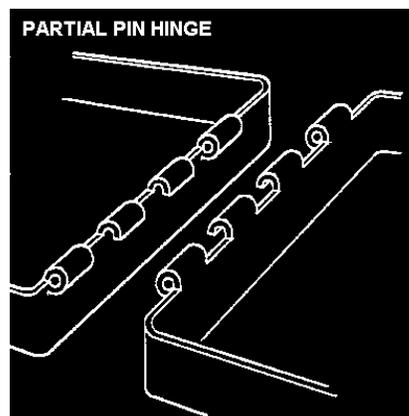


Figure 39.
Partial Pin
Hinge.

Projected Pin Hinge

Design. The projected pin hinge normally has two barrels molded on each mating piece. Pins projecting from the barrels on one piece fit into holes in the other piece. In this design, the part with the pins is easily removed to facilitate access for repairs, etc.

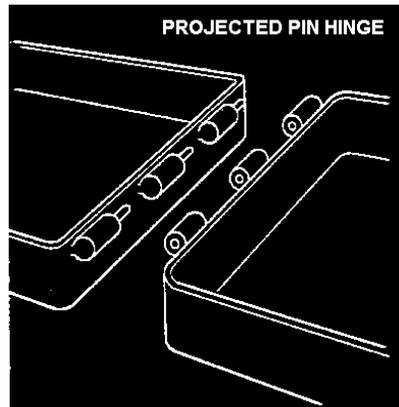


Figure 40.
Projected Pin
Hinge.

Load-Bearing Ability. When both mating surfaces are flush and a load is applied, the latch and hinges withstand the load. However, when the mating surfaces and hinge are in the open position, the load-bearing ability of the hinge is relatively low, since only the small cross-sectional area of the projected pins are withstanding the load in shear.

Cost. Tooling cost for projected pin type hinges is relatively low, since only the part with the holes requires side pulls in the tool.

Simulated Hole Hinge

Design. This design incorporates a hole in the barrel-shaped pieces without the use of side pulls. This is accomplished by coring U-shaped areas on the outsides of the barrels - two facing downward and one facing upward. Mating the barrels creates a through-hole to accept a metal pin. This type of hinge does not permit easy lift-off, since the entire pin must be removed. Also, completely hidden hinges are not possible with this design due to tool pull.

Load-Bearing Ability. The load-bearing ability of the simulated hole hinge can be improved by increasing the bearing surface on the outside U-shaped portions of the barrel.

Cost. The tooling cost for this type of hinge is potentially the lowest of the types discussed since no side pulls are required for either mating piece.

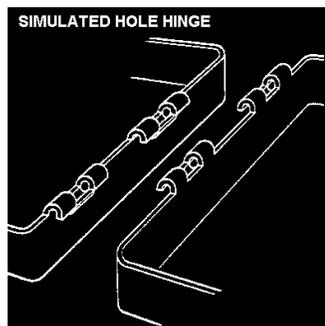


Figure 41.
Simulated
Hole Hinge.

Bosses

Bosses can be easily incorporated into structural foam parts to accept fasteners and support components. In many applications, the addition of molded-in bosses, mounting pads, stand-offs and retainers can replace costly brackets and miscellaneous small metal part assemblies.

In Engineering Structural Foam, there appears to be an optimum boss diameter for the best insert performance. Experimentation has shown the optimum boss diameter to be 1.6 to 2.0 times the diameter of the cored hole, with a minimum boss wall thickness of .080" (2mm). When a boss wall thickness becomes too thin, the walls will have higher stress concentration and will be subject to breakage. If the boss wall becomes too thick, there will be a greater chance of voids in the boss and it will behave somewhat like a pressure vessel. Hoop stresses will increase with increasing wall thickness due to the distribution of material in a cross-section. Thicker bosses are not necessarily stronger; they can result in an increased cycle time and ensuing part cost.

When utilizing bosses with wall thicknesses less than .120" (3mm), gussets or connecting ribs should be used for added strength. Bosses should be cored whenever possible to prevent the formation of a thick section in the part. Generous fillets should be designed in order to avoid stress concentration and resist torque loading.

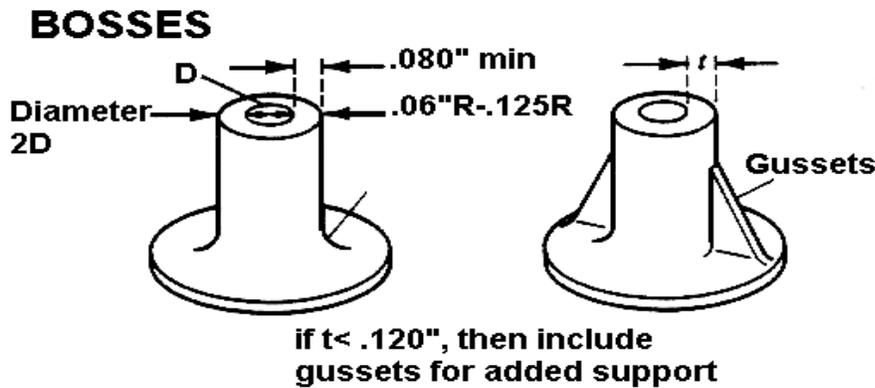


Figure 42.
Bosses.

Ribs

The addition of ribs will increase the rigidity and load-bearing capability of a structural foam part without increasing the wall thickness. In addition, ribs can reduce the cycle time and materials cost associated with thicker wall sections. Unlike injection molding, the structural foam process permits the use of thicker, and thus shorter, ribs for maximum rigidity opposite appearance surfaces without risk of sink marks. The surrounding wall thickness and resulting density reduction determines the thickness of ribs that can be designed without sink marks. Tall ribs that become very thin at the tip may cause problems with mold filling and will be areas of higher stress concentration.

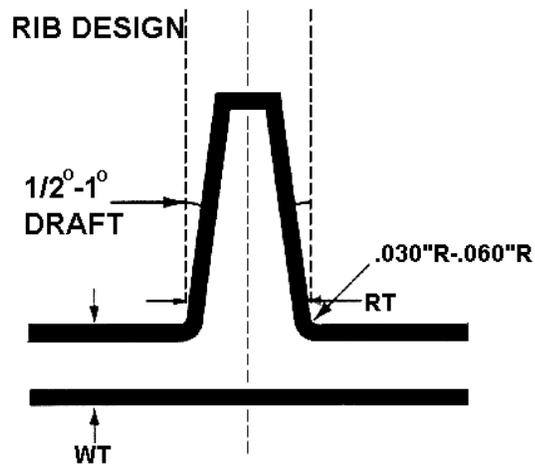


Figure 43.
Rib Design.

Guides

Molded-in structural foam guides can be used to locate printed circuit boards or any modular units, eliminating the need for metal bracketry or metal bending operations. Because of the strength and rigidity of the material, guides can be designed with snap-stops. The formulas given for snap-fits can be used to determine performance criteria for molded-in snap-stops. Horizontal card guides can also be molded in the center of a part with straight pull tooling technique.

Zero degree draft on guides is possible over limited areas when the wall section of the part is over $.200''$ (5mm). With wall sections less than $.200''$, the draft angle should be increased to $.5^{\circ}$ since cavity pressures are higher and the part will have a greater tendency to stick to the mold.

A technique to get the solid fit that 0° draft provides on a card guide without pulling it a long distance is to start with 0° draft for one inch where the card meets with the mother board and then increase the draft to $.5^{\circ}$ - 1.0° for the remaining distance.

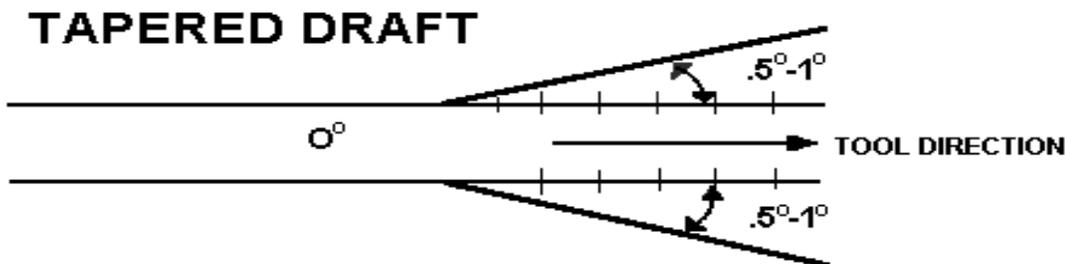


Figure 44.
Tapered Draft.

Louvers

Molding in louvers in structural foam parts eliminates costly metal stamping operations. In addition, louvers provide cooling capabilities to offset the insulative properties of plastic. Deflectors can also be molded in to channel the flow of air for maximum cooling.

Whenever possible, louvers should be oriented in the direction of material flow. In designs where this is not feasible, a runner should be located between louvers to channel the material to the outside of the louvers.

To utilize straight pull tooling for louvers located on the side of a structural foam part, the louvers can be designed to extend over the top corner of the part. When louvers are molded with a side pull, a witness line results around the core. Costly sanding operations are usually required to remove this line. Recess the area 0.020" and witness lines appear to be designed-in, thus reducing finishing costs.

