



Liquid Silicone Rubber Design and Capabilities

Adding functionality and reducing part count using a material uniquely suited for complex applications

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Introduction

Liquid Silicone Rubber (LSR) is a material capable of creating revolutionary change in part design and manufacturing. Developed originally for use by rubber molders, the resulting products were produced with a similar quality expectations from the freshly molded part. This often required secondary rework to achieve customer specifications. A technical approach born in Austria allowed for virtually flash and waste free manufacturing of this material in typical injection molding equipment retrofitted for the purpose. Companies adopting the latest processing methods, often hit by the rapid outsourcing of their thermoplastic product lines to China, tightly controlled their knowledge to prevent a similar exodus. This has retarded the growth of the industry significantly by generally limiting LSR's adoption to backup solutions for components specified as thermoplastic elastomers but unable to meet performance requirements.

Designers cannot utilize LSR's unique abilities without education in design guidelines and physical properties. Many limitations of thermoplastic elastomers are lifted entirely, rendering traditional injection molding guidelines inapplicable. Conversely, other considerations critical to successful design are imposed. Fortunately, a firm grounding in plastics provides the foundation to open the world of LSR manufacturing in a relatively short time. The key is to understand that though the equipment is outwardly similar and familiar to thermoplastic engineers, the material is governed by an entirely different process, requirement and rule set.

A molded LSR article can be a challenge in manual and automated assembly processes. Soft components are difficult to feed, may not support their own shape, and often require complex mechanical or chemical bonding methods to incorporate into a device. The next logical step is the application of LSR in two component molding processes. Thermoplastic substrates solve virtually all the assembly and handling concerns. The consistency and repeatability of the two-shot molding process eliminates the variation of assembly and reduces the qualification load by reducing the count of processes that must be vetted.

Multicomponent molding as a concept is not new. A wide variety of products have been engineered with anything from cosmetic detail to functional gaskets and seals. The flexibility of LSR to serve multiple functions in a single part with different characteristics depending on geometry is the key to unlocking the technology's full potential.

A Primer on Liquid Silicone Rubber

The focus of this paper will be on platinum-catalyzed liquid silicone rubber. The material is delivered in matched A and B components that must be thoroughly mixed in a 1:1 ratio (or 1:1 plus a third stream additive, such as color) before injection into a heated mold for vulcanization into the desired shape. It is considered convenient to consider the process as the inverse of thermoplastic injection molding. While superficially true, the detail is considerably more complex.

Properties

LSR articles enjoy a wide range of operating temperatures (-55C to 300C) with minimal degradation to many key properties. Chief among these, and a key differentiator from thermoplastic elastomers (TPEs), is compression set resistance. LSR seals and gaskets can be exposed to temperature extremes and

cycling and expect to maintain their shape and quality. While an excellent insulator in its natural state, the material can be made conductive through third-stream introduction of selected materials such as carbon. Slow to ignite, the material will continue to slowly burn if no flame retardant packages are added. V0 certifications are possible.

LSR is an inorganic compound and highly stable. General purpose materials are typically certifiable in their as-molded state for FDA requirements in the US, though they may require a post cure process to meet European standards. Medical grades of increasing purity are suitable for a variety of healthcare applications up to and including implantation.

Pigmentation is possible through a third-stream addition. Due to the nature of the delivery methods, color changes are more involved than a comparable thermoplastic process and can incur additional cost.

Grades

General Purpose

The entry level to LSR has a wide range of applications and certifications. Generally acceptable for food contact, this classification of materials is the workhorse of the LSR world. Seals, gaskets, valves, tubes, pumps, bellows, kitchenware, and more all fall into this category. Cost can be as little as \$4/lb.

High Tear

Originally developed for the childcare market, the enhanced tear strength implied by the classification is the key characteristic of the category. Often found in baby bottle nipples and sippy cups, high tear LSR both resists the initial notch and fares better in propagation.

LSR does not achieve its full tear strength when cured in the mold. The demolding process may challenge the integrity of the article. These formulations may aid in part removal for particularly difficult components.

Medical/Implantable

Highly pure LSRs capable of meeting strict extractable and bio requirements, the cost can reach into \$100+/lb.

Self-Adhesive/Bondable grades

Formulated with the intent of creating cohesive bonds to substrates, these grades are typically the first stop for multi-component molding. Substrate selection is key to success and will be a key discussion topic later in this paper.

Self-Lubricating/Self-Bleeding

Surface finish can be used to reduce the coefficient of friction in a molded LSR component. Self-lubricating grades weep methylphenylsilicone oil over time. Homogeneously mixed in the material, the bleed life is directly related to the volume of LSR in the finished article. This has a variety of applications, including lubrication of moving components, reducing coefficient of friction, and reducing slit healing. Counterintuitively, self-lubricating grades can also have adhesion promoters, allowing cohesive bond to correctly selected thermoplastic substrates.

Optical Grades

Creating an entirely new market for LSR, optical materials can be used to produce lenses and windows that are highly resistant to scratching and etching. LED encapsulation and protection is also possible.

Fiber Filled

LSR tear strength can be significantly enhanced using long glass or nylon fiber.

Low Volatile

After curing, LSR may require a post cure operation to reduce extractables to meet some food and healthcare application requirements. Low volatile materials are relatively new to the market and are formulated to meet extractable requirements without a post cure.

