ExxonMobil Chemical

Santoprene™
Brand TPVs

Design Guidelines for Thermoplastic Vulcanizates (TPVs)

TL00306

TECHNICAL LITERATURE

Design Guidelines for TPVs

Introduction

This document is a compilation of the experience within the Santoprene specialty products group of ExxonMobil Chemical (Advanced Elastomer Systems [AES]) on a variety of topics related to the design of rubber parts. It largely covers experiences using Santoprene thermoplastic rubber (TPV), however, many of the comments would apply to other thermoplastic elastomer (TPE) products sold by AES. In each section, the differences that apply to different TPE products are highlighted, where known.

The purpose of this document is to cover the general guidelines and theory behind the variety of rubber part design topics covered. Each section covers an individual topic and can generally stand on its own as a source of information for guiding the development of a part design.

This information is for general guidelines, but each application is unique and may not conform to the guidelines set forth in this document. Some engineering judgment is required to determine the appropriate use of these guidelines.

General Design Guidelines for Injection Molding

Introduction

Injection molding is one of the most frequently used techniques for manufacturing parts made of TPEs. It is a very versatile technology that is capable of mass-producing parts with complex geometries and tight tolerances, as opposed to thermoset rubber molding that has wide tolerances. The injection molding cycle time for TPEs is usually measured in terms of seconds and is dependent on the part thickness. In addition TPEs, being thermoplastic materials, can be reclaimed and recycled. Therefore, cost savings can be realized from faster cycle times and recyclability of TPEs.

In some instances, part features can be consolidated into a single component and may require more than one material. These parts can be molded using a technique known as 2-K or two-color injection molding, dual injection molding or co-injection molding. Alternatively, insert molding or overmolding, which is a two-step injection molding batch operation and lower capital investment, can be used. This flexibility to produce complex parts with multiple functions and multiple materials makes injection molding very popular.

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Geometry and Parting Lines

Geometric design of a part is usually dictated by its function, and is generally kept as basic as possible. Parting lines, which are witness lines appearing on part surfaces due to the interface between the two mold halves, should be located at non-critical or non-visible surfaces. The part geometry and its end use will affect the location of the parting line. Where possible, configure the part geometry so that the parting line can be simple and located on a single flat plane. Also, modify the parting line such that the mold halves do not slide when they come together.

Wall Thickness

The ideal case is to design the part to have uniform wall thickness throughout. This keeps shrinkage rates uniform throughout the part, thus minimizing warpage and sink marks.

In certain cases, part design may require variations in wall thickness. Gradual transition in wall thickness is recommended for these cases to minimize risk of warpage and sink marks. Limit wall thickness changes to approximately 25%.

Table I Wall Thickness Guidelines Using our TPEs

Guideline	Wall Thickness, mm (in.)
Minimum	0.5 (0.020)
Preferred Nominal	2.0 to 3.0 (0.080 to 0.120)
Maximum	6.0 (0.25)

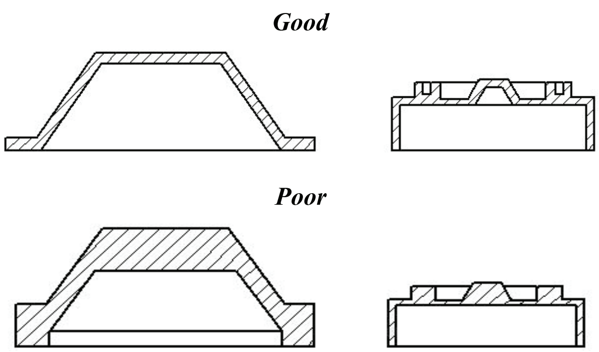

Figure 1
Wall thickness guidelines

Draft Angles

Draft angles facilitate ease of part release from the mold. The amount of draft angle is dependent on "depth of draw" of the part and should take into account the end use conditions. The draft angle is usually applied to the cavity side of the mold and to the core pins to facilitate the part release during the mold opening stage of the injection molding cycle.

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Table II Recommended TPE Guidelines for Draft Angles

Grades	Draft Angle
Soft - 35 to 80 Shore A	0.25° per side
Hard - 87 Shore A to 50 Shore D	0.5° per side

Holes

Where there are holes in a part, there will be weld lines due to polymer flow front separation which meets again after flowing past the core pins that define the hole. Such weld lines are areas of lower strength and should not be subjected to loads. Through-holes are easier to produce than blind holes because the core pin can be supported at both ends. For blind holes, the core pin is supported at only one end and it can be deflected under high pressures. Therefore, the depth of the blind hole is generally limited to twice the diameter of the hole. A stepped core pin can be used for greater hole depth. Alternatively, counterboring the sidewall will reduce the length of the unsupported core pin. These techniques can be seen in Figure 2.

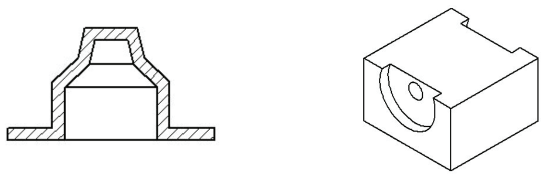


Figure 2
Hole techniques

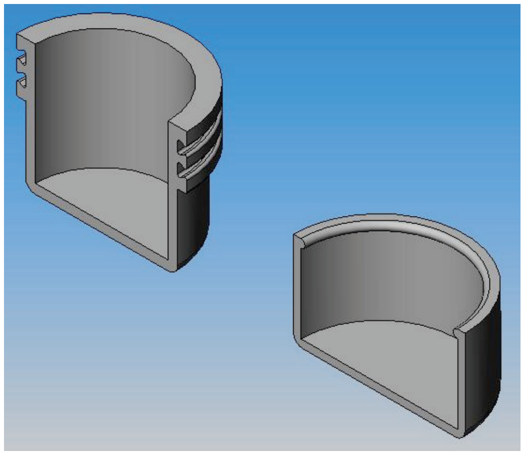
Undercuts

An undercut is an indentation or a protuberance on a part, which has the effect of making it difficult or impossible to eject the part from a simple rigid two-part mold. Due to the lower modulus of TPEs, it may be possible to eject a part with undercuts without the need for special cores or slides. This will, of course, depend on the TPE hardness and the shape and size of the undercut. Examples of different types of undercuts can be seen in Figure 3. The maximum undercut depth for various hardness of TPEs without the need for special cores or slides is shown below.

Table III Maximum Undercut Depths

TPE Hardness	Maximum Depth of Undercut, mm (in.)
35 to 55 Shore A	2.0 (0.079)
64 to 73 Shore A	1.6 (0.063)
80 to 87 Shore A	1.0 (0.039)
40 to 50 Shore D	0.7 (0.027)

External undercut



Internal undercut

Figure 3
Types of undercuts

Ribs and Bosses

The function of ribs is to increase the rigidity and strength of a part without the need to increase the wall thickness. Thick sections can be cored out and replaced with ribs to maintain the same stiffness and achieve material savings as well as reduction in cycle time. Ribs, flanges and strengthening members should be made with wall thickness of about 50% of the wall thickness of the sections they support. Tall ribs may require draft angles of approximately 0.5° for easy ejection. Typical rib designs can be seen in Figure 4.