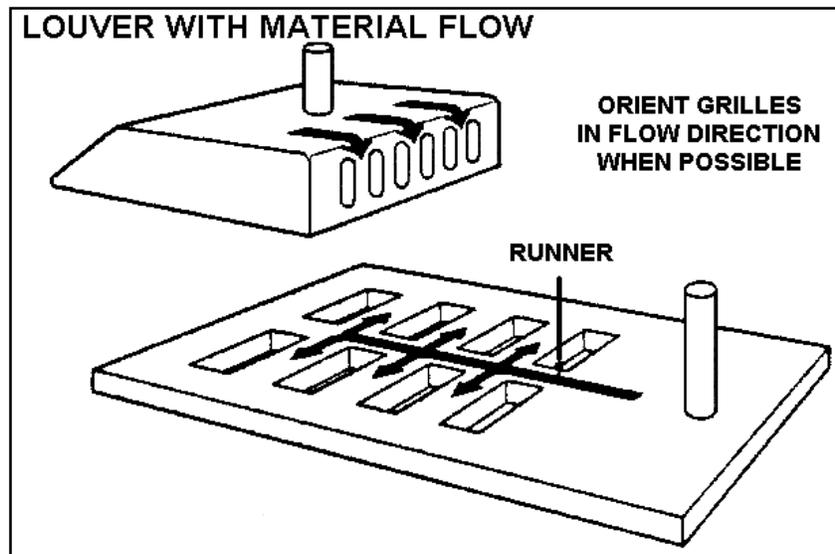


Figure 45.
Louver with
Material
Flow.

Nozzle Design

The structural foam process requires control of the nozzle to eliminate drool and maintain fast flow. Since this must be accomplished without using decompression or "suck back" so that the material does not foam prematurely, the most desirable method of nozzle control is a well-designed shut-off that will not restrict injection speed.

If a nozzle shut-off is not available, the effects of the drool may be minimized by closely controlling the temperature of the tip of the nozzle.

The nozzle land should be .188" (.476 cm) and the orifice should be .188" (.476 cm) minimum. When using a long nozzle, it is recommended that two heating zones be employed: one to maintain melt temperature in the main body and one to heat the tip for drool control.

In the nitrogen process, Teflon®, or other non-thermally-conductive nozzle tips are extremely helpful in preventing nozzle "freeze-off," as well as creating a better seal than the normal metal-to-metal nozzle.

Molds

Many materials have been used in the construction of structural foam production molds, and the choice of mold material depends upon a number of factors such as part design (plastic material and geometry), number of parts to be produced, plastic molding process and mold design. The particular usefulness of steels stems from the unique combination of properties achievable through alloying additions and suitable heat treatment.

Specific properties of steels that can be modified to achieve desirable characteristics are: hardness, wear resistance, corrosion resistance, strength and toughness. No other class of mold materials is as versatile as steel. While cast molds have been produced in aluminum, beryllium-copper and alloys with satisfactory results, machine molds are most commonly constructed of aluminum, mild steel or pre-hardened steel.

Structural foam molds are usually designed to withstand 1,000 psi, but the actual pressure is in the range of 300-400 psi. These low molding pressures permit the use of lower cost molds and “soft” metals. Therefore, in low pressure SFM, molds can be made of less expensive materials such as forged or supported cast aluminum, Kirksite®, steel, or epoxy, because of the low clamping forces required.

Steel molds are generally used in high pressure SFM where high clamp tonnages are required. Steel is specified primarily because of its abuse resistance. The softer materials scratch easily, lose their fine finish during long production runs and require care and high maintenance.

The most common tool steels used for plastic molds are AISI P-20, H-13, S-7, A-2 and A-6. The introduction of new molding materials, higher temperatures, and higher injection and clamping pressures has created a need for better corrosion resistance, improved control of mold temperature and higher compression strength. A plastic manufacturer’s most important demands on tool steel for long lasting molds are as follows:

- high compression strength
- excellent corrosion-resistance
- easy machinability
- easy repairability
- good wear-resistance
- good thermal conductivity
- good polishability

There is always a risk of indentation of the parting lines, but the risk decreases with increasing compressive strength on the part of the tool steel used. High compressive strength is also desirable because the tools are liable to mechanical damage during transport and installation. In some cases, the tools are nitrided to prevent the cavity from becoming scored or otherwise spoiled.

To improve the strength of the plastic product, an addition of glass fiber, asbestos, wood fibre, etc., is frequently made. These substances have an abrasive effect on parting lines, runner gates and inlet nozzles. For such products, it can therefore be advisable to choose a particularly wear-resistant tool steel.

Corrosion Resistance. Practically all molds used for molding come into contact with cooling water. The cooling water is sometimes contaminated with small amounts of acids and salts. In all water-cooled parts, such as inserts, molds, frames and holders, corrosion is likely to occur. Some plastics are also corrosive to the mold material. After a time, therefore, the tool must be taken out of service and cleaned.

A brief pause in production and high humidity can cause the mold to perspire, which causes the mold to rust, especially in seams. This corrosion can cause serious problems with dismantling the tool, since the parts become difficult to separate.

Thermal Conductivity. The limitation in maintaining a high production pace lies in the ability of the mold to conduct heat away from the plastic item. In this context, the thermal conductivity to the material is obviously important, as are heat transfer between tool and coolant and heat transport through the coolant.

Heat Treatment. The purpose of heat treating a finished tool is to retain suitable mechanical properties, such as hardness, toughness, and strength. The principal problems that arise in association with heat treatment are distortion and dimensional changes. To minimize these problems, the tool should be stress-relieved after rough machining. Some changes are inevitable during hardening, and while it is possible to limit and control them to a certain extent, the safest way is to use pre-hardened steel, for which no additional heat treatment is required.

Sprues, Runners and Gates and Gate Locations

Sprues, runners and gates are normally made as generous as possible, but not so large as to cause an increase in cycle time or in the amount of regrind generated.

Sprues

Sprues are usually tapered from the nozzle to the mold to reduce melt expansion to a minimum. A standard sprue bushing of .5" to .75" taper per foot (1.270 to 1.906 cm per meter) with a minimum "O" dimension of .219" (.557 cm) is recommended for use in injection machines. They should be of the minimum length possible to avoid cycle time increases and reduce unnecessary shear and to minimize adverse effects on polymer flow and injection speed.

Runners

Runners should be large enough to allow fast injection speeds. They should be designed to ensure that pressure is maintained on the melt to prevent premature expansion. On multi-cavity molds, the runner system should be designed so that mold fill-rates are balanced.

Full round and trapezoidal runner profiles are recommended in molds for Engineering Structural Foam. Full round runners should be a minimum of .375" (.952 cm) diameter, and depending on flow length, injection speed and part weight, can be as large as .75" (1.906 cm) diameter. Runners should be kept as short as possible. Cold slug wells should be included at the end of primary and secondary runners.

Gates

Gates should be sized to ensure fast and complete fill of the mold. Width and thickness of gates are usually smaller than part thickness to make removal from the part easy and to prevent an increase in cycle time.

Where possible, gates in foamed parts should be in the thinnest area to allow the low pressure melt to flow more easily into the thicker sections, and to ensure that the thinner sections are completely filled.

Engineering Structural Foam resins can be molded using common gate designs. The most frequently used types are direct-sprue and edge gates. Tunnel and pinpoint gates can be used, but should be limited to small parts with short flow lengths. Gates for structural foam perform the function of balancing flow to all parts of the mold. The gates, however, should not restrict injection speed. Gate land length and design can determine surface quality when trying to achieve an as-molded aesthetic part. If the gate and nozzle are increased and the vents are decreased, maintaining tool pressure of 35 psi, the increased mold pressure would greatly improve surface quality by eliminating splay.

Gate Locations

The following are important considerations in selecting gate locations:

- gates should allow for uniform flow lengths.
- gates should be located so as not to trap air.
- gates should favor flow into thin areas.
- gates should move weld lines away from impact and appearance areas.
- gates should be located in areas that will allow for easy degating and finishing.

Vents

In order to properly fill molds, it is essential to evacuate entrapped air and gas from the mold cavity. This is most readily accomplished by employing multiple vents in the mold. The amount of venting required depends upon the volume of gas to be evacuated and the rate at which it must be evacuated. High temperatures and air restriction as the mold fills can also cause burning of the part in the vent area.

The following guidelines are recommended when venting a mold:

- Machine relief slots to a width of .500" to .750" (1.270 to 1.906 cm) and a depth of .032" (.795 cm). Allow .25" (.635 cm) land at the extremes of flow (in the far corners, for example) and at 3" (7.62 cm) centers around the parting line. It is extremely important not to connect the relief slots.
- Machine vents 0.003" (.008 cm) deep at the extremes of flow and at difficult-to-fill areas.
- Progressively open vents as required to produce a part of consistent density and acceptable surface. (NOTE: Injection speed will affect density and surface; adjustments in injection speed should be made at the same time vents are being modified, so that an optimum combination is found.)

Figures 46, 47 and 48 illustrate typical venting methods that may be used alone or in combination to vent molds.

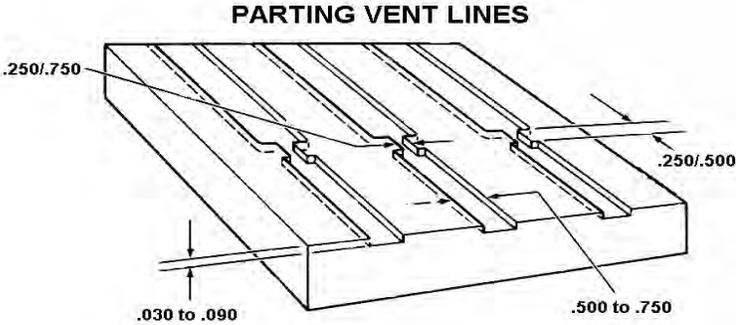


Figure 46. Parting Vent Lines.