Custom formulations

In general, LSRs are manufactured in batch processes. As the equipment requires frequent setups for normal operation, this drastically reduces the cost of a custom formulation. As a result, LSRs can be tweaked to meet specific customer requirements without a significant per pound increase.

Tooling

LSR molds share a superficial resemblance to their thermoplastic cousins, but must be treated as their own entity. While a grounding in traditional tooling serves as a good entry point for the concepts used for LSR, assumptions about function, pricing, and lead time require a complete paradigm shift for successful programs.

The material is as abrasive as a highly glass-filled thermoplastic. The root of silicone, silica, is key here. The mold is being pressurized with sand! Tools require special hardening techniques to withstand the flow of material entering the cavity.

Temperature control must be considered in tool design. Homogenous heat distribution across all cavities is a key part of maintaining a consistent molding process. Closed loop Calrod heater cartridges coupled with thermocouples in strategic locations are ideal for this application.

As a thermoset, any material wasted cannot be reutilized. Cold decks are analogous to thermoplastic hot runners, delivering material to the point of the cavity while preventing upstream curing. As with hot runners, cold decks are available in open tip and valve gated options.

- Open tip cold decks use a very small orifice to transfer material to the cavity. To prevent LSR leakage into the cavity between cycles, the tip itself cures while the part is heated. This serves two purposes. First, the cold deck is sealed while the mold is open. Second, it allows pressure to be built in the cold deck during injection. At a given pressure, the cured slugs of material will be released into the cavities. This pressurization and simultaneous release is the primary method of balancing the system across all cavities.
- Valve gated cold decks use pneumatically driven pins opened and closed by the machine's controls. In most systems, stroke adjustment is used to balance fill.

LSR flashes at gaps as small as .0002", or .005mm. This creates a few challenges:

- The normal clearance for ejector mechanisms is sufficient for LSR fill. As such, any penetration of the product area should be avoided if possible. If absolutely required, components need to be back tapered to precisely fit to the cavity and therefore be loaded from the front (cavity).
- Venting needs to be carefully engineered. Molds should be designed to be fully sealed from atmosphere and equipped with vacuum systems to evacuate air from the cavity before injection. LSR will create gas as it enters the cavity. If vents are required for final evacuation, they should be considered in the tool design but added only after first shots have been evaluated.
- Parting lines should be as flat as possible. Tapered and swipe-by shutoffs are very difficult to maintain for high volume production.

Ejection is ideally suited for air or external systems. Strategically timed and placed introduction of air is used to ensure predictable part location and orientation. Parts can then be stripped, picked, or dropped using end of arm tooling or specially designed wiper systems that ensure the tool is clear of parts before the next cycle begins.

The Molding Process

Material Conveying

As a shorthand, LSR molding has been referred to as the opposite of thermoplastic. This is a greatly simplified view, but can be seen in many ways as essentially correct. The following process is the most common in production today. There are variants for custom manufacturing, however these are typically application-driven and beyond this scope.

An LSR delivery consists of a pair of containers. Typical production will consume pail kits (88lbs total in a pair of 44 lb pails) or drum kits (880 lbs in a pair of 440 lb drums). Smaller kits and delivery methods are available for small parts or prototyping, but are beyond the scope of this work.

The kit should be normalized to the manufacturing facility's temperature to ensure process stability. When ready, the delivery containers are directly installed in a dosing system/pump station. Material is precisely metered out of the kit in a 1:1 ratio and delivered to a mixing block. This is the first time the two components meet. A third stream, such as a pigment or additive, can also be introduced at this point. Typical concentrations are anywhere from a small fraction of a percent to twenty percent, though other letdowns are possible.

The mixture is passed through a static mixing screw that is normally jacketed by cooling water to retard any cross linking. A homogenous mix is achieved that is practical for injection molding. From here, the material passes into the injection unit. From the outside, the equipment looks virtually identical to a thermoplastic injection molding machine. A low shear screw is installed in a water-cooled barrel. The screw is tipped with a spring-loaded check ring. The injection unit is normally equipped with a pneumatically actuated shutoff nozzle.

Injection

Superficially, machine parameters for LSR molding will be familiar to experienced thermoplastic engineers. Greatly simplified, however, LSR is essentially short shot molding. Thermal expansion of the material fills out the cavity as the material cross links and cures. The cavity pressure curve compared to

a thermoplastic part will essentially be flipped. The highest pressure is exerted immediately prior to mold open, whereas thermoplastic will typically be at transfer.

Injection is fast and pressures are relatively low. Tiny variations (25 PSI) in the hold profile can determine an acceptable part, a short, or flash at the end of fill.

Scientific molding principles that are core to thermoplastic processing have not firmly been established in the LSR realm. This has long been a goal of many groups in the industry, but no final product has been released.

Post Processing

There are a number of common operations secondarily performed to LSR components.

Post Cure/Post Bake

LSR does not fully cure in the mold. Articles can have the curing and properties finalized in an oven with a high degree of air circulation. Compression set particularly benefits from a post cure process.

Additionally, a post cure may be required to reduce extractables for medical and food grade compliance.

Slitting

Valve orifices may be cut in articles after molding. Without post cure or the introduction of a barrier material (often glycerin), the slit may heal to some degree. It is easily punctured, but this is often undesirable if it reaches a consumer.