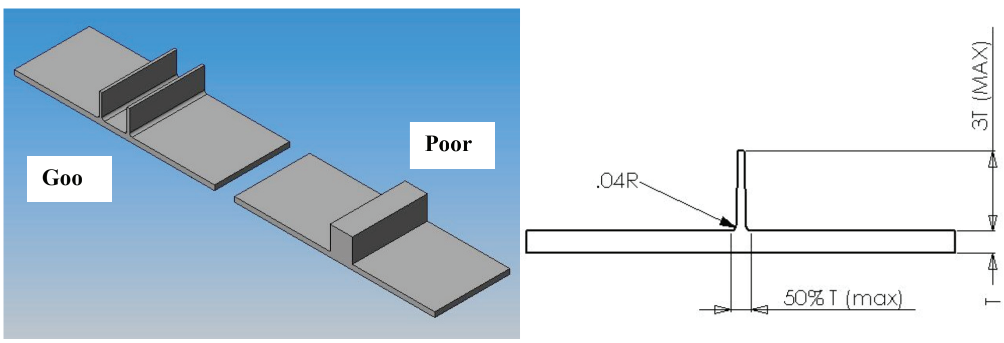


Figure 4
Typical rib designs and guidelines

Bosses are protruding studs or pads, and are often used to reinforce holes, to support metal inserts or mount subassemblies. Typical boss designs can be seen in Figure 5.

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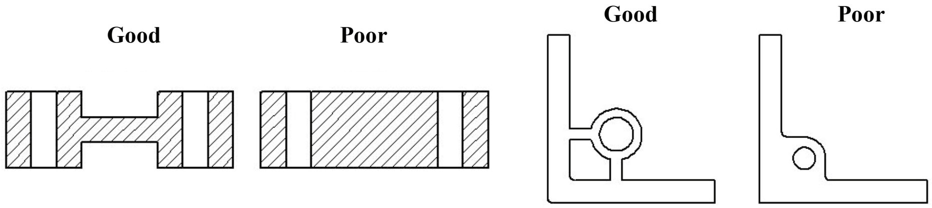

Figure 5
Typical boss designs

Radii and Fillets

Sharp corners will cause stress concentration, which may result in the failure of parts during end use. Adequate radii given to rounds and fillets will help reduce this stress. In addition, radii provide streamlined flow paths for the polymer melt, making it easier for part ejection. The minimum recommended radius for TPEs is 0.5 mm (0.020”). Also, an equal wall thickness should be maintained between the inside and outside radii.

Living Hinge

A living hinge allows a single molded part to flex open or close onto itself. It is a dynamic feature and relies on flex fatigue resistance of the material. With proper design, it can be flexed with ease and allow flex cycling in excess of one million cycles. Living hinge design guidelines are shown in Figure 6.

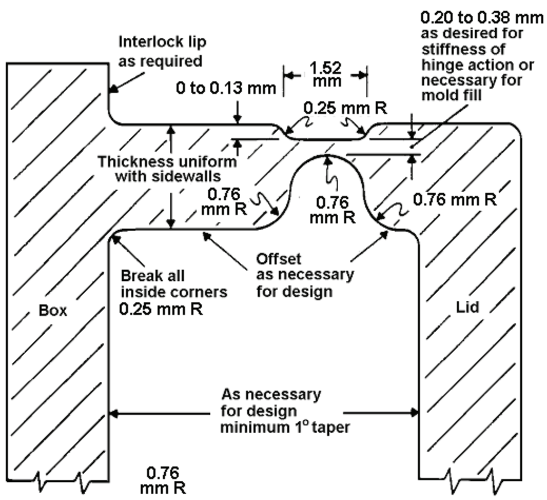

Figure 6
Living hinge guidelines

Surface Texture and Appearance

Surface texture of TPEs is generally matte, but as hardness increases, gloss level is increased. To impart gloss to TPE surfaces, treatments such as slip coating, priming or painting may be required; however, this will also alter surface characteristics. Overall, it is best to design the part with a matte look.

Surface texture can be added to injection molded parts made from TPEs. This is usually done using chemical etching, electric discharge machining, sand blasting or general machining of the mold cavity surface.

Excessively deep textures may disrupt polymer flow through the cavity, while excessively shallow textures may not show up well due to the high viscosity of the TPE melt. A depth range from 0.075 to 0.125 mm (0.003 to 0.005”) is preferred. Note that softer grades may require a deeper texture to gain the optimum effect. Harder grades of TPEs require a minimal draft, depending on the depth of texture used. Also, adding textures on vertical core and cavity surfaces will prevent sticking in the mold.

In most cases, the mold cavity surface for injection molding TPEs is specified as SPE-SPI #B3, which corresponds to surface roughness of 0.0001 to 0.0002 mm (0.00004 to 0.00008”).

Bonding in the Overmold Process

Frequently, an elastomeric part is overmolded through insert or two shot molding over a different material. Ideally, a chemical bond is formed between the substrate and overmold which results in a cohesive bond between the two. The table below shows common substrates and which Santoprene TPVs bond to them. This table shows some substrate materials and is not intended as a comprehensive list of materials to which Santoprene TPV bonds to.

Table IV Compatible TPEs that Bond to Various Engineered Thermoplastics

Substrate	Product Family	Grades	Durometer
Polycarbonate (PC)	Santoprene TPV	8211-55B100, 8291-55B100	55A
PC/PBT	Santoprene TPV	8211-55B100, 8291-55B100	55A
PC/ABS	Santoprene TPV	8211-55B100, 8291-55B100	55A
ABS	Santoprene TPV	8211-55B100, 8291-55B100	55A
Polystyrene (PS)	Santoprene TPV	8211-55B100, 8291-55B100	55A
ASA	Santoprene TPV	8211-55B100, 8291-55B100	55A
PMMA	Santoprene TPV	8211-55B100, 8291-55B100	55A
Polyamide 6 (Nylon 6)	Santoprene TPV	191-XXPA, 8291-XXPA	55A, 70A, 85A
Polypropylene	Santoprene TPV Vyram TPV	All*	35A to 50D

*except those listed above

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There are alternatives when incompatible materials are overmolded. Please see the Grip Design section for more information on available design alternatives when incompatible materials are used.

Related Documents

For processing details please read our "*Guide for Injection Molding for Thermoplastic Rubbers*" available from Technical Solutions on our website.