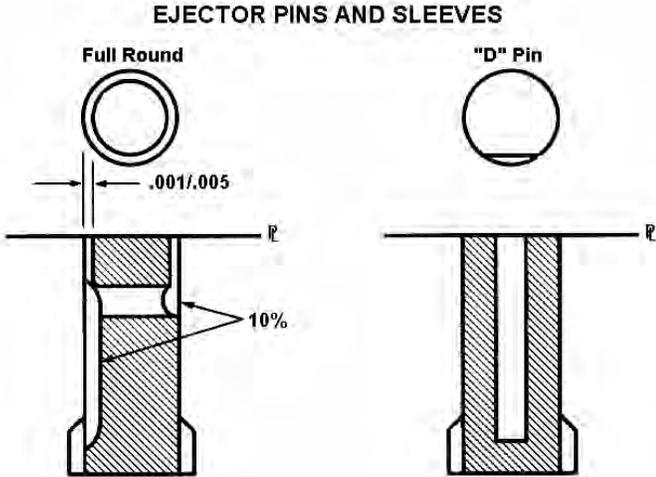


Figure 47. Ejector Pins and Sleeves.

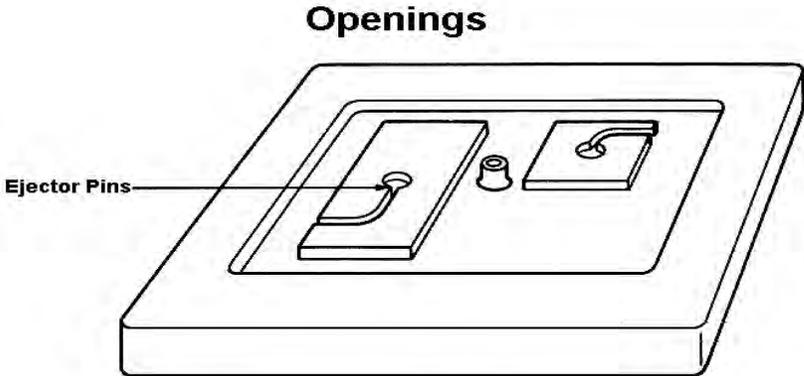


Figure 48. Openings.

SECONDARY OPERATIONS

Painting

Durable paint systems have been developed for structural foam parts which require fewer finishing steps than for metal fabrications. These systems add color, gloss, texture and solvent, UV and mar-resistance to the substrate.

Although well-molded parts can be coated without any surface preparation, structural foam parts are often lightly sanded to promote paint adhesion, or to remove surface imperfections that cannot be remedied by tooling changes or processing improvements. Parts should be totally free of surface contamination before painting. Counter-pressure paint systems sometimes differ from those used for standard structural foam.

SAFOAM® uses CO₂ as the foaming gas. CO₂ will diffuse through most plastics very rapidly, allowing for immediate painting with either water-based or solvent-based paint.

Assembly and Fastening

Virtually all fastening systems associated with thermoplastic assembly can be used on structural foam parts. When selecting a fastening system, the supplier of any particular system can make recommendations for optimizing performance of that system in Engineering Structural Foam. The actual testing of a system in an application will always be the best method to insure reliability.

Self-Tapping Fasteners. These fasteners are viable for permanent assemblies or when less than ten field assembly/disassembly operations are anticipated. Structural foam's relative freedom from molded-in stresses, coupled with its compressible cellular core, makes thread rolling screws preferable to the thread cutting variety. Cored holes should be molded whenever possible to obtain maximum performance.

SELF-TAPPING FASTENERS

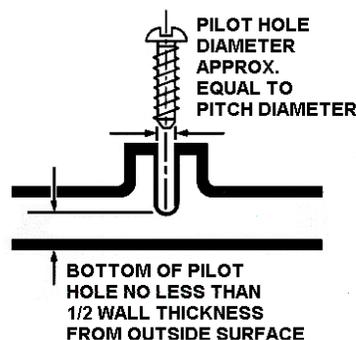


Figure 49.
Self-Tapping
Fasteners.

Ultrasonic Inserts. One of the most popular methods of assembling Engineering Structural Foam parts is through ultrasonic inserts. These inserts perform very well, plus provide the flexibility of repeated assemblies/disassemblies for the foam parts.

In order to obtain maximum performance from ultrasonic inserts, correct hole sizes are critical. Wherever possible, the hole should be molded into the foam part. Drilled holes will yield much lower performance value because their interior surface will not have a continuous skin.

Expansion Inserts. Expansion inserts are placed in pre-formed holes and expanded against the side of the hole by insertion of a screw. These inserts offer lower performance than ultrasonic inserts, but are more economical and suitable for many common assemblies.

Expansion insertion causes cold forming of the material, and while the compressible cellular core makes Engineering Structural Foam parts less susceptible to residual stress, the following guidelines are recommended to minimize insertion and high hoop stresses:

1. Boss diameters should be approximately two times the diameter of the insert.
2. When designing component parts for clearances, be sure that the insert and not the plastic carries the load.
3. Heating cycles associated with finishing a structural foam assembly may cause relaxation and loosening of inserts. Finished parts should therefore be checked during production to guard against insert failure.

Molded-In Inserts. Molded-in inserts are compatible with Engineering Structural Foam resins. When using these inserts, reinforced grades of material are generally preferable due to their lower coefficients of thermal expansion. However, suitably designed inserts can be used with unreinforced grades of material. If molded-in inserts are required, thorough testing for any possible part cracking or insert loosening is advised.

Press Fits. Press fits can be used to attach metal pins, bushings or inserts to a foam part, provided correct diametral interferences are predetermined in the design. Long-term reliability will depend upon the creep behavior of the material used.

Assuming the metal shaft does not deform greatly when pressed in, a simplified Lamé equation for thick walled cylinders can be used to determine the amount of diametral interference:

$$\Delta D = \frac{S_d D_s}{L} \left(\frac{L + \nu_h}{E_h} \right)$$

$$L = \frac{1 + (D_s / D_h)^2}{1 - (D_s / D_h)^2}$$

Figure 50.

Where:

D = Diametral interference
S_d = Design stress
D_h = O.D. of hub
D_s = O.D. of shaft
E_h = Tensile modulus of hub
L = Geometry factor
ν_h = Poisson ratio of hub

The holding and assembly force may be approximated by multiplying the joint pressure, joint area, and coefficient of friction of the materials together.

$$F = PA\mu_f = \frac{S_d}{L} (\pi D_s \ell) \mu_f$$

Figure 51.

Where:

F = Assembly force
P = Joint Pressure
D_s = Shaft diameter
l = Length of press fit
μ_f = Coefficient of friction
S_d = Design stress

If the press fit assembly must operate at elevated temperatures the strength of the interface will be reduced due to changes in thermal expansion and the resin's modulus of elasticity. To calculate the loss of interface due to thermal expansion of a metal shaft pressed into a structural foam hub:

$$D - D_o = (\alpha_h - \alpha_s) D_o \Delta T$$

Figure 52.

Where:

D_o = Original diameter
D = Diameter at operating temperature
α_h = Coefficient of thermal expansion of hub
α_s = Coefficient of thermal expansion of shaft
ΔT = Change in temperature

When examining long-term performance, the apparent modulus of the structural foam resin determined from the creep curves must be utilized.

Ultrasonic Bonding. Engineering Structural Foam allows the designer to use ultrasonic assembly methods, including:

- Insertion - the process whereby a metal piece is implanted in the plastic.
- Staking - the process of melting and forming the upper portion of a stud so as to retain another material, usually metal.
- Spot Welding - the process of creating small localized bonds between two parts.

Continuous and large area welding techniques are not generally recommended for use with foam, since the cellular core tends to dissipate much of the ultrasonic energy in a far field weld.

Vibration Welding. Vibration welding is a relatively new process for bonding large parts. Basically a low frequency friction weld, it is capable of producing strong, pressure-tight joints. This method lends itself very well to Engineering Structural Foam parts that require permanent loads over large areas. Although butt joints are normally used in this process, the geometry of the part may require a flange to increase rigidity. Since the process resembles ultrasonic welding, there may be considerable flash during bonding, and cosmetic flash traps are recommended on critical appearance surfaces.

Sonic and vibration welding techniques generally perform better in thinner wall designs than in thicker ones. As the wall section is widened, a greater amount of energy is absorbed by the cellular core, and bonding becomes more difficult to achieve.

Solvent Bonding. Foamable resins can be solvent-cemented to themselves or other plastics using a number of commercial solvents.

Adhesive Bonding. Solventless adhesives can be used to bond foamable resins to themselves or other plastics. Since each application has unique requirements of flexibility, temperature resistance, etc., careful selection of adhesive is recommended. Epoxies, urethanes and silicones are typical candidates for adhesive bonding.

GENERAL GUIDE FOR LOW PRESSURE SFM SET-UP

1. Injection pressure should be set high enough to provide the maximum injection speed possible without burning. Keep in mind that some resins are sensitive to high shear. High speed injection usually gives improved surface quality.
2. Back pressure should be used (100-200 psi) to give consistent, even filling and mixing during plastication.
3. Screw speeds of 20-50 RPM are usually used.
4. Shot size should be set about 25% less than the mold volume, although the desired weight reduction may specify the exact setting.
5. Minimum cushion is used (i.e. the shot size should be such that the screw nearly bottoms out during injection). Holding pressure should not be used.
6. The rear zone temperature should be low enough to prevent premature decomposition and gas loss through the hopper.
7. Mold temperatures affect surface finish, skin thickness, and cycle time. Hot molds give a glossier surface, thinner skins and longer cycle times. The normal range is 60-160°F (16-72°C), but higher or lower temperatures are not unusual.
8. Quenching a part in water immediately on removal from the mold is helpful in reducing cycle times and post-blow in parts with thick sections.
9. Cycle times depend on the polymer and part thickness and mold temperature. SAFOAM® gives lower cycle times than exothermic foaming agents.
10. Vent size and location should be decided upon by experimentation with the mold using metal shims before cutting the mold.
11. SAFOAM® tends to clean out residues of exothermic chemical foaming agents and other additives (i.e. colors) over time. The CFA residues can cause misleading results until they are no longer present.
12. Although SAFOAM® poses no problems in painted parts on its own, any exothermic residue in re-grind can cause blistering or pin-holing. Parts with exothermic re-grind should be treated as exothermic CFA parts.