Cryogenic Deflashing

If a part has a particularly troublesome area where flash cannot be controlled, low temperature tumbling and cleaning can aid in removal. These areas may be avoidable through best practices in part and mold design.

Coating

The primary coatings for LSR enhance surface lubricity and tactile quality. These are typically used in consumer applications with skin contact, such as wearables.

Printing/Decorating

Though expensive, it is possible to decorate LSR. The low surface energy of the material that causes difficulty in bonding is the same barrier to traditional decoration, but it is technically feasible and performed in production today.

Key Design Elements

Nominal wall, draft angle, undercut, and flow length are all terms engrained in a plastic part designer's lexicon. LSR virtually frees an engineer of many the rules governing molded part design, though it should be noted it introduces a few of its own.

Injection Molding Theory

To fully understand why thermoplastic design guidelines are in place and where LSR differs requires a brief exploration of what happens to each material as it enters the cavity. What follows is a very simple overview that should help illustrate what is happening at the polymer level.

Thermoplastic

Thermoplastics fall into two general categories: amorphous and crystalline materials. Put simply, amorphous materials have a randomized polymer structure akin to a bowl of spaghetti (this analogy is furthered with LSR below). As their name implies, crystalline materials have a higher level of predictable structure in their lattice. As the materials are melted, the polymers are randomized. Injection tends to elongate the polymer chain in the direction of flow. Many differences start to occur as the materials solidify.

Amorphous resins revert to their randomized pattern as they cool. As they tend toward softer materials, this often manifests as differential shrinkage in the machine (flow) path versus the transverse (across flow) direction. Warp can be the result. The longer and thinner the flow path, the more dramatic the effect.

Crystalline materials follow a similar pattern, but having a more rigid structure do not necessarily warp to the same degree as their amorphous counterparts.

As thermoplastic cools, it shrinks. Ideally, if the part is a nominal thickness, the shrinkage will be normalized. Thicker areas may show sink.

LSR

The main advantage LSR has during injection is it does not yet have its matrix, therefore it does not have a polymer memory. The polymer chains are similar to the bowl of spaghetti of an amorphous material, but instead they behave like the bowl has been left out too long. The starch that begins to bond the spaghetti to the shape of its bowl is a good analogy for the cross linking taking place as the material cures.

LSR is particularly well-suited to high cavitation, low durometer applications that require low levels of molded-in stress. There are many documented cases where a thermoplastic elastomer met functional requirements and performed well in a single cavity prototype. However, during scale-up, very minor variations in mold balance created varying levels of warp across the mold. Conversion to LSR eliminated the molded-in stress causing the warp and created the consistency required for part function, automation, and assembly.

Design Freedoms

- LSR is virtually free of differential shrink, fill profile concerns (thin to thick to thin is acceptable), and flow length constraints.
- Nominal wall is not necessary.
- Many undercuts will demold without the need for additional tool actions.
- Draft angle may not determine location of the part when the mold opens. While it may be beneficial, it is not strictly required to follow standard practices.

Design Constraints

- Avoid geometries that require swipe by and tapered shutoffs to minimize flash.
- Excessive thickness first becomes a cycle time concern (.250" or more), then a moldability constraint. Very thick sections may shred when the mold opens.

Tolerances

LSR products are subject to changes in their dimensions after processing and vulcanization. This can be due to a variety of factors, such as mold shrinkage, gate location and type, thermal expansion of the mold, post cure conditions (if present), and any additives in the base LSR set or combined through a third stream.

These changes should be determined and allowed for when designing such items as tooling used in the manufacture of a given product. Products with tightly held tolerances should be prototyped or kept metal safe to aid in final tooling configurations.

As soft products, LSR metrology requirements must be defined and understood before tooling release. Free-state versus fixtured measurement is often overlooked but critical for repeatable results.

Prototyping to Production

Because injection considerations have far less impact on a finished component, LSR articles can be quickly prototyped by laying material into a cavity set and heating for a short time to cure. Aluminum is preferred for this process, but 3D printing has opened new possibilities in this arena. Cavity sets can be printed from temperature resistant material, or the part itself can be printed for casting into a modeling rubber. This can drastically reduce iteration time compared to cutting a tool for a thermoplastic molding environment.

The lead time for world class injection molds can be lengthy. Plastics purchasing managers are often taken aback to see lead times up to six months for two component tooling. This is part of the paradigm shift required when considering LSR components. Though related to thermoplastic injection molding, it is a different process. Effort industrywide is focused on reducing lead time to more manageable levels, but it must be considered and accounted for early in the project.

Two Component Molding

Multimaterial molding is a well-established concept in the injection world. There are a few barriers to LSR and thermoplastic molding, that, when understood, can easily be dismantled.

Mentioned earlier, the concept of LSR molding being the antithesis of thermoplastic establishes a bias that they are incompatible. LSR is rarely considered as a solution. This is incorrect. Because the injection molding machines are easily configurable for LSR or thermoplastic (indeed, many in the industry are equipped for both), any injection unit can be set up as required.

Molds themselves are more of a challenge. There are few moldmakers in the world that have a track record for building robust two component molds. However, the technology exists, and those that have pioneered it are extremely capable.

There are three primary categories of LSR two component molds. These mirror the thermoplastic-only industry.

1. Robotic transfer: thermoplastic substrates move to the LSR overmolding cavities by external means, usually an end of arm tool.
2. Rotary platen or core beam: substrate is transferred by means of an indexing platen, or is held on a set of cores that rotates into the LSR molding position.