Technical Literature (TL)
Glass encapsulation with Santoprene TPV
Injection Molding of Corners and End Caps to EPDM Weatherseals
Injection Molding of Santoprene 8000 TPV 8211-55B100
Injection Molding of Santoprene TPV PA
Shrinkage Rates for Injection Molding of Santoprene TPV

Design Guidelines for Injection Molding Grips

Introduction

Soft-touch grips have become more prevalent in the marketplace due to the numerous advantages they provide. They can provide a non-slip surface, which improves control and safety. There is a significant reduction in vibrations over stiffer grips, which can yield higher accuracy, superior comfort and reduced fatigue. TPE grips can also be more durable and impact resistant.

Guidelines

The following key parameters in grips applications are reviewed:

- The visual appearance.
- The human interface.
- The mechanical performance.

Visual Appearance

Aesthetics play a major role in the design of grips. Common issues regarding the appearance of a part are color, surface finish, uniformity and texture(s). It is good practice to design the soft grip in a different color from the rigid portion. This highlights the extra effort for producing the design and part, and often contributes to the perception of enhanced value.

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Human Interface

The grip should be designed to complement human physiology. Contours can be designed in with curves and grip thickness to match the hand. Finger lobes can be included to better locate the hand to the desired location. While contouring is beneficial to part design, it may cause problems in manufacturing due to large variations in wall thickness, so careful consideration must be given to the manufacturability of the part.

A tactile surface can be designed to give the grip a superior feel. At high force points, extra friction can be designed in the grip. Ribs, grooves or surface texturing can also be used to improve tactile feel. The TPE should be placed on the grip in the areas where the palm and fingers of the hand grip the part or in areas where the wrist or fingertips come in contact with the device.

Grip thickness is another concern in the area of ergonomics. Commonly, there are three types of grip designs available.

1. **Soft-look part** which has a thin layer of soft material to give a soft appearance. Since the thickness is normally less than 1.5 mm (0.059"), the users can always feel the substrate. For thin layer applications, higher hardness (60 Shore A to 50 Shore D) materials are usually utilized since they improve mechanical properties such as abrasion resistance.

2. **Soft-feel** is made using a soft material that may have a hardness less than 60 Shore A and a thickness greater than 1.5 mm (0.059"). Typically, the thickness will be from 1.5 to 2.0 mm (0.059 to 0.079"). Both the soft material and the hard substrate can be felt. This is the most common design.

3. **Soft-grip** uses hardness in the range of 40 to 60 Shore A and a thickness greater than 5 mm (0.20").

Figure 7
TPE thickness in grip cross-section

Design can greatly affect the softness of a grip. Since the solid material is not compressible, it needs room to flow when compressed. This can be accommodated by designing in raised or

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underlying ribs, which will result in a grip that has a soft feel due to the design and not just the material.

Mechanical Performance

The structural strength of the grip is derived from the rigid substrate underneath the TPE. This is a function of geometry and the substrate modulus. The grip should be designed for acceptable mechanical performance of the structural component. Bond strength of the TPE to the substrate is also a factor in the mechanical performance of the part.

There are numerous methods of bonding the TPE to the substrate. A melt fusion is possible if the materials are compatible (refer to Table IV for bonding of compatible materials).

If the substrate is not fusible to the TPE, a mechanical interlock can be designed which gives a strong bond, but not as strong as a melt fusion. Possibilities are: snap fits, encapsulating the rigid structure with TPE, attachment with flow through-holes, notches or grooves. To achieve maximum bond strength, holes should typically be placed apart by 10 to 15 mm (0.39 to 0.59"). For through-hole diameters or notch/groove widths, a design maximum is one-half the thickness of the TPE.

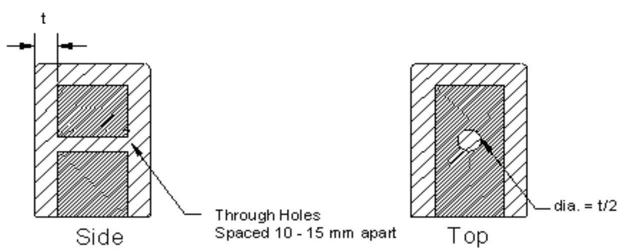

Figure 8
Through-hole design - overmolded grip cross-section

An undercut can be used to hold a non-bonded handle in place, as shown in Figure 9. The TPE will be held in place by the undercut and will also shrink on to the substrate.

Figure 9
Mechanical lock design – mechanical lock cross-section

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Related Documents

For processing details please read our "*Guide for Injection Molding for Thermoplastic Rubbers*" available from Technical Solutions on our website.

TLs
Bonding and Decorating – Primes, Adhesives, and Tape
Injection Molding of Santoprene 8000 TPV 8211-55B100
Injection Molding of Santoprene TPV PA
Shrinkage Rates for Injection Molding of Santoprene TPV
Santoprene 8000 TPV Series General Product Information

Shutoff Design for Overmolding

Introduction

When overmolding a TPE on a rigid substrate, the mold must close very tightly on the substrate to keep the TPE from flowing by the seal area (flash) during mold filling. The shutoff is a design feature put into the part to assure that the closing mold halves achieve a solid, high pressure clamp onto the substrate. The principle concept is that to avoid flash and to properly fill a cavity for overmolding on a substrate, there must be some area high pressure clamping contact while the Santoprene TPV is filling the cavity. On very simple geometry this is not difficult to achieve. But, on complex three-dimensional (3-D) geometry where there may be sculpted shapes, the shutoffs can be more difficult to achieve. Therefore, specific detail is designed into the part to provide an area where the mold closes on a land area surrounding the cavity to be filled with the Santoprene TPV over a rigid substrate.

Shutoff Designs

There are typically three types of shutoff designs used to overmold Santoprene TPV on a rigid substrate. They may be used in either two shot molding or insert molding processing. These designs are:

- Recessed shutoff.
- Flush fit shutoff.
- Two sided overmolding.

The **recessed shutoff** is shown below. This design is typically used for parts with complex parting lines.

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Figure 10
Recessed Shutoff

Figure 11 shows how to achieve a thicker rubber layer with this recessed shutoff design. Here there is a radius or chamfer to blend the part thickness in the edge transition area.

Figure 11
Thicker substrate shutoff design

The flush fit shutoff design is shown in Figure 12. It is used typically in simpler geometries where there may be thicker substrate stock and less complex shutoff lines.

Figure 12
Flush Fit Shutoff Design

Two-sided overmolding is shown in Figure 13. It is generally recommended for flat surfaces and flexible surface designs.

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Figure 13
Two sided overmolding design

Related Documents

For processing details please read our "*Guide for Injection Molding for Thermoplastic Rubbers*" available from Technical Solutions on our website.

TLs
Injection Molding of Santoprene 8000 TPV 8211-55B100
Injection Molding of Santoprene TPV PA
Shrinkage Rates for Injection Molding of Santoprene TPV
Santoprene 8000 TPV Series General Product Information

General Design Guidelines for Extrusion

Introduction

Geometric parameters such as wall thickness, ribs, radii, hollows and hinges influence both processing and performance of extruded profiles.

