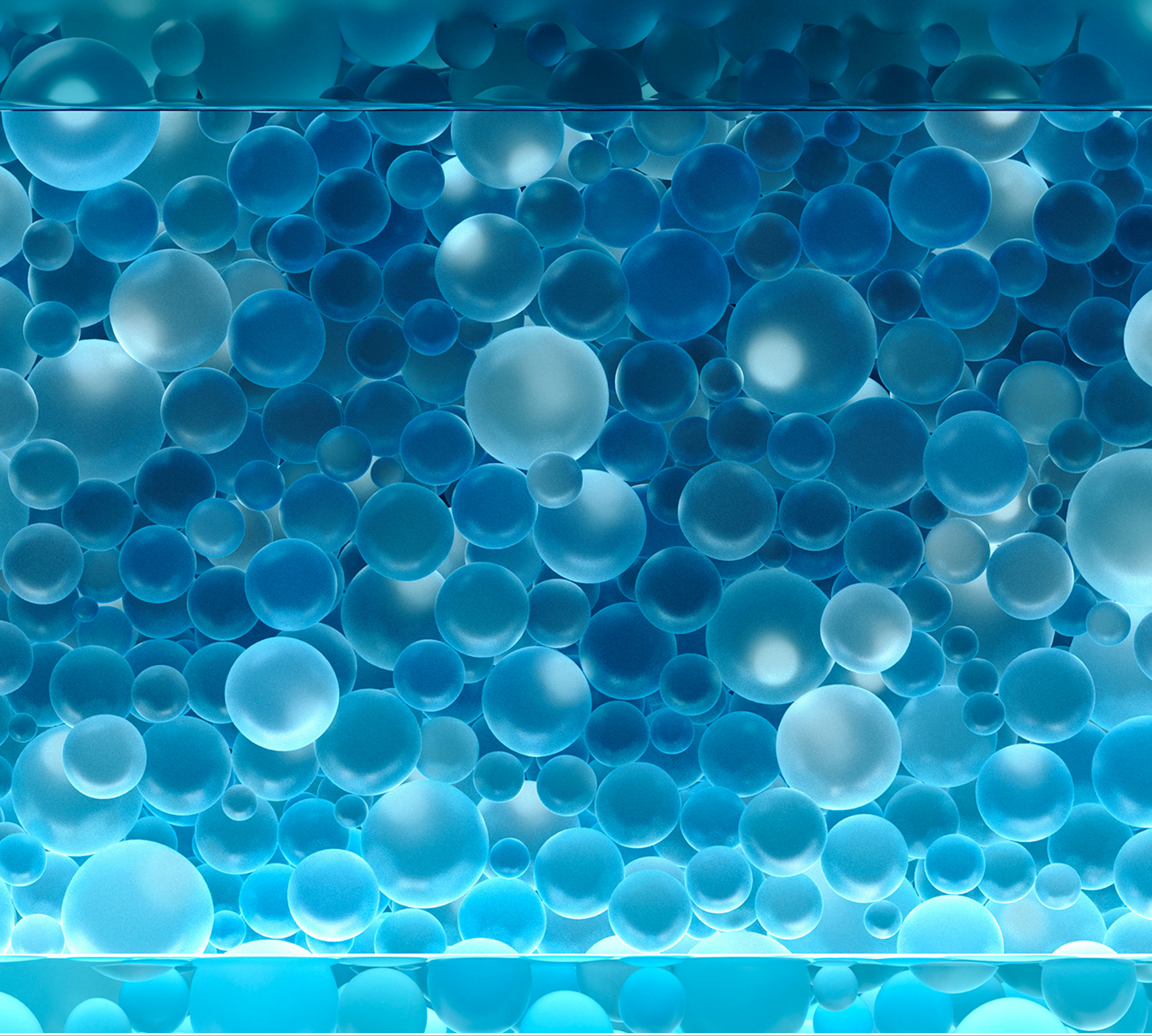

Silicone Processing Options for Life Science Applications

Chemistry, product design, processes and economics

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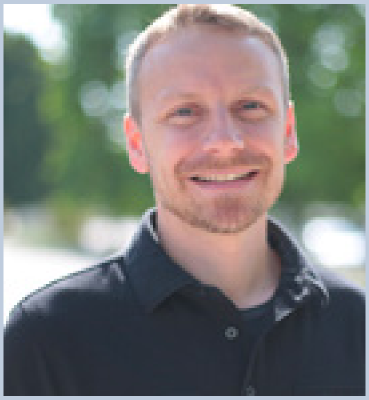
Silicone Processing Options for Life Science Applications