INCORPORATION OF SAFOAM® IN SFM

There are several ways of incorporating **SAFOAM®**, including:

1. Pre-blending/tumbling with the resin.
2. Auger feeding directly into the hopper throat using the “screw retract” signal to control the auger.
3. Using a meter-blender mounted above the machine hopper.

SAFOAM® is added as a percentage by weight of resin.

ENGINEERING STRUCTURAL FOAM RESINS

PROPERTY	UNITS	TEST METHOD
PHYSICAL		
Solid Density *	oz/in ³	ASTM-D792
Solid Specific Gravity*		ASTM-D792
Foam Molded Specific Gravity		ASTM-D792
Wall Thickness	Inches	
Water absorption • 24 hrs. 73°F @ Equilibrium 73°F	%	ASTM-D570
Mold Shrinkage Flow ** Mold Shrinkage Cross Flow	10 ⁻³ in/in	ASTM-D1299
THERMAL		
Deflection Temperature @ 66 psi Under Load @ 264 psi	°F	ASTM-D648
Thermal Conductivity	BTU/hr/ft ² (°F/in)	ASTM-C177
Specific Heat	BTU/lb./°F	
Coefficient to Thermal Expansion	10 ⁻⁵ in/in/°F	ASTM-D696
Flammability Rating		US 94*** ASTM-E162
UL Temperature Index - All Properties	°F	UL 746B
MECHANICAL		
Tensile Strength	Psi	ASTM-D638
Elongation at Break	%	ASTM-D638
Tensile Modulus	Psi	ASTM-D638
Flexural Strength	Psi	ASTM-D790
Flexural Modulus	Psi	ASTM-D790
Compressive Strength (10% deformation)	Psi	ASTM-D695
Shear Strength (ultimate)	Psi	ASTM-D732
Creep at 500 psi - 73°F, 1,000 hrs.	% strain	ASTM-D674
Falling Ball Impact	ft/lbs	GE Test Method
ELECTRICAL		
Dielectric Strength	Volts/ mil	ASTM-D149
Dielectric Constant 100Hz		ASTM-D150
Dissipation Factor 100Hz		ASTM-D150
Surface Resistivity	ohm x 10"	ASTM-D257
Volume Resistivity	ohm cm x 10"	ASTM-D257
Arc Resistance	Seconds	ASTM-D495
High Voltage Arc Tracking Rate	in/min	UL 746A
High Ampere Arc Ignition	No. Of Arcs	UL 746A
Comparative Track Index	Volts	UL 746A
Hot Wire Ignition	Seconds	UL 746A

* Specific gravities listed are for comparative purposes and are not necessarily indicative of specific gravities obtainable in molded parts. All ASTM general test methods are followed, except specimen size with four-sided skin is varied to accommodate structural foam processing.

** Molding equipment, processing parameters and part configuration should be considered when designing for tight tolerances. For tight-tolerance molding, a tool development program might be recommended.

HEAT TRANSFER AND AGING OF CLOSED CELL FOAM INSULATION

HEAT TRANSFER MODEL

The heat transfer model was developed by Mark Schuetz and Leon Glicksman at the Massachusetts Institute of Technology. Schuetz has shown that the total thermal conductivity of foam is a combination of three contributions: conduction through the polymer, conduction through the cell gases, and thermal radiation. Convection as a heat transfer mechanism in closed cell foam insulation is negligible.

Conduction

Microscopic analysis of the cell structure in a polyurethane foam shows that the cell faces are composed of thin membranes which are bounded on all sides by thick elements termed ‘struts’. Each strut forms at the intersection of three cell walls and results from drainage during foam formation. The thin cell membranes and relatively thick struts comprise the two structural elements in the foam geometry. Conduction through the polymer has been analyzed by considering the distribution of polymer material between cell walls and struts and by evaluating conduction in the actual cellular structure through upper and lower limiting models.

By staggering the cells, the effect of the tortuous path of conduction can be determined. Heat flow through randomly oriented planes and randomly oriented sticks gave the same analytical results as the preceding analysis. This suggests that the conduction term is essentially independent of cell geometry. For any given cellular geometry, the cell walls will be statistically oriented for greater heat flow as compared to the struts.

The cell gas conductivity, k_g , can be combined with the polymer conduction term when the cell gas composition is uniform within the foam cross section. The case when the cell gas composition varies across the foam thickness will be discussed later in the manual. The upper and lower limits to the conduction term can now be summarized. The upper limit of the conduction model is given by:

$$k_{s+g} = k_g + \left(\frac{2}{3} - \frac{f_s}{3} \right) (1 - \delta) k_s$$

Figure 53.

Three parameters must be experimentally obtained from the foam to evaluate the polymer conduction term in Figure 53. The polymer distribution parameter, f_s , is the fraction of the polymer material contained in the struts of the foam. An experimental technique to calculate this parameter is presented in the Gas Diffusion Model section of this guide. Note that the coefficient of the polymer conduction term reduces to the two limiting

results when f_s is zero (no struts) and f_s is unity (no walls). The porosity, δ is the fraction of the total foam volume which is occupied by the cell gases and is given by the following,

$$\delta = \frac{\rho_s - \rho_a - \rho_f}{\rho_s - \rho_g}$$

Figure 54.

where ρ_s , ρ_a , ρ_f , and ρ_g are the densities of the polymer, air, foam and cell gases, respectively. The polymer conductivity, k_s , must also be determined. Mark Sinofsky developed a transient hot wire thermal conductivity testing technique at the Massachusetts Institute of Technology to measure the thermal conductivities of foam polymers. The majority of Sinofsky's data is on urethane foam polymers but isocyanate, polystyrene and phenolic polymers have also been tested. The lower limit of the conduction model is given by:

$$k_{s+g} = k_g + 0.8 \left(\frac{2}{3} - \frac{f_s}{3} \right) (1 - \delta) k_s$$

Figure 55.

The difference of 20 percent in the solid conduction term between the two limiting models results from a consideration of the tortuosity of the conduction path. The uncertainty between the two limiting models amounts to less than five percent of the overall foam conductivity.

Thermal Radiation

The approach to the modeling of thermal radiation in the past has been to assume that the cell walls in foam insulation are opaque to thermal radiation.

Thermal radiation in foam insulation involves radiant transport in non-gray, emitting, absorbing and anisotropically scattering media. For commercially available foams, it has been shown that the attenuation of thermal radiation is primarily absorption dominated and that scattering can be treated as isotropic. These results simplify the experimental means of determining the contribution due to thermal radiation heat transfer and yet only introduce a margin of error of 10 to 15 percent in the radiation heat flux term.

The experimental approach has been to directly measure the attenuation of thermal radiation in foams by placing thin foam slices in an infrared spectrophotometer and measuring the percentage transmission of radiation through each sample. Figure 55 shows a typical spectrograph for a thin slice of polyurethane foam. The transmission spectrum is approximately uniform so that an average transmission value can be determined for the sample thickness. Additional tests are conducted on other foam samples covering a range of thicknesses. When the percentage transmission values are plotted versus sample thickness on a semi-log plot, the data forms a straight line.

Figure 56 shows a plot of the average percentage transmission values obtained experimentally versus sample thickness. The data shows that thermal radiation is exponentially attenuate in the foam as the foam thickness increases to larger and larger values. As expected, the percentage transmission extrapolates to 100 percent at zero sample thickness. The slope of the line is termed the foam's extinction coefficient, K , and is the key parameter required to quantify thermal radiation heat transfer in the foam.

HEAT TRANSFER MODEL

The thermal radiation contribution including the foam's extinction coefficient is combined with the conduction heat transfer contributions to obtain an expression for the overall foam thermal conductivity,

$$k_{eff} = k_g + \left(\frac{2}{3} - \frac{f_s}{3} \right) (1 - \delta) k_s + \frac{16\sigma T_m^3}{3K}$$

Figure 56.

where T_m is the mean temperature of the foam and σ is the Stefan-Boltzmann constant. The contributions due to conduction through the polymer and thermal radiation will remain essentially constant during foam aging. The cell gas conduction contribution will change as atmospheric gases diffuse into the cells of the foam and Freon gas diffuses out of the foam. A gas diffusion model is required to predict the changes in cell gas composition that occur during foam aging. The cell gas composition, in turn, determines the cell gas conduction contribution in the heat transfer model.

GAS DIFFUSION MODEL

The gas diffusion model was developed by Douglas W. Reitz and Leon Glicksman at the Massachusetts Institute of Technology.

An overview of the aging process in closed cell foam insulation is shown in Figure 57. A freshly made foam contains primarily Freon gas with small concentrations of carbon dioxide, oxygen and nitrogen. Any carbon dioxide formed during foam formation rapidly diffuses out of the foam. Oxygen and nitrogen diffuse into the cells of the foam over time while Freon gas simultaneously diffuses out of the foam. The high molecular weight of Freon causes it to diffuse much more slowly through the foam structure than oxygen or nitrogen. This overall diffusion process leads to a decline in the R-value of the foam during its lifetime. The use of a facing at the surface of the foam board may reduce the rate at which the foam ages.