3. Core back: Slight movement of the core reveals molding area for LSR. This is a particular challenge in LSR due to shutoff requirements.

Substrate selection

Temperature

LSR is a high temperature vulcanization material, formulated to cure most efficiently in the 350-375F range. This is beyond the softening point of many traditional thermoplastics. Substrates should be selected that can withstand these molding temperatures. While the mold temperature can be lowered to accommodate lower heat deflection or melting temperatures, it comes at a significant cycle time penalty.

As an example, a two-component application was presented utilizing a polycarbonate substrate weighing approximately 3.1 grams. The projected cycle time due to the lower HDT was approximately 120 seconds. Substituting a high temperature PEI reduced the cycle time to 50 seconds. Even though the PEI was over five times more expensive per pound, the finished piece price was substantially lower. Additionally, the mold's manufacturing capacity more than doubled without any additional investment—a very significant savings when the work cell represented over a million dollars in tooling and automation. This total cost of ownership must be analyzed early in development to maximize the investment.

Compatibility

Bonding is the other major consideration in substrate selection. There are many methods of ensuring a link between materials, but the ideal and most cost-effective scenario is a fully linked article delivered directly from the mold. Self-adhesive LSRs only form cohesive bonds with selected thermoplastic substrates. LSR manufacturers can provide lists of materials compatible with their formulations.

If the application requires use of a substrate that does not naturally form a cohesive bond with LSR, there are other methods for creating it.

- Liquid primers are available that can be brushed, sprayed, or used to dip the article before overmolding. It should be noted that these typically require additional measures for safe handling.
- Corona, plasma, flame, and UV bombardment can interrupt the polymer chain at the surface of the article, creating attachment points for the LSR. The overmolding process must be performed shortly after application to prevent the ambient atmosphere from closing off the bonding sites.

Design

LSR can be challenging to incorporate into high volume assemblies. Its inert nature makes it very difficult to bond a molded part to another component. Small geometries are often difficult to feed using inexpensive methods such as bowl feeders. Many designs do not hold their shape well in a free state. By incorporating the LSR into a thermoplastic substrate, these concerns are eliminated while reducing part count, enhancing reliability and repeatability, and ensuring consistent shot to shot quality.

Successful implementation of a two-component assembly relies mainly on established practices, adding in the typical freedoms and restrictions already discussed when utilizing LSR. There are a few additional guides and features to be discussed.

Shutoffs should be as flat as possible. Small crush ribs molded into the thermoplastic around LSR geometry will aid in creating a good seal and are virtually invisible after the overmold process. Though it is technically feasible to manufacture robust tooling around such a feature, inner and outer diameter shutoffs should be avoided.

Runner systems may be molded into the substrate to allow LSR distribution throughout the finished article. Widely variable wall sections are acceptable in the overmold geometry. Undercuts will generally release, but note that full adhesive strength between the LSR and the substrate is not established in the molding cycle and the bond will be enhanced over time.

Sealing

LSR is a primary candidate for long-term sealing applications against many gasses and fluids. Its excellent compression set resistance and functional temperature range make it ideal for multiple use, storage, and harsh environments.

O-Rings and Static Seals

Simply replacing installed o-rings can simplify a component considerably. An overmolded o-ring is guaranteed to be in position in every instance, cannot be forgotten in assembly, and does not need to be accounted for in automation or by an operator. From a design standpoint, simply eliminating the need for the o-ring groove or an inner or outer retaining ring can solve design problems where space is a consideration.

Other sealing challenges can often be solved simply with LSR. Consider a perimeter gasket along the outer diameter of an article. In many instances, testing is required to ensure correct installation. The gasket may twist on entry into a bore, or when pressing it around the perimeter it may be overstretched in one area, compressed in another, creating a weakness. Overmolded LSR solves these issues by being immobile in the assembly.

Dynamic Seals

In addition to the enhancements offered to static sealing applications, LSR can also benefit dynamic sealing applications. Air and water valves are key examples. LSR has proven capable over millions of cycles in harsh environment testing.

The integration of a self-lubricating LSR in dynamic seals is particularly well-suited to sliding applications. The oil keeps components functioning predictably without the need for a separate lubrication operation either during assembly or periodically after the component is installed. This oil can also compensate for imperfections in the sealing surfaces, aiding in tight shutoffs in low pressure applications.

Functional Features

LSR's feature set creates opportunity for functional areas difficult or impossible in other comparable materials. Combining properties such as compression set resistance, thickness variation, and elasticity can yield exciting possibilities for engineers and product designers.

Pumps

Extruded LSR has been a material of choice for peristaltic pump tubing for many years. However, by molding the LSR on to the fittings, a significant advantage can be realized. Sealing concerns and assembly operations are eliminated.

Check valves

LSR will be familiar to many check valve designs. The typical umbrella type with an undercut on the stem can be seen in consumer products, medical devices, and many commercial applications. Tweaking the geometry, material selection, or even the LSR formulation can yield different cracking pressures for different applications.

In a two-component scenario, check valves can take advantage of the materials that *are not* chemically compatible. By specifically preventing a bond, functional valves can be integrated that are perfectly matched to their sealing surfaces. Taking this a step further, cohesive bonds can be achieved in specific areas by introducing a promotion technology to a locking area. In this method, a mechanical bond can be further enhanced by a chemical bond, guaranteeing the parts will never be disassembled.