John Thomas, tooling manager, Composite Sealing Systems Division, Parker Hannifin

John Thomas is a journeyman tool and die maker and holds a bachelor of science degree in mechanical engineering. Since joining Parker in 2007, he has held positions of increasing responsibility, including senior manufacturing engineer and manufacturing engineering lead.

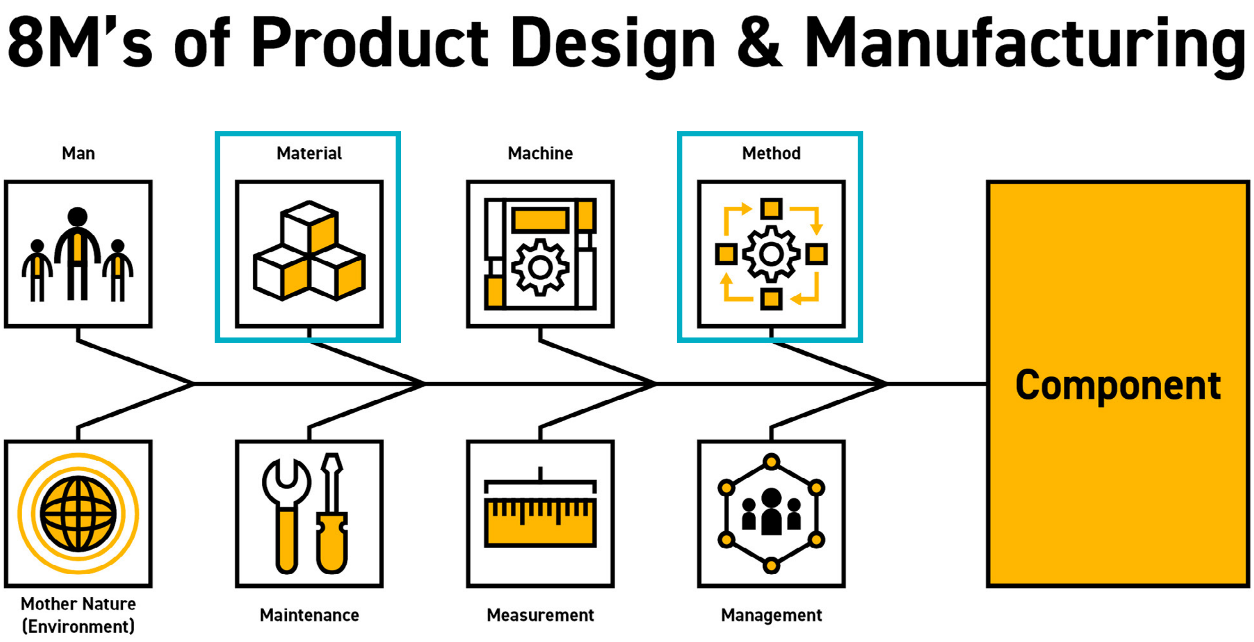
Introduction

Silicones are widely used in life sciences because they have a broad variety of unique properties that allow engineers to design products from everything from ventilation masks to catheters to septa to molded grommets to medical tubing to extruded profiles.

This white paper explores the versatility and unique qualities of silicone as the medical device material of choice, the different methods of manufacture for medical silicone components and devices, and how design for manufacturability (DFM) aids in selecting the right manufacturing process for your medical device application. We will provide some thought-provoking ideas relative to the design and manufacture of medical grade silicone products for the life sciences.

To begin, we will look at the famous Ishikawa diagram, also known as a cause-and-effect or fishbone diagram. For our purposes, we are using the eight M's version, which covers man, material, machine, method, management, measurement, maintenance and Mother Nature (environment). This white paper will address two of these: the material and the method of manufacture and their interplay with design and economics.