Cuddihy and Moacanin showed that foam insulation can be treated as a homogenous media that obeys Fick's law of diffusion. Commercially available foams will satisfy the requirement of homogeneity unless the foam contains large voids, collapsed cells or other defects that disturb the local gas diffusion process. The one-dimensional form of Fick's law that is applicable to diffusion in foams is given by,

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{D} \frac{\partial p}{\partial \tau}$$

Figure 57.

where p is the partial pressure of the gas in the foam board and D is the diffusion coefficient of the gas in the foam. The diffusion coefficient determines the transport rate of the gas through the foam medium and must be obtained for each diffusion gas. Two major factors must be considered in developing an expression for the diffusion coefficient: 1) the effect of the foam's cellular structure on the gas diffusion rate, and 2) the

mechanism of gas transport through the polymer membranes that separate adjacent cells in the foam structure. The effects of cellular geometry on the diffusion rate will be discussed first.

Foam Cell Geometry

The cell morphology in foam insulation was quantitatively analyzed by preparing two-dimensional, planar views of the cell structure. The view of the cell structure shown in Figure 58 was obtained by treating a foam with an embedding resin. A foam sample was placed in an initially liquid, low viscosity resin that filled in the open cells at the surface of the sample. The resin-treated sample was cured in an oven and then cut into thin sections using a microtome. The resin can be seen filling in the center of the cells normally occupied by cell gases.

The two-dimensional sections provide a means of determining the distribution of polymer material between cell walls and struts within a foam. The fraction of polymer material contained in the cell walls is of primary importance since the struts play essentially no role in the gas diffusion process. The polymer distribution parameter is determined by measuring the cell wall thickness and surface area to volume ratio of a foam using the two-dimensional sections. The cell wall thickness can be measured at high magnification using a scanning electron microscope. The thin polymer membranes are subject to swelling as a result of interaction between the embedding resin and the polymer material. The extent of the polymer-resin interaction was investigated by measuring the thickness of a polyurethane film before and after use of the resin. The measurements revealed a swelling of the polymer material between 34 to 69 percent due to the resin. Thus, the measurements should only be used as an upper limit estimate to the actual cell wall thickness in the foams.

The surface area to volume ratio of a foam is also measured from the sections. A test line is drawn across a section photograph and the number of intersections between the test line and foam cell walls are counted. The sample's surface area to volume ratio, S_V , is expressed in terms of the parameter, N_L (number of intersections/test line length). In general,

$$S_V = 2N_L \quad \text{Figure 58.}$$

and is valid when uniformity of sampling is attained and the samples are representative of the structure. By combining the surface area to volume ratio with the cell wall thickness, t , the fraction of polymer contained in the cell walls can be determined,

$$f_w = \frac{(S_V)(t)}{(1 - \delta)} \quad \text{Figure 59.}$$

where $(1 - \delta)$ is the fraction of the foam volume occupied by polymer material (struts plus cell walls). Measurements of polymer distribution in five polyurethane foams showed that the cell walls contained only 10 to 20 percent ($f_w = 0.10$ to 0.20) of the polymer material in a foam. Thus, most of the polymer material is not retained in the cell walls of a foam where it can be utilized in reducing gas diffusion into the foam cells.

The diffusion of a gas through the cell structure shown in Figure 64 can be modeled by assuming that the cell walls are spaced, on average, one cell dimension apart. The idealized cubical cell structure shown in Figure 59 can then be used as a first approximation to the actual cell structure in Figure 58. The assumptions used in conjunction with the cell geometry in Figure 59 are:

1. uniform cell wall thickness
2. resistance to diffusion only in cell walls
3. one-dimensional gas flow
4. no pinholes or cracks in cell walls

Each cell wall can be considered a resistance to diffusion with a diffusion coefficient, D_s , that determines the transport rate of a gas through the cell wall. Each cell has an average cell dimension, d , and each cell wall has a uniform thickness, t . Summing over all resistances and equating to an effective resistance, the effective diffusion coefficient, D_{eff} , that determines the transport rate of a gas through the foam's cellular structure is given by,

$$D_{eff} = \frac{t + d}{t} D_s \cong \frac{d}{t} D_s$$

Figure 60.

since $d > t$. In addition to the cell geometry parameters, the effective diffusion coefficient is directly proportional to the cell-to-cell gas transport rate, defined by the polymer diffusion coefficient, D_s . This transport coefficient must be considered before continuing with the development of the model.

Gas Transport Process

A side view of a cell wall with thickness, t , separating two adjacent cells is shown in Figure 60. The gas transport process through the membrane is defined as having three stages. In the first stage, the gas, at concentration c_1 or pressure p_1 (the two are related by the ideal gas law), is absorbed on to the surface of the membrane. The dissolved gas then diffuses along a concentration gradient through the membrane to the opposite surface in the second stage.

Finally, the dissolved gas comes out of solution to a lower pressure p_2 or gas concentration c_2 . The absorption step at the surface of the membrane is controlled by the solubility of the gas in the polymer. In general, Henry's law is obeyed so that the gas pressure at the membrane surface is linearly proportional to the gas concentration within the membrane. The three-step process is termed permeation and is driven by the difference in the gas partial pressure across the membrane. The defining equation for the permeability at standard conditions (**STP**: 273 K, 76 cm Hg) is,

$$Pe = \frac{(V_{STP})(t)}{(p_1 - p_2)(A)}$$

Figure 61.

where V_{STP} is the volume flow rate of gas at **STP** passing through a membrane of thickness t and area A under a differential gas pressure $(p_1 - p_2)$. Each gas is not influenced by the presence of other permeating gases although water vapor and Freon may have some plasticizing effects on the permeation of the other gases.

A diffusion coefficient is defined in terms of the membrane permeability which accounts for all three steps of the transport process through the cell membrane. The diffusion coefficient is based on the difference in the gas phase concentrations (C_1-C_2) and assumes the following,

1. Henry's law is obeyed by the diffusion gas.
2. The ideal gas law applies to the diffusing gas.
3. Any interaction between the gas and the polymer does not significantly alter the permeation process outlined above.

Using these assumptions in combination with the definition of the permeability in Figure 61, the diffusion coefficient D_s is given by,

$$D_s = \left(P_{STP} \frac{T}{T_{STP}} \right) Pe_s$$

Figure 62.

where P_{STP} and T_{STP} are the gas pressure and temperature at **STP**, respectively and T is the test temperature. The permeability of each diffusing gas in the foam polymer must be evaluated for use in the gas diffusion model. Permeability data has been obtained using both the variable volume permeability testing method and the variable pressure permeability testing method (see ASTM D1434-75 for a discussion of the testing methods). Test films were prepared by combining the foam components (excluding the blowing agent) and casting them into thin films (one to three mils thick). The films were post-cured in an oven. Note that catalyst levels had to be reduced to avoid bubble formation.

The results of the cell-to-cell gas transport analysis can now be combined with the gas diffusion model. Before summarizing the model, it is important to note that the cell shape in foams is more accurately represented by a pentagonal dodecahedron or a truncated octahedron than a simple cubical cell. The surface area to volume ratios of these cell shapes can be related to the average cell dimension, d , in the foam's cell structure. The pentagonal dodecahedron and truncated octahedron have surface area to volume ratios of 3.46/d and 3.55/d, respectively, when in an aggregate of cells each shares half of its surface area with adjacent cells surrounding it. Using the pentagonal dodecahedron cell shape and the results from Figure 62, the effective diffusion coefficient defined Figure 60 becomes:

$$D_{eff} = \frac{3.46}{(S_V)(t)} \left(P_{STP} \frac{T}{T_{STP}} \right) Pe$$

Figure 63.

Combining this result with Figure 59 shows the dependence of D_{eff} on the fraction of polymer in the cell walls f_w and foam density:

$$D_{eff} = \frac{3.46(\rho_s - \rho_g)}{f_w(\rho_f - \rho_g + \rho_a)} \left(p_{STP} \frac{T}{T_{STP}} \right) Pe_s$$

Figure 64.

These equations may be applied to the gas diffusion process under any high temperature aging conditions (i.e., 60°C) by simply substituting the appropriate high temperature permeabilities and the permeability test temperature. The two forms of the gas diffusion model provide insight into the foam parameters that must be influenced in order to reduce the gas diffusion rates in foams. An obvious but costly choice is to increase the foam density. Significant improvements without necessarily affecting the foam's density can be achieved, however, by increasing the fraction of polymer material in the cell walls or by decreasing the polymer permeabilities of the diffusing gases.

TROUBLESHOOTING

Trouble Shooting Splay. Splay or swirl in structural foam molding is a rough surface with a random occurring pattern, usually increasing as you come closer to the gate. When the blowing agent is added in the barrel of the injection molding machine or extruder, the blowing agent converts from powder, pellet, or liquid form into a liquid gas molecule. The pressure and temperature inside the barrel keeps the blowing agent in a liquid form. Once the pressure is released inside the mold, the blowing agent's liquid molecules convert again into gas bubbles. When the liquid molecules of gas are converting from the liquid form into the gas form, they either absorb heat (endothermic) or give off heat (exothermic). These gas bubbles instantly go to the surface of the leading edge of the plastic. The gas bubbles move very quickly through the plastic because they are very low in molecular weight. As the plastic is filling the mold, these bubbles on the leading edge are smeared against the surface of the mold. The smearing of the bubbles is splay. The bubble size is determined by the particle size of the blowing agent. The larger the particle size, the larger the bubbles will be, resulting in a rougher surface.

All gases are very sensitive to differences in temperature and viscosity. In low viscosity with hot materials, the bubbles will be large. In low viscosity with cold materials, the bubbles will be small. In high viscosity and cold materials, the bubbles will be non-existent.

The following table offers solutions to common splay problems:

PROBLEM	RECOMMENDATION
Starburst pattern originating at the gate	Increase injection speed
Heavy swirls at the gate	Reduce injection speed
Splay pattern around post/rough rib	Lower mold temp, especially at area of rough surface. Add venting
Splay near vent is different from other areas	Change size of vent. For rough surface, close vent slightly. For smoother surface, open vent slightly.