Springs

Through specific geometry, LSR can be formed into functional springs that collapse under predictable loads. This can be used as a type of valve as a chamber opposite the spring is pressurized. Appropriate seals can be molded into the substrate without an additional operation.

Lenses

Overmolding optical-grade LSRs onto substrates to create lenses is another relatively recent development in LSR. The substrate acts as a fixture for assembly to bulbs or other optical devices.

Grips

The high friction inherent in a finished LSR part lends itself well to grips. The specific feel can be manipulated through geometry, such as rib structures. In general, TPE would be a material of choice in this arena due to cost, lead time, and wider vendor base. However, if the molded part is using LSR for a different functional characteristic, overmolding the grip concurrently can come at little or no penalty.

Hinges

Living hinges are well known in the thermoplastic world. LSR can build on this. For example, consider a two-component container lid. A gasket may be overmolded for the main seal, and elastic hinges can be stretched to fasten to the container to compress that seal for a more secure fit.

Insert Molding

To this point, discussion has been confined to materials converted by the mold itself. Insert molding, as part of a single or multi-component process, expands the possibilities still further.

There are several requirements for inserts placed in any injection mold with a few additional considerations for LSR.

- Consistency and tolerances: Inserts must be tightly controlled and consistent. Volumetric changes can cause inconsistency in the injection process. Even small dimensional tolerances can affect the mold's ability to shut off or hold the insert, and oversized components can severely damage the mold, depending on material.
- Temperature resistance: In this case, most thermoplastic molds will expose inserts to higher temperatures as melted thermoplastic is typically hotter than the 375F of an LSR mold.
- Mechanical strength: Thermoplastic injection pressure and the force exerted by LSR's thermal expansion can damage weaker materials.

- **Chemical compatibility:** This takes several forms and is generally more applicable to LSR. While a cohesive bond to many metals can be achieved, LSR will fatigue at the bond interface if subjected to cycling. In those cases, overmolding a thermoplastic first that the LSR can then be bonded to will alleviate failures. Inserts must also not contain any substances that interfere with the cross-linking reaction. Sulfur particularly affects LSR cure and must be avoided.

Advantages

Qualification

Multi-component molding can meet the same process capabilities that standard molding achieves. When replacing an assembly, this high standard can improve quality while drastically reducing qualification activities.

In the case study below, the qualification of two molded components replaces similar efforts for the thermoplastic substrate, nozzle insert, spring, gasket, and valve. Additionally, there is only one assembly operation to validate. The product certification is limited to two materials rather than five, plus adhesives and bonding promoters.

Quality

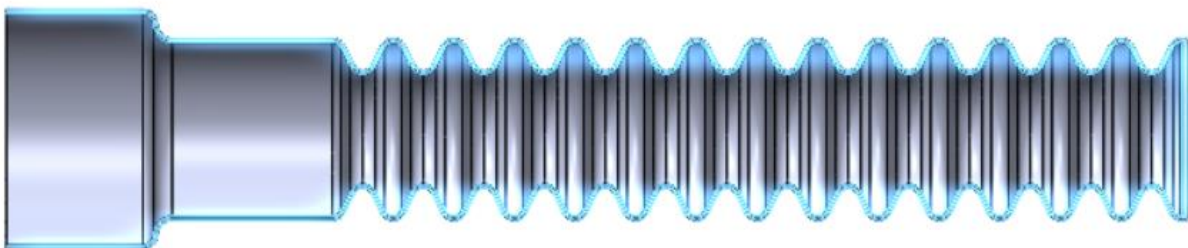
Consistency of injection molding is well documented. Process capability for properly designed and tooled LSR components is little different than the thermoplastic world.

Variation requires that tolerances be applied to individual components in an assembly. The tolerance stack will then be larger than any single component. By combining assembled components in a multi-component scenario, tolerance stacks can be collapsed.

Design Examples

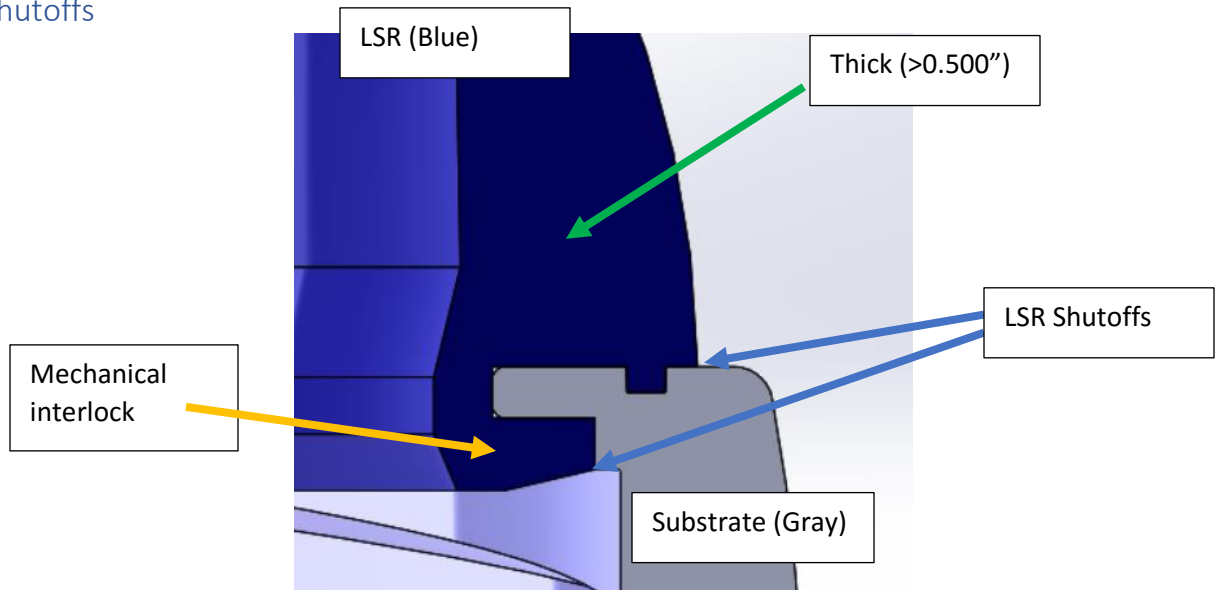
These are examples of successfully molded LSR components.