Wall Thickness

Uniform or near uniform profile wall thickness will yield improved ease of processing, lower costs, better tolerance control, better surface finish, and allow more complex shapes. Minimum wall thickness is 0.5 mm (0.02") while maximum wall thickness is 9.5 mm (0.375"). Thinner wall sections are possible, but would require use of Santoprene 8000 TPV series. Wall transitions should be smooth and limited as much as possible as this will aid in die balancing.

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Ribs

As in wall transitions, if the thickness variation is too abrupt and large, there may be problems in balancing the flow. The thickness of ribs should be 50% of the nominal wall thickness and generous radii should be applied at the base.

Radii

All sharp points should be replaced with a radius. The minimum radius for extruded section is 0.20 mm (0.007").

Hollows

In the profile cross-section, it is possible to have hollows. The extrusion die will initially give the hollow its shape and pressurized air can be used inside the hollow to help it maintain its shape as it cools. Another method is to use vacuum on the exterior of the extrudate to aid in supporting the hollow and its shape.

As can be seen, more hollows necessitate increasingly complex die design and it becomes more difficult for the profile to retain its shape. Unless required by design, hollows should be minimized or avoided altogether.

Figure 14
Hollow sections with interior walls

Air blown inside the profile as it is being extruded is a means to cool the interior walls of the part. This requires that the air have a point to escape via cutting in line or punching.

Foam Extrusion

Santoprene TPVs can be foamed via chemical and mechanical methods. For chemical foaming, blowing agents such as bicarbonates can be used. The foam density achievable is from 0.97 (typical unfoamed TPE) to 0.70 specific gravity. Lower densities are subjected to a patent from AES. The blow agents should have a degradation onset temperature at about 180 to 190°C (355 to 375°F) since most extrusions of TPEs are processes at 195 to 215°C (385 to 420°F). For the

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mechanical method, water is the working medium. Here, the technology is known as "water foaming". This is a patented technique and AES is one of the patent owners. Specialized equipment is necessary to achieve consistent foam structure and density. The reduction in density is from 0.97 down to 0.20; densities in between this range can be achieved through process control. Reduction in density does affect mechanical properties and should be considered in profile design for the application.

Multi-Layer Extrusion

Co-extrusion is the technique of combining two materials into a single part in a single extrusion process. Two extruders are lined up to supply a die block that channels the respective polymers into the correct paths to give the two-material extrudate. Compatible materials, such as TPE and polypropylene, will give parts that are fused together. A co-extrusion is a good means to mix a hard and soft section. Typically, this is used where the high durometer section, be it Santoprene TPV or polypropylene, provides the structural support for the part while the low durometer material provides the flexing. This is very common in sealing applications where the seal area is a soft, pliable material which can be compressed to generate a good seal. When trying to balance the flow, it is easier to use a hard grade of Santoprene TPV as the rigid material instead of polypropylene.

Welded Joints

Heat welding is a popular method for bonding extrudates made from TPEs. The heat is introduced to the joining faces to cause surface melting, and the faces are put together with slight pressure to ensure no gas entrapment in the interface. The heat can be introduced via a hot plate, heater element or hot air. Upon cooling, the joint is almost as strong as the part itself. Another method in joining extrusion profiles is to use adhesive systems. Some priming may be required, depending on the joint material combination and the bond strength required. Please refer to our TL on *Bonding and Decorating -- Primers, Adhesives, and Tapes* for suitable equipment and their manufacturers.

Hinges

Hinge points are a means to relieve strains at a point or to concentrate the bending about a specific point. If a lip is exhibiting bending about a point, the strain will be localized in the corner as shown in the drawing below.

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Figure 15
Hinge Point

The inclusion of a hinge point should be considered for either of two purposes:
1. To make the lip more pliable.
2. To concentrate the bending strains at the hinge location in order to promote better elastic recovery.

The hinge is a notch in the profile to make a thin section in comparison to neighboring geometry. Because neighboring walls are thicker, as the lip is deformed the thinnest section, the hinge, will bend first. Thus, hinges are useful to control the bending of a lip. Because it is bending about a thinner section, the force to deform the lip will drop but the relevant thickness can be readjusted to account for this if required. Also, since the strains are localized, the elastic recovery should be better.

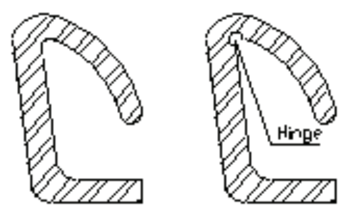

Figure 16
Hinge Design

Note that it is important not to make the wall too thin at the hinge location as it needs enough thickness to dissipate the strains through the thickness and to avoid a propensity towards kinking of the part. Judicious sizing of the hinge is required to ensure the proper thickness. Finite Element Analysis (FEA) can be employed to determine if the thickness is appropriate. Practical processing tolerances and resultant profile geometry should also be considered in determining the optimum design.

Lip Seals and Bulb Seals

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Lip and bulb seals are commonly used for sealing applications. Generally, a bulb seal is better due to it having superior elastic recovery in comparison to a lip seal. Bulb seals provide significantly higher sealing forces than lip seals. This is because a bulb seal can be abstracted as a lip seal on each side providing sealing force. All things being equal, the bulb seal requires more force to compress than a lip seal which translates into a higher sealing force.

Kinking

To delay the onset of kinking, two solutions are available. The first is to increase the wall thickness of the part. Higher wall thicknesses will reduce kinking. Increased wall thickness has more impact on the inside radius of bending. The other solution is to foam the part. A foamed part allows the material to compress on the inside bend. It has been determined that the durometer of the material has little impact on kinking.

Related Documents

For processing details please read our "*Extrusion Guide for Thermoplastic Rubbers*" available from Technical Solutions on our website.

TLs
Chemical Foaming Process for Santoprene TPV
Flocking of Santoprene TPV Profiles
Foaming of Santoprene using Water-filled Polymers
Low Friction Coatings on Santoprene TPV
Slip Coat
Water Foaming of Santoprene TPV

General Design Guidelines for Blow Molding

Geometry and Parting Lines

Common blow molded articles tend to be two-dimensional (2-D) and lie on a single plane. Examples are bottles for beverages, hair treatment liquids, tomato ketchup, etc. The parting line is very easily selected as it is usually the plane of symmetry.

In engineered applications, the articles may be required to take a 3-D definition and lie through all three planes. An example is an automotive air duct that needs to conform to the available space under the hood and must lie around the engine block. In many cases, it may be possible to simplify such complicated designs by several methods such as:

- Implementing convoluted sections to allow the duct to bend where it needs to and keeping the rest as straight sections to control the natural bend of the convoluted section

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upon assembly. Using this method, the duct can be blow molded as a straight duct and bent during assembly. The parting line in this case becomes simple and is usually at the plane of symmetry.

- For simple and short bends, the duct can be blow molded without the need for convoluted sections by simply tilting the axial axis of the duct relative to the parison axis; however, this method may require a secondary machining operation to even out some wall thickness and, in some areas of the blow molded duct, wall thickness distribution is sacrificed for manufacturing simplicity.