The Throttle for Endothermic Blowing Agent is Temperature. When the shot is completely in the mold, the blowing agent will go to the hottest area with the lowest resistance—the core. The foaming agent will foam in this area. As the foaming continues in the core, heat is being absorbed by the blowing agent and the surface of the parts is being cooled by the cold mold surface. By controlling the melt temperature and mold temperature, you can change the foaming conditions.

Shot speed also plays an important part in the foaming process. Shot speed affects surface melt temperature due to shear heat. Shot speed also affects mixing of the liquid blowing agent and plastic. The faster the shot speed, the better mixing and more surface shear heat is added. The more shear heat, the thinner the viscosity, the larger the surface bubbles or surface splay. If the shot speed is too slow, there will be less shear heat, mixing will be worse, and the surface splay or surface bubbles will be larger. In other words, it is important to achieve a correct balance between shot speed and temperature.

Most experienced foamed molders use a large nozzle orifice and fast shot speed. This allows for good mixing and low shear heat.

Blowing Away Sinks. A sink mark is a depression or dimple on the surface caused by internal shrinkage after the gate seals or by a short shot.

What Causes Sinks?

- **Increase in Shrinkage:** As the part continues to contract, it pulls away from cavity walls allowing shrinkage to take place. The center or core of the part is the hottest area (this is where foaming takes place) and the longest to cool.
- **Increase in Wall Thickness**
- **Lack of Cavity Pressure**
- **Part Design**

Thicker sections take longer to cool than thinner sections, which allow for additional shrinkage to take place. Thicker parts will result in more sinks than smaller parts.

Shape of the part affects the rate of cooling. Round parts will allow for a more uniform distribution of the plastic and sink marks will be very minimal.

Highly polished surfaces reflect light which exaggerates the appearance of sinks (magnifying glass).

- **Rib to Wall Ratio**
- **Amount of Foaming Agent (enough to fill the mold)**
- **Type of Material**
- **Amorphous Plastics-**Plastics with highly branched molecular chains and with long side chains that cannot assume a tightly packed condition in any region because of their irregular structure. Chain molecules of this type are intertwined like a tangled ball of yarn. Amorphous plastics are transparent as glass (ex. CD).
- **Filled & Fiber reinforced Plastics-**A composite structure comprised of a thermosetting or thermoplastic resin and fibers that have high strength and good electrical resistivity.
- **Semi-crystallines-Thermoplastics** that contain both crystalline (molecules exist in an orderly arrangement) and amorphous regions.
- **Crystallines-**Consisting of numerous tiny crystals that are not completely formed.

TYPE OF PLASTIC	DESCRIPTION	SHRINKAGE LEVEL
Amorphous Plastic	Irregular Structure	Low Shrinkage/Minimal Sinks
Filled & Fiber Reinforced Plastic	Composite structure	Lower Shrinkage
Semi-Crystallines	Combination of Crystallines & Amorphous Plastics	High Shrinkage
Crystallines	Regular structure consisting of tiny crystals	High Shrinkage

REDUCING SINKS/MOLDING RECOMMENDATIONS

- Use **SAFOAM[®]** @1-5% dosing
- **SAFOAM[®]** acts as a lubricant and improves melt flow and filling of the polymer.
- Increase nozzle size and gates.
- If using gas counterpressure, reduce pressure until Splay appears, then increase by 10 psi.
- Reduce hold pressure.
- Reduce shot size.
- Increase injection speed.
- Increase venting.

The **SAFOAM**[®] family of endothermic chemical foaming agents are designed to produce parts of superior quality. They are easy to use and provide the plastic processor with new opportunities and applications that are not possible with most other types of chemical foaming agents.

The answers to the most commonly asked questions about **SAFOAM**[®] are given below. They are based on our experience in the commercial use of **SAFOAM**[®] with various customers.

GENERAL INFORMATION

Q. 1 What is the difference between endothermic and exothermic chemical foaming agents (CFA)?

A. Exothermic CFA such as Azodicarbonamide (or 1,1-azobisformamide), 4,4-Oxybis (benzenesulfonyl hydrazide (OBSH), or 5-Phenyltetrazole (5-PT) release heat during decomposition and require care during handling and processing to avoid problems caused by overheating.

Endothermic CFA, such as **SAFOAM**[®], need energy (i.e. they absorb heat) during decomposition resulting in improved processing properties such as:

- Extrusion speed
- Wider operating temperature

Q. 2 What is SAFOAM[®] in simple chemical terms?

A. **SAFOAM**[®] is a mixture of polycarbonic acid and carbonates. It is very stable, and during decomposition, produces only carbon dioxide gas in a very controlled fashion.

Q. 3 What makes SAFOAM[®] different from other endothermic CFA?

A. Unlike the other endothermic CFA, which are usually a mixture of an acid and sodium bicarbonate, **SAFOAM**[®] contains modified citric acid salts, which are very tightly controlled on particle size and purity. This gives a predictable, controlled gas release. **SAFOAM**[®] is a buffered foaming agent, which helps prevent corrosion due to acid or base reaction.

Q. 4 How does controlled gas release help?

A. A controlled decomposition means that most of the gas is contained in the polymer melt and does not escape at the rapid rate of other exothermic and endothermic CFA.

Q. 5 What is the gas yield of SAFOAM[®] and the other CFA?

A. Based on 100% active powders, these are typical gas yields at 350°C:

SAFOAM [®] RPC	-	180 cc/g
SAFOAM [®] FP	-	200 cc/g
Azodicarbonamide	-	225 cc/g
5-PT	-	210 cc/g
Other endothermics	-	80 cc/g

The gas available in **SAFOAM**[®] gives the same or greater weight reductions at the same use level of other CFA even though the other CFA yield higher gas volumes. These values are approximate and were obtained by a gas evolution and rate apparatus.

Q. 6 What are the effects of using a CFA at too high a level?

A. Using more CFA than necessary for the desired effect is not only costly, but can cause other problems (i.e. excessive surface splay, extended cycle time or post-blow in injection molding). In extrusion, excessive CFA levels can cause sag or dimensional control problems.

Q. 7 Why are SAFOAM® concentrates typically 40% active?

A. Experience has shown that most processors prefer to use concentrates. A 40% concentrate gives the best combination of dispersion and cost effectiveness. High active concentrates (70%) can cause dispersion problems which lead to variation in the finished product. With recommended use levels of about 1%, it is difficult to achieve accuracy and part consistency with 50 - 70% concentrates.

Q. 8 Which SAFOAM® should I use?

A. SAFOAM® is available as a powder, but most processors prefer to use a concentrate for convenience of handling, etc. Call Reedy International Corporation at (732-264-1777) for recommendations.

Q. 9 How much SAFOAM® should I use?

A. Tables on the insides of the front and back covers give guidelines for use of SAFOAM®. The use levels recommended are good starting points, but you should optimize for your application. In any case, never use more SAFOAM® than necessary for the desired end effect. If you need more help contact Reedy International Corporation at (732) 264-1777.

Q. 10 How do I get samples of SAFOAM® and technical assistance?

A. Contact Reedy International Corporation at (732) 264-1777. If you have a new or difficult application, technical assistance can be provided on-site, if necessary.

INJECTION MOLDING

Q. 11 What causes sinks and splay?

A. Please refer to the trouble shooting section in the user guide.

Q. 12 We have problems with 'sink marks'; will SAFOAM® help with these?

A. Yes. At very low levels of SAFOAM® (.1 - .5% activity) sink marks can be eliminated with no visible surface effects. Do not overpack the part when using SAFOAM® for sink marks, as high pressure will prevent cell formation necessary for sink mark removal.

Q. 13 We have a warping problem caused by molded-in stress. Will SAFOAM® help relieve this?

A. Yes. Using the same technique as for sink marks can eliminate warp or molded-in stress, and still retain good physical and appearance properties.

STRUCTURAL FOAM MOLDING (SFM)

Q. 14 We want to use SAFOAM® to produce SFM on our conventional injection molding machines. What modifications are needed?

- A. Several modifications are recommended if good, consistent quality parts are to be produced:
- A positive nozzle shut-off valve capable of providing a positive closure at cylinder pressures in the range of 1,500-2,000 psi minimum. It can be hydraulic, pneumatic, or spring actuated. Its purpose is to maintain pressure on the melt to prevent gas escape, to stop ‘drooling’ of resin between shots, and to eliminate nozzle freeze-up.
 - A suckback is sometimes used to prevent ‘drooling’.
 - Boosters to increase injection speed and an accumulator to increase capacity are desirable modifications.

Q. 15 What clamp capacity is needed?

- A. Clamp capacity is determined by the molding parameters since molded filling and pressure profiles depend upon the molding process used. There is no need for the high post-injection pressures used during cooling in solid parts. The mold needs only to resist the relatively low pressure of the expanding gas as the part fills out. As a guide, only about 10-20% of the clamp required for solid molding is needed for SFM.

Q. 16 What other factors are important?

- A. If the mold is not designed for SFM, then adequate venting must be provided. Vents in the 0.005-0.010 inch (.127-.254 mm) range are used in SFM. Sprues, runners and gates are usually generous in size in SFM.

Q. 17 We use the gas counter-pressure SFM process. Is SAFOAM® suitable for this?

- A. Yes. Lower gas counter-pressures (40-60 psi) can be used. This is a positive advantage over the high gas counter-pressures required by most other CFA or nitrogen.

Q. 18 We use the direct-gassed nitrogen low pressure SFM process. Should we use SAFOAM®?

- A. Yes. Low levels of SAFOAM® (.1 - .5% activity as a nucleant) will have beneficial effects. These include better surface quality, fewer voids, and additional weight reductions of up to 10%. SAFOAM® gas makes the nitrogen more melt-soluble and smaller, more uniform cells are produced. This usually leads to improved physical properties and shorter cycle times.