Bellows balloon



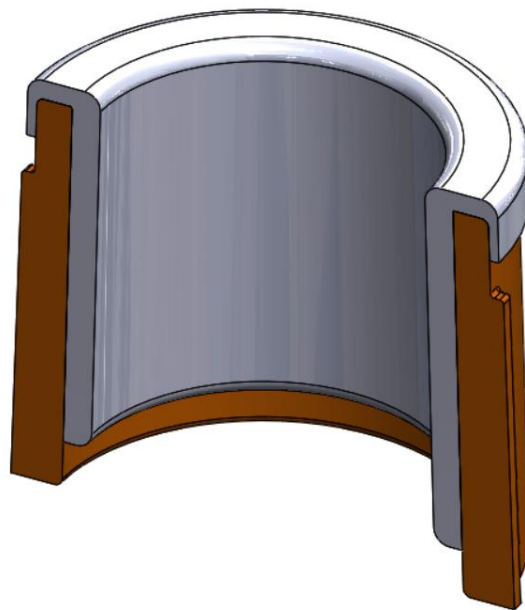
This component, shown as a cross section with the thickness highlighted, exemplifies LSR's ability to demold even complex undercut geometry. Air is used to inflate and blow the finished article off the core. The gate is in the center of the closed end (pictured right). Nominal wall section is .012".

Shutoffs

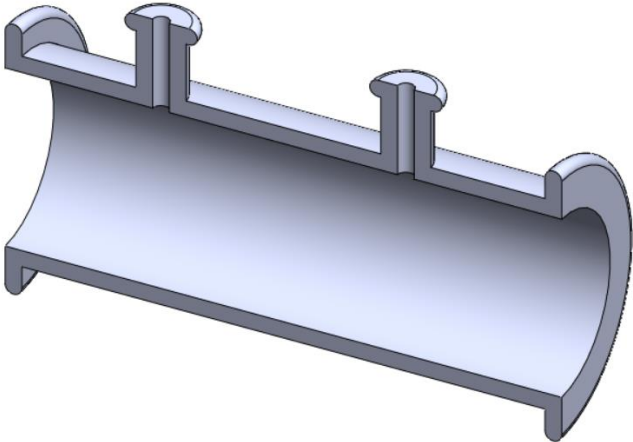


This geometry has a few concerns:

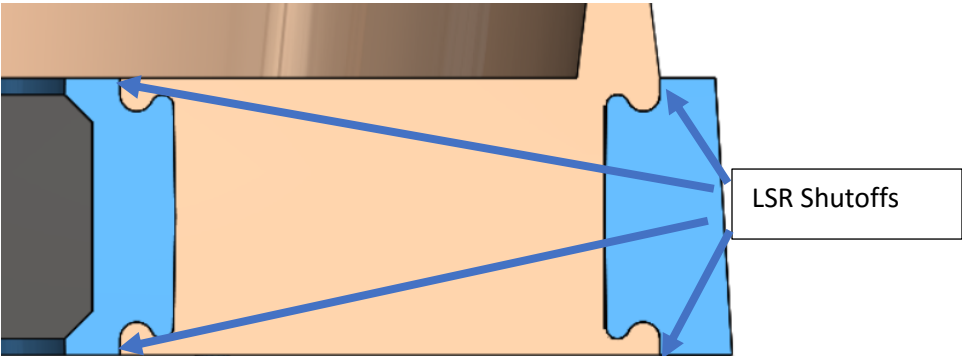
- LSR shutoffs should generally be in line. This allows mold steel to pinch the thermoplastic substrate, preventing flash.
- The thick wall section will drive cycle time well above the sixty second threshold. It also may compromise part integrity when the mold opens.
- The mechanical interlock created by bringing LSR under the substrate is not necessary with proper material selection. With a cohesive bond, the LSR will fail before its bond does. In this case, it prevents the mold from being a simpler, less costly, and more efficient rotary two-shot mold. The substrate must be robotically transferred to the LSR cavity.



The shutoffs in this example should be avoided if feasible. An outside diameter is not an ideal surface as the steel closing on it cannot crush around the entire perimeter, rather only in the direction of the slide pull. The inside diameter shutoff is nearly impossible to create without damage to the substrate.