In more complicated designs, it may not be possible to simplify using convoluted sections -- the flexibility of convoluted sections is not desired for functional reasons or tilting the duct axis relative to the parison axis cannot achieve a proper molding. In such cases, the conventional blow molding technique will not suffice and the 3-D blow molding technique will have to be used. In this 3-D method, the parting line will follow the axial axis of the article and is usually the line defining the duct symmetry.

Wall Thickness

Circumferential wall thickness distribution is generally controlled by the head tooling diameter in extrusion blow molding and press blow molding, and by the preform mold in the injection blow molding process. It is also dependent on the blow ratio. The greater the blow ratio, the more tolerance may be required for circumferential wall thickness.

Longitudinal wall thickness distribution is greatly dependent on the parison control, melt strength of the TPE at the processing temperature and the blow ratio.

The minimum wall thickness achievable is dependent on the melt strength of the material, the weight of the part and the tooling diameter.

For most grades of TPEs, mold shrinkage runs from 0.014 to 0.018 mm/mm (in/in). Softer grades will exhibit slightly higher shrinkage. The actual shrinkage will vary depending on the part shape, wall thickness and other particulars (please refer to our *Blow Molding Guide*).

Draft Angles

Draft angles for TPEs are similar to those applied for blow molded polypropylene articles; that is, about 2 to 3°. However, for lower durometer TPEs, or softer grades, the draft angle may need to be increased up to 4°.

Typically, a 1° draft angle would be the minimum requirement provided that the draft angle need not be applied to surfaces that protrude less than one parison thickness, and draft angles must take into account the durometer of the TPE being processed, and the number and configuration of the protruding or recessed elements in the design.

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Radii

In general, radii below 0.25 mm (0.01”) should be avoided. Although smaller radii can be machined into a mold, the resultant radii formed on the blow molded article will probably be about 0.25 to 0.30 mm (0.01 to 0.012”), depending on the processing conditions such as blow pressure, melt temperature, mold temperature, etc.

A typical radii specification would be 0.5 mm (0.02”).

Seals, Crush Ribs

The function of crush ribs is to provide sealing onto uneven surfaces. They should be implemented in a minimum of one pair and are circumferential and spaced near to each other. The crush ribs should be designed with a 2 to 5% interference fit to the mounting surface so that it is “crushed” between a clamp and the mounting surface. Exact suggested interference is a function of the durometer and application. The preferred clamp is a band type and an alternative is the wire clamp.

In designing the crush ribs, the amount of protrusion to cause the interference is important. The shape should be rounded so that line contact with the mounting surface is made on initial contact and the contact spreads as the crush rib is clamped down.

Crush ribs can be formed in the blow molding process with a sharp extension of the cavity as shown below. In some cases, they can also be formed by machining the TPE, and this method is limited to the accessibility.

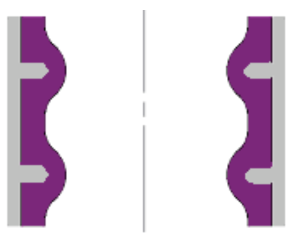

Figure 17
Shape of cavity to form crush rib

Convolutes

Convoluted parts can be made from TPEs via blow molding with great ease. The limitation is that the wall thickness distribution from root to tip cannot be made uniform, and this is due to the blowing process and how the polymer flows as the parison stretches to take the convolute cavity

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shape. Another limitation is the tip radius; it should not be less than 0.1 mm (0.004") or the tip may not form properly.

For taller convolutes, it may be recommended to consider the flat tip convolute design to afford greater ease in forming the convolute tip without loss in convolute performance. In designing the convolute, the control dimension is the tip thickness, tip radius, root radius, convolute height and convolute width or pitch.

In blow molding of the convolutes, the parison should be sized as close as possible to the convolute root diameter. The blow ratio to form the convolute tip is kept to the minimum possible for better wall thickness control, since the convolute tip is a functional portion of the convolute. The use of a parison controller in extrusion blow molding will help control the wall thickness distribution of a series of convolutes in the longitudinal direction so the convolutes will extend and collapse in a uniform manner or in the desired sequence.

See also our section below on convolute design for functionality.

Related Documents

For processing details please read our "*Guide For Extrusion Blow Molding for Thermoplastic Rubbers and Thermoplastic Elastomers*" available from Technical Solutions on our website.

TLs
Regrind Stability of Santoprene TPV in Blow Molding

Designing a Seal

Introduction

Sealing falls into one of two categories, *static* or *dyanamic*. The design of a seal will change dramatically depending on which of these two categories the application falls into. *Static* sealing applications deform the seal once whereupon the seal is held in place for the rest of the application life. An example of a static seal is a pipeseal buried underground. A *dynamic* seal is one that will open and close intermittently. An example of this category of seal would be a glass run channel on an automobile. The window is opened and closed by the user and the seal moves in response to this.

Static Sealing Applications

When an elastomer is deformed and held for some time under constant strain at a specified temperature, the deformation stress will decay with time. This process is called s*tress relaxation*, which is the result of distinct physical and chemical processes.

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Physical processes are due to the viscoelastic nature of the elastomer and may involve re-orientation of the molecular network, the movement of entanglements as well as the breaking of secondary valence bonds upon the application of stress. Chemical processes include the chain scission of molecules through thermal and oxidative degradation.

The physical relaxation predominates during the early stage of the deformation process while the chemical relaxation is perceived at medium/long term depending on the material sensitivity to heat aging.

In static sealing application, a rubbery part may be compressed between two rigid mating parts and the sealing performance is related to the deformation level of the part. The "sealing" pressure should always be higher than the environmental pressure to allow the seal to perform effectively.

The deformation stress applied on a seal decreases with time and increasing temperature.

Compression stress relaxation data for our TPEs have been accumulated in AES laboratories since 1990, along with different testing methods. Depending on the method of testing, it is possible to estimate the initial compression force needed to meet the sealing requirements at long term in a specific application.

Theory

It can be demonstrated that for a physical stress relaxation process, the force decay is linear with the compression time on a logarithmic scale. This phenomenon can be expressed by the following relationship:

$$(F_t / F_o) * 100 = 100 - B * \log (t/t_o)$$

where:
- t = Residence time of a seal under constant constraint
- t_o = Time at which a specimen is put under constraint
- F_t = Residual force at time "t"
- F_o = Compression force at time "t_o"

Each material can be characterized by the value of parameter "B". This parameter is called the "sensitivity factor" to time and temperature or the "loss per decade".

The most common method used to determine stress-relaxation data in compression is ISO 3384, method A. It is noteworthy that with this method, all the measurements are made at the temperature of the aging.

Performance at 23°C (73°F)

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When all measurements are made at 23°C (73°F), this method allows prediction on the sealing performance of a part at long term, provided that the significant drop on stress decay between time "0" and 30 minutes is taken into account.

The force decay which could not be measured on our stress relaxometer from compression time "0" to 30 minutes, at the time of this writing, has been obtained from the compression of the standard button between the plates of a tensiometer.