Q. 19 We currently use an exothermic CFA to produce SFM. Why should we change to SAFOAM®?

- A. Reduced cycle times (15 - 20%) mean higher output. Mold plate-out deposits are eliminated. Faster de-gassing means faster post-finishing. The SAFOAM® brochure lists several other advantages.

QUESTIONS AND ANSWERS

Q. 20 What about food contact considerations?

A. **SAFOAM**[®] is composed of GRAS (Generally Recognized As Safe) or FDA sanctioned components. It is suitable for food contact applications.

Q. 21 What about re-grind? How is it affected?

A. Unlike some CFA, which do not decompose fully in the processing and can cause CFA variations due to re-grind activity, **SAFOAM**[®] re-grind can be considered as “virgin” polymer as far as the CFA is concerned.

BLOW MOLDING

Q. 22 Can **SAFOAM**[®] be used in blow-molding?

A. Yes. Weight reductions of 5 - 15% have been achieved.

Q. 23 What **SAFOAM**[®] grade should be used and at what additive level?

A. Follow the guidelines given on the front and back covers.

Q. 24 What blow-pressure is recommended?

A. Blow-pressure should be the minimum needed for part fill-out. It should not be set so high as to compress the foam structure completely.

Q. 25 Are physical properties affected?

A. Yes. Impact strength is reduced by foaming, but stiffness normally is increased compared to the unfoamed part.

Q. 26 What effect has **SAFOAM**[®] on fillers and pigments?

A. Any fillers or pigments present will produce extra nucleation which results in finer cell structures. Because **SAFOAM**[®] has an opacifying effect, it may be possible to use lower levels of pigments and opacifiers.

ROTATIONAL MOLDING

Q. 27 Can **SAFOAM**[®] be used to foam roto-molded parts?

A. Yes. **SAFOAM**[®] powders work well in roto-molding. The best results are achieved by using **SAFOAM**[®] in combination with exothermic foaming agents.

Q. 28 What special techniques are used to foam roto-molded parts?

A. The mold vent is plugged (or it is equipped with a pressure valve) to prevent escape of the foaming gas during heating of the mold. The mold is filled with just enough polymer and **SAFOAM**[®] to fill the mold (i.e. it is “short-shotted”) and the mold is heated. After the mold is removed from the heat, and prior to cooling, the vent plug is removed or the pressure valve is opened. The gas now expands the melt to fill the mold. The advantage of the pressure valve is that the mold can be pressurized prior to heating and pressure released in a controlled manner. This retards gas escape and generally results in appearance improvements.

NOTES ON PROPERTIES, UNITS AND DATA LISTINGS

Property	Significance/Comments	Units		
		English	Metric	ASTM Test
Compressive Strength	The ability of a material to resist a force that tends to crush it.	lb/in ²	kg/cm ²	D695
Density	The equivalent property to specific gravity; measured by displacement.	lb/ft ³	g/cm ³	D792
Deflection Temperature, 66 lb/in²	The measure of temperature at which a specimen deflects 0.01 inches under a load of 66 lb/in ² .	°F	°C	D648
Deflection Temperature, 264 lb/in²	The measure of temperature at which a specimen deflects 0.01 inches under a load of 264 lb/in ² .	°F	°C	D648
Dielectric Strength	The voltage that an insulating material can withstand before dielectric breakdown occurs.	V/10 ⁻³ in	V/mm	D149
Dissipation Factor	The ratio of the power dissipated in watts in an insulating material to the product of the effective voltage and the current. Measured at a frequency of 10 ⁶ cycles per second.	Constant		D150
Effect of Strong Acids	A descriptive notation to indicate the material's performance.	Text		D543
Elongation, Break	The increase in distance between two gauge marks at the break point divided by the original distance between the marks. A zero value in the field indicates that it measured less than one.	%		D638
Elongation, Yield	The increase in distance between two gauge marks at a yield point divided by the original distance between the marks. A zero value in the field indicates that it measure less than one.	%		D638
Flexural Modulus	The ratio, within the elastic limit, of the applied stress on a test specimen in flexure to the corresponding strain in the outermost fibers of the specimen.	lb/in ²	kg/cm ²	D790
Flexural Strength, Yield	The measurement of resistance of the material to fracture during bending.	lb/in ²	kg/cm ²	D790

NOTES ON PROPERTIES, UNITS AND DATA LISTINGS (CONT'D)

Property	Significance/Comments	Units		
		English	Metric	ASTM Test
Hardness	The resistance of a material to compression, indentation and scratching. There are several scales that are commonly used.			
Izod, Notched, LT	The energy required to break specimens in which there is a v-notch to create an initial stress point but measured at low temperature (-40°C). (The value 999 in the tables indicates that the specimen did not break.) The measurement of notched izod for structural foam is of limited value.	ft lb./in	kg cm/cm	D256
Izod, Notched, RT	The energy required to break specimens in which there is a v-notch to create an initial stress point. (The value 999 indicates that the specimen did not break.)	ft lb./in	kg cm/cm	D256
Linear Mold Shrinkage	The difference between the size of the part and the size of the mold cavity. Values given are often the average of a range.		in/in	D955
Melt Flow	Rate of extrusion of molten resin through a die of a specified length and diameter. The conditions of the test (e.g. temperature and load) should be given. Frequently, however, the manufacturers' data lists only the value, not the condition as well.		g/10 min	D1238
Refractive Index, Sodium D	The ratio of the velocity and light in a vacuum to its velocity in the material.		Constant	D542
Tensile Modulus	(Also called modulus of elasticity). The ratio of nominal stress to the corresponding strain below the proportional limit of a material.	lb/in ²	kg/cm ²	D638
Tensile Strength, Break	The maximum stress that a material can withstand without breaking when subjected to a stretching load.	lb/in ²	kg/cm ²	D638
Tensile Strength, Yield	The maximum stress that a material can withstand without yielding when subjected to a stretching load.	lb/in ²	kg/cm ²	D638
Thermal Conductivity	The rate of heat flow under steady state conditions through unit area per unit temperature gradient in a direction perpendicular to an isothermal surface.			C177
U.L. Temperature Index	The maximum temperature below which a material maintains its electrical and mechanical integrity over a reasonable period.		°C/mm	

NOTES ON PROPERTIES, UNITS AND DATA LISTINGS (CONT'D)

Property	Significance/Comments	Units		
		English	Metric	ASTM Test
Vicat Softening Point	The temperature at which a flat ended needle will penetrate a specimen under a specified load using a uniform rate of temperature rise.	°F	°C	D1525
Volume Resistivity	The measure of the ratio of the potential gradient parallel to the current in the material to the current density.		Ohm/cm	D257
Water Absorption, 24 hours	The percentage of water absorbed by a material when immersed in water for 24 hours; water absorbed in a material chiefly affects its electrical properties.		%	D570

GLOSSARY

- A -

Alloy - A composite material produced by blending polymers or copolymers with other polymers under selected conditions to achieve greater physical properties.

- B -

Boss - Protuberance on a plastic part designed to add strength, facilitate alignment, provide fastenings, etc.

- C -

Clamping Plate - A plate fitted to a mold and used to fasten the mold to a plate.

Clamping Pressure - The pressure applied to the mold to keep it closed during the cycle.

Cooling Channels - Channels located within the body of a mold through which a cooling medium is circulated to control the mold surface temperature.

Cooling Fixture (shrink fixture) - A jig or block to hold the shape of a molded part after it is removed from the mold until it is cool enough to retain its shape

- D -

Daylight Opening - The clearance between two platens of a clamping press in the open position.

Delamination - The surface of the finished part separates or appears to be composed of layers of solidified resins. Strata or fish-scale-type appearance where the layers may be separated.

Density - Weight per unit volume of a substance expressed in grams per cubic centimeter.

Diaphragm Gate - Used in symmetrical cavity filling to reduce weld line formation and improve filling rates.

Direct Gate - The sprue feeds directly into the mold cavity.

Drooling - The extrusion or leakage of molten resin from a nozzle or nozzle sprue bushing area while filling or shooting.

Dwell - A pause in the application of pressure to a mold, made just before the mold is completely filled, allowing any gases formed or present to escape from the molding material.

- E -

Ejector Pin (knockout pin)- A pin or plate that is driven into a mold cavity from the rear as the mold opens to force out the finished part.

Extrusion - The compacting of a material and forcing it through an opening in more or less a continuous fashion.

- F -

Family Mold - A multi-cavity mold where each of the cavities forms one of the component parts of the assembled finished parts.

Fan Gate - This gate is used to help reduce the stress concentrations in the gate area by spreading the opening over a wider area. Less warpage of parts can usually be expected by the use of this type of gate.

Fick's Law - The basic law of diffusion of different molecular species into each other. Fick's law states that the flux of a given component will be in the direction in which the concentration of that component decreases most steeply at a rate given by the product of the mutual diffusivity and the gradient. Most published diffusivity data are for two-component systems. Fick's law, which has many equivalent forms, is the defining equation for diffusivity.

Fill - The packing of the cavity or cavities of the mold as required to give a complete part or parts free of flash.

Fillet - A concavely curved transition at the angle formed by the junction of two plane surfaces, i.e., a rounded inside corner. Also, the material making up the transition. Where the surfaces are likely to

endure bending toward or away from each other, the fillet distributes and reduces the stress that would otherwise be magnified at the corner.

Flash - Extra plastic attached to a mold part along parting lines.

Flow - A qualitative description of the fluidity of a plastic material during the process of molding. A measure of its processability.

Flow Line - Marks visible on the finished item that indicate the direction of flow in the cavity indicating a cold mold or melt.