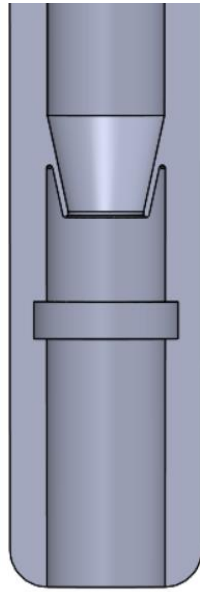


Here, small (3mm) pins are shutting off on a main core pin. It is difficult to ensure that the holes will be flash free over long term production.



Example of LSR shutoffs ideally situated.

Wall Sections



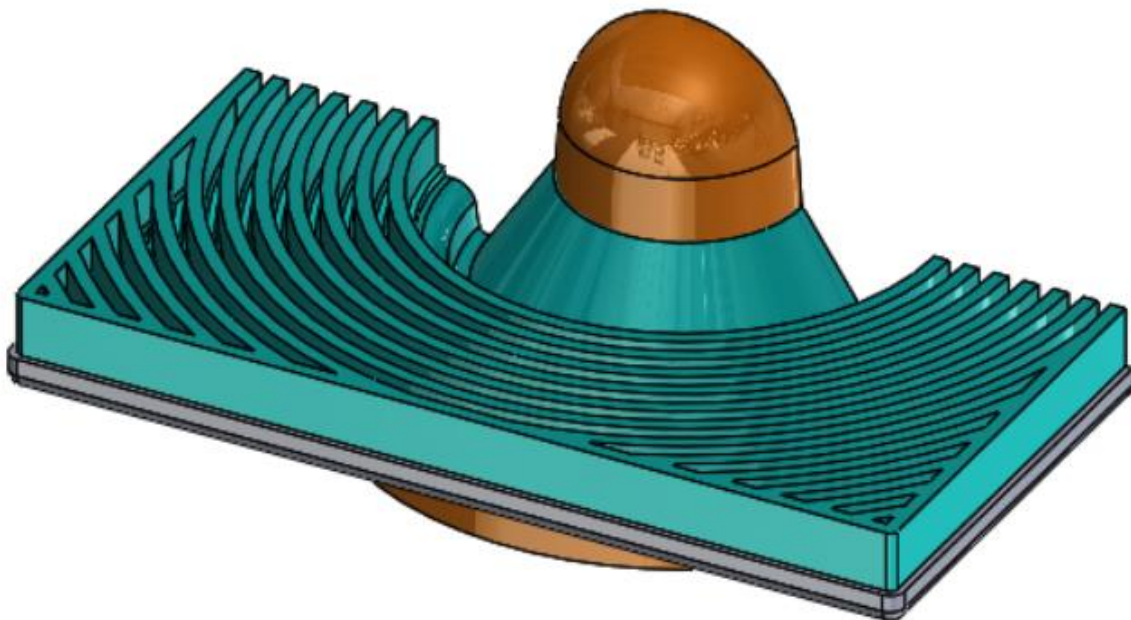
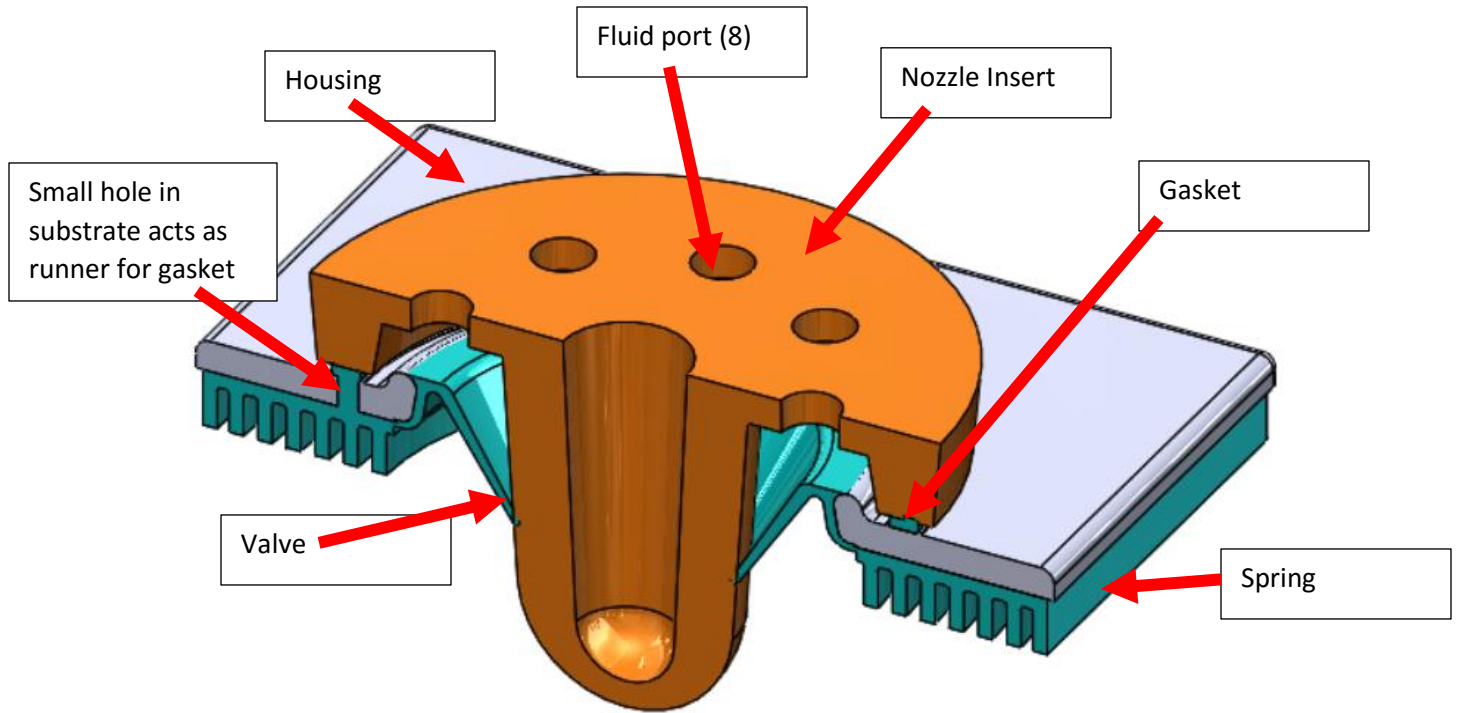
In this cross section, note the three different wall thicknesses. Pictured are .120", .080", and .010". These can all be filled without concern. Additionally, note the lack of draft. Finally, of particular interest is that the undercuts shown are fixed in steel and the part is pulled free. There are no mold splits internal to this component.