Table V Typical Compression Force Retention for Santoprene TPV from 0 to 30 Minutes

Santoprene TPV Grade	Compression Force Retention* (from 0 to 30 minutes)
111-35	69%
101-55	65%
101-73	60%

* Injection molded buttons 6.2 mm (0.24") thick, 13.0 mm (0.51") diameter; compression speed: 2.54 mm (0.10")/minute. No lubricant used.

No chemical degradation is expected before target (it is shown from the result of the test on Santoprene TPV grades 101-55 or 101-64 that no chemical degradation is observed after 16 years aging; at the time this document is written the test is still going on). The table below underlines the behavior of Santoprene TPV grades in compression stress relaxation at 23°C (73°F), the softer the grade the lower the sensitivity to the time effect.

$$Ft/F_o*100 = A - B * \text{Log}\,(t/t_o)$$

Table VI Summary of Compression Stress Relaxation Data for Santoprene TPV (method ISO 3384, A; residence time over 40,000 hours at 23°C ([73°F])

Santoprene TPV Grade	"A"	"B"
101-55	98.5	6.4
101-64	97.6	7.7
101-73	98.3	8.7
103-40	97.2	9.0

* Injection molded buttons 6.2 mm (0.24") thick, 13.0 mm (0.51") diameter; compression speed: 2.54 mm (0.10")/minute. No lubricant used.

Performance at High Temperature

When the temperature of the application is higher than 23°C (73°F), it is difficult for the design engineer to estimate a sealing performance from this method. It does not reflect correctly real life conditions where a seal is compressed at 23°C (73°F), heat aged and cooled down at 23°C (73°F) or lower under strain.

Another stress relaxation method is therefore presenting much more interest for engineering calculations; it is based on room temperature measurements after the heat aging of compressed specimens; ISO 3384, method B.

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An example of a complete force decay from initial compression force (t_o=0) at 23°C (73°F) followed by heat aging at 80°C (175°F) up to 1500 hours is given in the graph below. Behavior of three of our automotive weatherseal grades is shown.

Figure 18

Compression stress relaxation with heat aging at 80°C (175°F), ISO 3384

More information can be found in our TL, "*Sealing with Santoprene TPV*"

Tips for Designing a Santoprene TPV Static Seal

1. Examine the specifications on sealing in terms of pressure and peak temperature.

2. Choose Santoprene TPV grade 101-55 or 101-64 for a start.

3. Depending on the peak temperature at performance, apply the relevant compression stress relaxation data to estimate the initial compression stress level that would lead to good sealing performance at long term as per specifications.

4. Check from the stress-strain relationship of the material what should be the compression ratio as to meet target.

5. If the compression ratio is below 25% then Santoprene TPV 101-55 or 101-64 might be acceptable. If the estimated compression ratio is found over 25%, choose a harder material such as grade 101-73 or 101-80 and follow the same procedure as above.

6. Always bear in mind that a "hard" grade can be also perform in sealing applications provided that the mating surface is not irregular; if it is, a soft grade can be used but with

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a trade-off on the compression level -- higher compression levels than 25% are not advised but tolerated up to 45%, tolerances included.

7. As Santoprene TPV grades are nearly incompressible materials, care must always be taken to give the material room to expand. In other words, when a part made of Santoprene TPV is compressed by 25% in a groove, the width of the Santoprene TPV part cannot exceed 70% of the groove width.

Dynamic Sealing Applications

Dynamic sealing happens when a seal is put under strain for a definite period of time, after which the strain is relieved for some time and then applied again. This loading can be at specific frequency or random.

A typical semi-dynamic application is an automotive belt line seal (BLS) whose main function is to seal on a door window in contact with the glass in closed position and/or during the movement of the glass and/or after unloading.

Another dynamic application is found in building profiles where rubbery materials have to seal against air and water despite the action of the air blowing and slightly deflecting a window frame. The seal is required to follow the movement of the surface of contact to ensure the requested tightness level.

In a pipe connection, the seal must react to a movement (angular deformation) from the environment.

Dynamic sealing starts with constraints similar to static sealing -- when under strain, the seal is expected to ensure tightness against the environmental conditions, therefore, the requirements valid for static sealing are also valid at short term for dynamic sealing and the data obtained from the stress relaxation testing can be used here as well. However, the elastic recovery (ER) of a dynamic seal has great importance.

Theory

As a dynamic sealing process starts like a static sealing process, reference the theory already described in the section related to static sealing where the concept of sealing is introduced.

On top of this static sealing behavior, however, we must take into account the ability of a material to snap back, after unloading, to its initial shape.

Traditionally, the compression set (CS) method is used to evaluate the performance of a seal in a dynamic application. This short-term test (a 24 hour constraint is typical for thermoset rubber parts) does not capture the actual performance of a seal.

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The CS method consists of compressing a standardized button (*e.g.,* 6.2 mm [0.25”] thick, 13 mm [0.51”] diameter, as in the compression stress relaxation test or 12.4 mm [0.49”] thick, 29 mm [1.15”] diameter) to 75% of its original height, generally for a short period of time, and measuring its height 30 minutes after unloading. The CS is expressed with the following relationship:

$$CS\ (\%) = ((H_i - H_f) / (H_i - H_s)) * 100$$

where: H_i = initial height
H_f = final height
H_s = spacer height

CS is complementary of the ER and is defined as:

$$100 - CS\ (\%) = ER\ (\%)$$

Thus, a higher compression set translates into lower elastic recovery and can result in poor sealing performance.

CS data for Santoprene TPV can be found in our TL, “Sealing with Santoprene TPV”.

The ER performance of a material is determined by its viscoelastic properties as revealed by the results of a stress relaxation test; because ER is a time-dependant property, its level is affected by the initial speed of compression and by the residence time under constraint. The longer the residence time under strain, the lower the speed of recovery and the higher the set.

The ER performance is significantly affected by the temperature to which the sample is submitted while under load; the higher the temperature, the lower the ER and the higher the CS. After heat aging, the ER is significantly altered if the specimen is cooled down under strain.

The following conclusions have been drawn from ER testing performed on buttons and lip seals in our laboratories:

- The geometry of a part significantly influences the ER.
- The elastic recovery of a lip seal may be significantly improved by the presence of a small radius or a hinge leading to a concentration of strain.
- Within the limits of the experimentation, no significant change of the ER was found with a hinge placed on one side of the seal or on the other side, *i.e.,* with a hinge working in tension or in compression.
- A significant improvement of the ER is recorded when the hinge is moved upward towards the top of the lip, with maximum 45% local strain.
- The elastic recovery is improved when the lip anchorage angle is increased, *i.e.,* when the displacement path is longer and, therefore, local strain higher.
- Within the limits of the investigations, no improvement of the ER was found with a back-to-back double hinge, but the local strain level was possibly too low to record an improvement.