- G -

Gate - An orifice through which the molten resin enters the mold cavity.

GEAR - Gas Evolution and Rate.

- H -

Hot Runner Mold - A mold in which the runners are insulated from the chilled cavities and are kept hot.

- I -

Injection Molding - A process where a heat softened plastic material is forced from a reservoir into a cool cavity that produces the desired shape

Injection Pressure - The pressure on the face of the injecting ram when injecting material into the mold.

Injection Ram - The ram or screw that applies pressure to the molten plastic material to force it into the mold cavities.

- J -

Jetting - A turbulent flow in the resin melt caused by an undersized gate or where a thin section becomes thicker.

Jig - A tool for holding parts of an assembly during the manufacturing process.

- K -

Knit Lines (weld lines) - The marks visible on a finished part made by the meeting of two flow fronts during the molding.

Knockout Pin (ejector pin) - A rod or device for knocking out a finished part from a mold.

- L -

Laminar Flow - The flow of a resin in a mold is accompanied by solidification of the layer in contact with the surface that acts as an insulator through which material flows to fill the remainder of the cavity.

Land - The horizontal bearing surface of a semi-positive or flash mold by which excess material escapes; the bearing

surface along the top of the flights of an extruder screw; the final shaping surface of an extrusion die usually parallel to the direction of melt flow; the mating surfaces of any mold, adjacent to the cavity depressions, that, when in contact, prevent the escape of material.

Land length - In an extrusion die, the distance across the land in the direction of melt flow between the lands.

L/D Ratio - The term used to define an extrusion screw. This is the screw length to screw diameter ratio

Low Marks - Wavy surface appearance of a molded object caused by improper flow of the plastic into the mold.

- M -

Machine Shot Capacity - Generally based on polystyrene. This is the maximum weight of plastic which can be displaced or injected by a single stroke.

Melt Index - A measure in grams of plastic material that can be forced through an orifice of 0.0825 inches when subjected to a force of 2,160 grams in 10 minutes at 190°C.

Metering Screw - The extrusion screw that has a shallow constant depth and pitch section usually over the last three or four flights.

Modulus - Derived from the Latin word meaning “small measure”, a modulus is a measure of a mechanical property of a material, most frequently a stiffness property; the absolute value of a complex number or quantity, equal to the square root of the sum of the squares of the “real” and “imaginary” parts.

Moisture Marks or Welds - Marks on the finished part that are caused by moisture in the resin and look like weld lines except they may be in the wrong areas for weld lines.

- O -

Orange Peel - A surface finish on a molded part that is rough and splotchy. Usually caused by moisture in the mold cavity.

- P -

Packing - The filling of the mold cavity or cavities as full as possible without causing undo stress on the molds or causing flash to appear on the finished parts

Parison - The hollow plastic tube from which a container is blow molded.

Pinch-off - A raised edge around the mold cavity that seals off the part and separates excess material mold closes around parison in the blow molding operation.

Plasticate - To soften by heating and mixing.

Profile Die - Extrusion die for the production of continuous shapes.

- Q -

Quench Bath - The cooling medium used to quench molten thermoplastic materials to the solid state.

- R -

Ram - The portion of an injection machine that moves backward and forward to deliver the shot of resin to the nozzle and mold. The screw in a reciprocating screw machine.

Ram Travel - The distance the injection ram (or screw) moves in filling the mold.

Restricted Gate - A very small orifice between runner and cavity in an injection mold. When the part is ejected, this gate readily breaks free of the runner system.

Runner - The channel that connects the sprue with the gate for transferring the molten plastic to the cavities.

- S -

Shear - The movement, in a fluid or solid body, of a layer parallel to adjacent layers.

Shot - The complete resin from a molding cycle, including scrap.

Short Shot - Failure to fill the mold or cavities of the mold completely.

Shrink Fixture (cooling fixture) - A jig or block to hold the shape of a molded part after it is removed from the mold until it is cool enough to retain its own shape.

Shrinkage - The difference found on a molded part as compared to the actual mold cavity dimension.

Single Cavity Mold - A mold having only one cavity and producing only one finished part per cycle.

Sink Marks - A shallow depression or dimple on the surface of a finished part due to shrinkage or low fill of the cavity.

Slip Plane - Marks evident in or on finished parts due to poor welding or shrinkage upon cooling.

Splay Marks - Marks or droplet type imperfections found on the surface of the finished parts that may be caused by the spraying of the hot melt through the gates and into the cool cavity where they set up.

Split-Ring Mold - A mold in which a split cavity block is

assembled in a chase to permit the forming of undercuts in a molded piece. These parts are ejected from the mold and then separated from the piece.

Specific Gravity - The density of any material divided by the density of water at standard temperature usually 4°C.

Sprue - The feed opening provided in injection molding between the nozzle and cavity or runner system.

Sprue Bushing - A hardened steel insert in the mold that accepts the extrusion nozzle and provides an opening for transferring the molten plastic.

Sprue Gate - A passageway through which resin flows from the nozzle to the mold cavity.

Striations - Marks evident on the molded part surfaces that indicate resin flow directions or impingement.

Submarine Gate (tunnel gate) - A type of edge gate where the opening from the runner into the mold is located below the mold parting line.

Suck Back - When the pressure on the sprue is not held long enough for the resin to cool before the screw returns, some of the hot resin in the cavities or runner system may expand back into the nozzle and cause sink marks on the finished piece.

- T -

Tab Gate - A small, removable tab about the same thickness as the molded item but usually perpendicular to it for easy removal.

Thermoplastic - A material capable of being repeatedly softened by heat and hardened by cooling.

Thermoplastic Elastomer - (TPE) Any of a family of polymers that resemble elastomers in that they are highly resilient and can be repeatedly stretched to at least twice their initial lengths with full, rapid recovery, but are true thermoplastics and thus do not require curing or vulcanization as do most rubbers.

Thermoset - A material which can undergo a chemical reaction by the action of heat or catalyst, leading to a relatively infusible and cross-linked state.

Tunnel Gate (submarine gate) - A type of edge gate where the opening from the runner into the mold is located below the mold parting line.

- V -

Vent - A shallow channel or opening cut in the cavity to allow air or gases to escape as the material fills the cavity.

- W -

Warp - Dimensional distortion in a molded object.

Weld Line (knit lines) - The marks visible on a finished part made by the meeting of two flow fronts during molding.

COMMON ACRONYMS

ABS Acrylonitrile-butadiene- styrene	EC Ethyl cellulose	HMC High strength molding compound	MPPE Modified polyphenylene ether
ASA Acrylic-styrene- acrylonitrile	EMA Ethylene-methyl acrylate	HME High-vinyl modified epoxy	MPPO Modified polyphenylene oxide
ASTM American Society for Testing and Materials	EP Ethylene propylene	HMW High molecular weight	MSDS Material Safety Data Sheets
CA Cellulose acetate	ESCR Environmental stress crack resistance	LCP Liquid crystal polymer	MMA Methyl methacrylate monomer
CAB Cellulose acetate- butyrate	ETFE Ethylene- tetrafluoroethylene	LDPE Low density polyethylene	MMA Methyl methacrylate monomer
CAP Cellulose acetate- propionate	EVA Ethylene-vinyl acetate	LIM Liquid injection molding	MW Molecular weight
CBA Chemical blowing agent	FDA Food and Drug Administration	LLDPE Linear low density polyethylene	PA Polyamide (nylon)
CFA Chemical Foaming Agent	FR fiber reinforced	LMC Low-pressure molding compound	PAI Polyamide-imide
CPE Chlorinated polyethylene	FRP Fiber-reinforce plastic	LMW Low molecular weight	PAN Polyacrylonitrile
CPVC Chlorinated polyvinyl chloride	GEAR Gas evolution and rate	MA Maleic anhydride	PB Polybutylene
DSC Differential Scanning Calorimetry	HDPE High density polyethylene	MBS Methacrylate-butadiene- styrene	PBT Polybutylene terephthalate
DTA Differential Thermal Analysis	HIPS High-impact polystyrene	MDPE Medium-density polyethylene	PC Polycarbonate
	HM High-modulus		

COMMON ACRONYMS

PCTFE Polychlorotrifluoro- ethylene	PIE Polyisobutylene	RH Relative Humidity	UHMW Ultra-high molecular weight
PE Polyethylene	PMMA Polymethyl methacrylate	RIM Reaction injection molding	UL Underwriter's Laboratories
PEC Polyphenylene ether copolymer	PMS Paramethylstyrene	RP Reinforced Plastics	UV Ultraviolet
PEEK Polyetherether ketone	PMT Paramethylpentene	RTM Resin-transfer molding	VAE Vinyl acetate-ethylene
PEH Polyphenylene ether homopolymer	PP Polypropylene	SAN Styrene-acrylonitrile	
PEI Polyetherimide	PPE Polyphenylene ether	SMA Styrene maleic anhydride	
PEO Polyethylene oxide	PPO Polyphenylene oxide	SMC Sheet molding compounds	
PES Polyethersulphone	PS Polystyrene	SPE Society of Plastics Engineers	
PET Polyethylene terephthalate	PU Polyurethane	SPI Society of Plastics Industry	
PETP Polyethylene terephthalate	PVAL Polyvinyl alcohol	TGA Thermal Gravimetric Analysis	
PF Phenyl-formaldehyde	PVDC Polyvinylidene chloride	TPE Thermoplastic elastomers	
PFA Perfluoroalkoxy (resin)	PVDF Polyvinylidene fluoride	TPU Thermoplastic polyurethane	
PI Polyimide	PVF Polyvinyl Fluoride		
PIB Polyisobutylene	RH Rockwell hardness	UHM Ultra-high modulus	

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