Case Studies

The following parts are actual applications that have been modified to eliminate intellectual property or non-disclosure concerns.

Multifunction Valve

This two-piece valve is a prime example the importance of early consideration in the design process. Originally envisioned as a four-piece assembly, the redesign drastically reduced cost while increasing ease of assembly and consistency of quality. Part is sectioned for clarity.



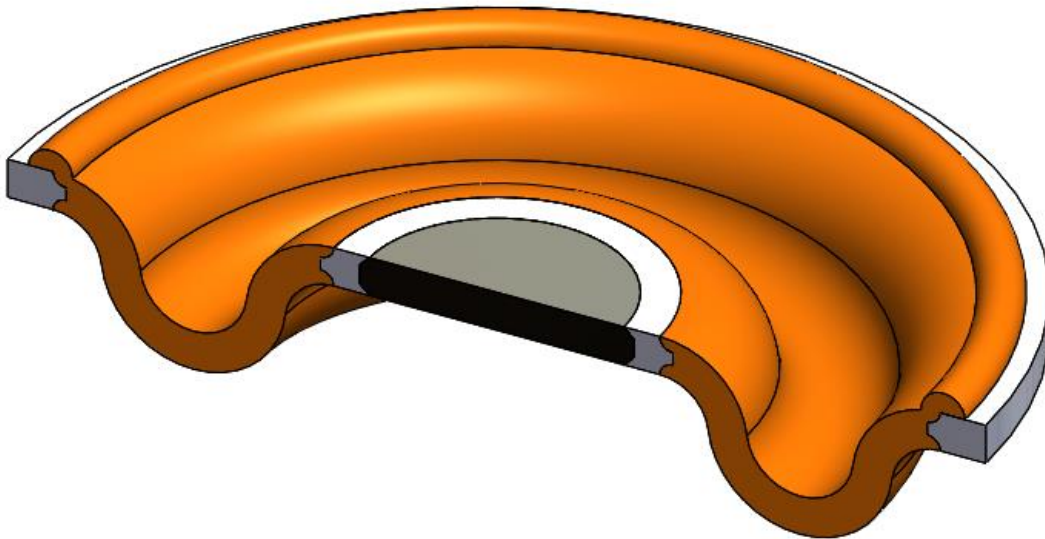
The housing, gasket, valve, and spring are molded as a single component and presented as a finished article from a two-component transfer mold. The nozzle insert is installed separately and 100% function tested to ensure proper valve cracking pressure and sealing.

The nozzle insert is fixed in the assembly. The housing is designed to absorb vibration (spring) while maintaining a seal against the nozzle insert (gasket). A dose of fluid is retained under a small pressure by the valve sealed against the nozzle insert. When fluid pressure increases to a predetermined amount, the valve is forced open and the dose is dispensed.

As originally envisioned, the gasket was designed as a standard o-ring. The LSR spring replaced four mechanical steel springs. The valve was to be bonded in place.

Damper

The vibration damper shown in section below was intended to be molded from TPE (orange) over thermoplastic. As an additional twist, there is a steel component captured in the center of the inner thermoplastic ring. At room temperature, performance was roughly as expected, though the central mass was not fully parallel due to the warp of the TPE. However, degradation at both ends of the temperature spectrum (specified as 0-120F) suffered significantly. Additionally, the seal bead on the outer perimeter experienced compression set failure above 140F.



Prototypes were quickly manufactured from LSR. Temperature performance exceeded requirements. Incidentally, the warp was also eliminated.

Two restrictions drove this design. There was insufficient space in the device to mold a solid thermoplastic center and bond the steel as a secondary operation. Due to the repeated cyclical movement of the damper, the LSR could not be bonded directly to the steel. Thus, the insert is first

overmolded with thermoplastic (injected simultaneously with the outer ring). The subassembly is transferred into the LSR mold half and joined with the web.

Conclusion

LSR's use as a niche material is valid and fills a need in many product designs. Its versatility isn't fully realized in many designs currently in development. Engaging and educating product designers before commencing engineering activities can yield significant downstream results with part reduction, quality enhancements, and efficiency gains.