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Tips for Designing a Dynamic Seal

1. Consider the dimension of the gap to be filled -- average and extreme sizes.

2. Choose between a bulb or a lip design, knowing that the elastic recovery from the former can be significantly better than from the latter, in relation with the stiffness of the geometries; but the compression force from a bulb will be significantly higher than for the lip with the same wall thickness. The choice between the bulb and the lip might be dictated as well by the processing method, such as injection molding where a bulb is excluded. A bulb seal may generally be deflected to 50% and hinges can be created to further enhance the elastic recovery and force the bulb to deflect the expected way.

3. A lip seal should be designed to obtain a concentration of minimum 20% and a maximum of 45% strain in the bending area. Extreme care must be taken to make sure the seal is bending where intended.

4. Assistance from FEA can be requested for the estimation of the deformation force, either to support the choice between different structures or to check the (approximate) level of the deformation force meeting or not the specifications of the end-user. The initial compression force decay of Santoprene TPV can be significantly higher than the force decay for a thermoset rubber material, therefore, some concession on the specified compression force may be worth discussing with the end user.

5. When a decision is made on the geometry to use for a seal, it is time to fine-tune the shape to optimize the elastic recovery. The geometric details on the bulb or on the lip will be applied in terms of wall thickness and radii in line with the knowledge and experience of the design engineer who will estimate, with or without assistance from FEA, the importance of these details to meet the requirements of the application.

Related Documents

TLs
Sealing with Santoprene TPV
Compression set and Elastic Recovery with Santoprene TPV

Designing Tube, Duct and Bellows

Introduction

The objective is to estimate the minimum wall thickness of a smooth wall tube to resist external/negative (vacuum) or internal/positive pressure. There are two types of applications

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where the design guidelines can be applied, *e.g.,* ducts and tubes (these latter being single component without reinforcement).

These guidelines are not relevant to hoses (consisting of a lining, reinforcement and usually an outer cover), as their mechanical properties are mainly driven by the reinforcement.

Ducts

Examples include automotive clean air ducts (vacuum or external pressure), turbo air duct (internal pressure), appliance bellow. In such applications, a smooth wall section may be required when the space available for part envelope is limited or when longitudinally rigid sections are needed.

To avoid axial elongation, **the trend in turbo air duct design is to maximize the proportion of smooth wall section on convoluted sections that are often made of Santoprene TPV 203-50.** Considering this trend may stiffen the air duct too much and make the clamping forces too weak to maintain the part in place, a compromise must be found between pressure resistance and flexibility. To permit the determination of that compromise, the specifications must mention the maximum reaction forces air duct extremities should not exceed. Moreover, sequential blow molding can be used in order to combine hard and soft materials, the latter being used in the clamping/sealing area.

An oval cross-section instead of circular can be used if the envelope is smaller in one direction, but weakness from the greater radius must be taken into account. For a conservative calculation, the oval duct will be seen as a cylindrical duct with a radius equal to the greater radius of ellipsis. However, it is recommended to avoid as much as possible the use of oval sections as they are not appropriate for sealing. Moreover, their processing is generally more difficult than that of a circular section.

Hydraulic Tube Design

While for ducts the most important parameters to consider are the absolute displacements (internal pressure) and/or the collapse pressure (external pressure), the most important parameters to determine when considering the design of tubes is the maximum working pressure (MWP), determined from the minimum burst pressure (MBP).

The MWP is a fraction of the MBP, depending on the security factor. The security factor depends on the application, but can be as high as 4.

The MWP depends on the material, the geometry, the operational conditions (static, dynamic), the required working life, the required minimum bending radius, the temperature, the resistance to the media with which the tube comes into contact and/or external influences (ozone, UV light, weathering), etc.

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The theory described below concentrates on providing a formula to determine the MBP for tubes.

Material Selection

The material selection is subject to the type of application and the type of process used to produce the part. Following is a summary of possible materials convenient for the two applications and processes considered in this section.

Table VII Material Selection for each Application Type and Available Process

	External Pressure	Internal Pressure
Mono-extrusion	Santoprene TPV 101-87 is viewed as a compromise between the resistance to collapse and sealing requirements. Choice is driven by specifications and economics. Increased wall thickness on smooth wall sections and/or use of stiffeners may be required.	Santoprene TPV 101-80 for tubes and 103-40 or 103-50 for ducts. The grade choice may be also driven by a fluid resistance at a high temperature. When resistance to abrasion is required, Santoprene 8000 TPV may be selected for tubes (or as the external layer of a hose).
Co-extrusion	Soft Santoprene TPV grade for sealing at ends. Hard Santoprene TPV grade for smooth and convolute sections).	Santoprene TPV 103-40 for sealing at ends and a harder material for smooth sections (polypropylene or 103-50).

Theory

The ways to estimate the resistance to external pressure, the deformation under internal pressure and the burst pressure are reviewed below. The results are only fully reliable when the deformation occurs within a strain range where linearity is found in the stress-strain relationship of the material of choice.

Depending on the type of test (tension, compression and shear), the temperature and the load speed, Santoprene TPV grades can be divided into two categories: the "rubber-like" material type (exhibiting a curve with a positive slope until rupture) and the "yield" type material (exhibiting a yield point and a negative slope). Most of Santoprene TPV grades are rubber-like with the exception of 103-40 and 103-50.

The yield point at 23°C (73°F) is found to be about:

- 25% with Santoprene TPV 103-50.
- 30% with Santoprene TPV 103-40.

It is not advised to stretch these materials over their yield point in the stress-strain relationship. Therefore, in the case of duct application, it is important to verify that the pressure is not going above the yield point.

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In the case of tubes, it is more important to determine the pressure leading to rupture (burst) rather than the pressure at the yield point. Indeed at 23°C (73°F), the quotient between the stress at yield point and the stress at rupture is 1.5 for 103-50 and 2.25 for 103-40, while the relationship proposed to estimate the burst pressure is very conservative and significantly over this ratio for these grades (see below). Moreover, the MWP is usually referred as 1/3 to 1/4 of the MBP.

The Negative Pressure Case

In case of a significant deviation from linearity, a non-linear FEA approach is advised to obtain an accurate answer.

With hard Santoprene TPV grades like 101-87, 103-40 and 103-50, a linear relationship is observed between 0 and 2% elongation at 23°C (73°F) and the elastic modulus (E) can be estimated as shown below.

For all calculations, it is recommended to use 80% of the E.

$$E_w = 0.8*E$$

Let us consider the following tube:

Figure 19

Definition of length, medium radius, external radius and thickness

and let us estimate, using one such method, the minimum thickness needed for a tube to resist to vacuum.

This method uses a set of design equations to determine the wall thickness of any given length of tube.

where:

r_o = external radius
E_w = modulus of elasticity = 0.8E
v = Poisson's Ratio = 0.47 for Santoprene TPV

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P = external pressure (internal vacuum)

$$A = \frac{1}{2}\tan^{-1}\sqrt{\frac{(8C-1)^3}{(12C-1-32C^2)^2}}$$

$C = E_w/\{4(1-\nu^2)P\} + 1/8$

Note: E_w and P must have the same units.

Tips for Designing Smooth Section

Check the specifications - A smooth section might resist a positive or a negative pressure. Typical examples are:

- A conventional automotive clean air duct should not collapse under vacuum at the highest temperature of the performance.
- An automotive turbo air duct that should not extend nor blow over specified limits under a positive pressure at the peak temperature of the application.
- A hose should not rupture under specified conditions of pressure and temperature.

For a conventional automotive clean air duct, it is relatively easy to estimate the minimum wall thickness of a smooth section from the method detailed above. Remember that a reduction of volume can be obtained through the use of stiffeners as detailed above.

With a turbo air duct, the smooth section is generally made of polypropylene or Santoprene TPV grade 103-50 to meet the requirements on stiffness at high temperatures. The wall thickness with Santoprene TPV 103-50 can be estimated from the relationship given in the relevant section above.

With a tube, the burst pressure, and herefrom the operating pressure, can be estimated from a simple relationship as shown above, from the knowledge of the properties at break of Santoprene TPV grades at the highest temperature of an application. Always remember that chemical resistance, resistance to kinking and resistance to abrasion might be additional driving forces in the choice of the grade.

Related Documents

TLs
Ducting Hose
Open braid Hose
Santoprene TPV for Material Transfer Hose

Designing Convolutes

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Introduction

TPEs are used in a wide variety of bellow shaped parts/applications and replace conventional thermoset rubber. The design of a thermoset rubber part typically uses thick walls to achieve strength and flexibility. TPEs can use thinner wall designs with a convoluted bellow shape with stiffer TPE grades to accomplish the same mechanical requirements. Because these TPE grades are much stiffer, the designs required are quite different from a conventional thermoset rubber. These bellow shapes are used in a wide variety of applications across a number of industries. These would include:

- Automotive clean air ducts (vacuum).
- Automotive turbo air ducts (pressure).
- Automotive shock absorber bellows.
- Automotive rack and pinion bellows.
- Automotive tie rod end seal.
- Automotive constant velocity joint boot.
- Automotive drive shaft boot/gear boot.
- Automotive door bellow.
- Appliance bellow.

The bellows are fabricated using extrusion blow molding, injection blow and press blow molding, and injection molding. Design considerations are required to accommodate limitations for each of these processes.

Guidelines

The shape of a convolute can be described as shown in Figure 20. The terms shown here are:

Figure 20
Convolute design variables

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Where:
- h = convolute height
- w = convolute pitch
- O.D. = outer diameter of convolute
- I.D. = inner diameter of convolute
- t_{tip} = thickness of tip
- t_{root} = thickness of root
- r_{tip} = radius of tip (measured to outer surface)
- r_{root} = radius of root (also measured to outer surface)
- theta = included convolute angle
- alpha = wall angle
- L = length of convoluted section
- N = number of convolutes (typically counting tips)

A key relationship for convoluted bellows is based on these geometry factors:

Wall length, *l*, defined from the wall angle and diameters:

$$l = \{\text{O.D.} - \text{I.D.} - [(t_{tip} + t_{root})/2]\} / \cos(\text{alpha})$$

Since the root thickness is usually greater the **minimum compressed length**, $L_{min\ compressed}$, of a convolute section is

$$\mathbf{L}_{\mathbf{min\ compressed}} = 2\ N\ r_{root}$$

For many applications, *e.g.*, air ducts, there is a **maximum working length** to which a bellow should be stretched open. This is generally described as the length at which the included angle, theta, between the convolutes reaches 90°. The equation for this length with uniform convolutes is

$$\mathbf{L}_{\mathbf{max\ working}} = 2\ N\ l \sin(90°/2) = 1.414\ N\ l$$

Vacuum collapse resistance and pressure resistance are treated separately in other sections. Refer to these to determine how to calculate the required wall thickness and angles for applications like air ducts that are exposed to these conditions.

Geometry Effects

General design of convolute shapes is dictated by the requirements for flexibility, bellows stiffness, diameters, extension and collapse limits. Some typical designs are used in specific applications. These will be discussed in separate sections following, but in general there are some guidelines that can be followed that will help to tune a design to the performance requirements of a given bellows.

In the following, the general effect of varying the convolute design parameters will give a designer an understanding of the range of variables to adjust to achieve the balance of performance desired in a convoluted bellows for a wide variety of applications.

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Table VIII Convolute Variations

Variation	Variable	Effect
Convolute height (h)	Taller	• More flexibility. • Lower force to collapse and extend. • Crush resistance increase.
	Shorter	• Less flexibility. • Higher force to collapse and extend. • Crush resistance decreases
Convolute width (w)	Wider	• Easier to extend. • Harder to collapse. • Crush resistance decreased.
	Narrower	• Easier to collapse. • Harder to extend. • Crush resistance increased.
Convolute Angle Variation (alpha)	Larger	• Easier to extend. • Harder to collapse. • Crush resistance decreased.
	Smaller	• Easier to collapse. • Harder to extend. • Crush resistance increased.
Convolute Tip Radius (r_{tips})	Larger	• Easier to extend. • Harder to collapse. • Increases length of bellows.
	Smaller	• Easier to collapse. • Harder to extend. • Decreases length of bellows.
Convolute Root Radius (r_{root})	Larger	• Easier to extend. • Harder to collapse. • Helps keep material at the root during blow molding.
	Smaller	• Easier to collapse. • Harder to extend. • Helps distribute material to bellows tip during blow molding.

Convolute tip thickness should be the only thickness specified on a blow molded bellows. The blow ratio will eliminate the ability to set the root thickness. The tip thickness should only be set at a minimum value for blow molded bellows since the fabricator will require some tolerance variation. The tip thickness will have the following effects:

Thicker Tip	**Thinner Tip**
Harder to extend and collapse. More resistant to abrasion and impact. Crush resistance increased.	Easier to extend and collapse. Crush resistance decreased.
Square Top width increased	**Square Top width decreased**
Crush resistance increased. Bellow length increased when number of convolutes same.	Minimum collapse length increased. Functions more like a round top.

For processing details please read our "*Guide For Extrusion Blow Molding for Thermoplastic Rubbers and Thermoplastic Elastomers*".

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Summary

For more information, contact your local representative or call for technical assistance (contact information on back cover). Also, we welcome your visit to our web site:

http://www.santoprene.com

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santoprene.com/answer

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Our full line of elastomeric solutions

Santoprene™ *brand TPVs*
The benefits of vulcanized rubber with the processing ease of thermoplastics

Vistamaxx™ *specialty elastomers*
New options for elasticity in nonwovens, films and polymer modification

Exact™ *plastomers*
Polyolefins used to enhance polymer toughness, sealing and clarity

Exxelor™ *modifiers*
Functionalized polymers to enhance performance of engineered thermoplastics

Vistalon™ *EPDM rubber*
High performance polymers for a wide variety of applications