Fig. 1. The Ishikawa diagram, also known as a cause-and-effect or fishbone diagram



Material - The Chemistry of Silicones

The versatility and unique qualities of silicone

The chemistry of silicones

Silicone is a very desired material in the life sciences and other industries. Unlike other synthetic elastomers made of hydrocarbons, Silicone is derived from sand (SiO2), water and natural gas derived methanol. Common organic synthetic elastomer molecules have repeating carbon (C) atoms. The chemistry on the top of figure 2 below is the chemical structure for synthetic polyisoprene. As can be seen, in the backbone chain, those black elements are carbon-to-carbon (C-C) and there is a carbon-to-carbon (C-C) chain or repeating chain structure, which is the basis for many synthetic elastomers.

On the bottom of the figure is the key differentiating characteristic, which is the silicon (Si) and oxygen (O) substituted chain versus that C-C chain of polyisoprene.

Silicone, also known as polysiloxane, is a chain of siloxane bonds (-Si-O-Si-). Organic units are introduced to the silicone molecules to add various characteristics. With two methyl groups attached to the backbone, polydimethylsiloxane (PDMS) is the most widely used silicone. The siloxane structure and elements used in the backbone of silicone polymer enables us to have unique and desirable properties for life science applications.

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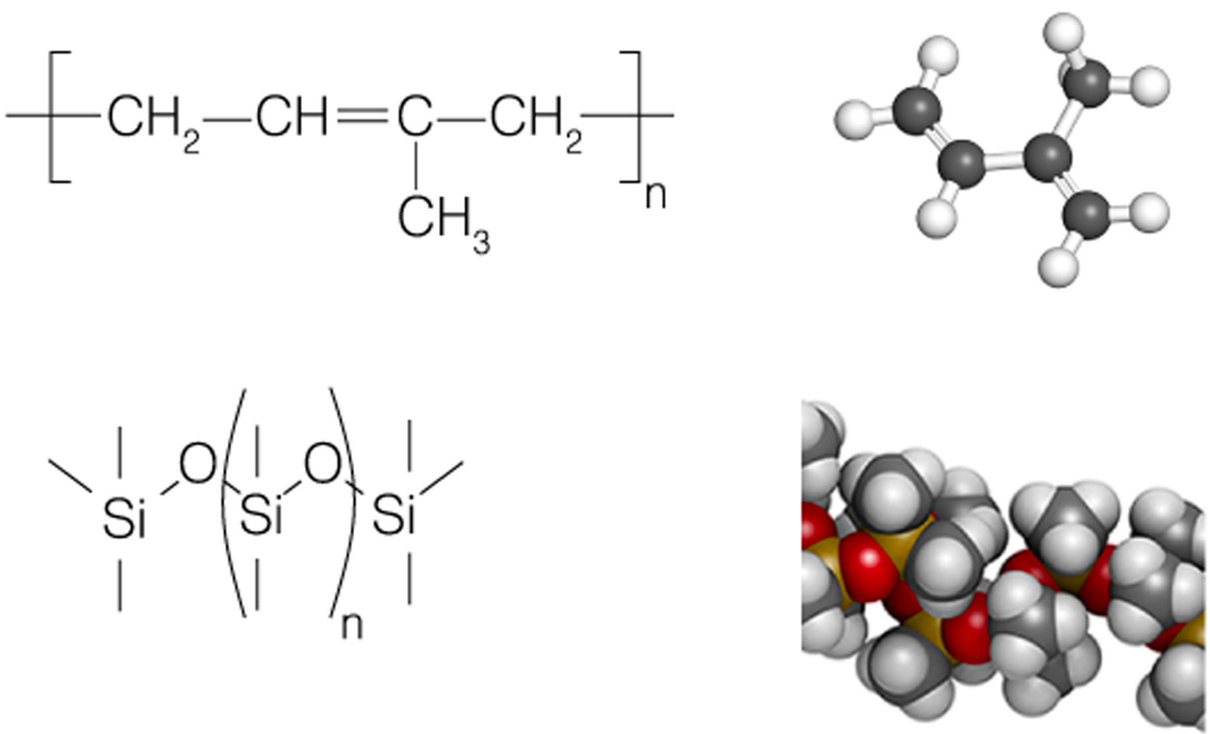


Fig. 2. Chemical and molecular structure of silicone

Properties of Silicones

Siloxane bonds have much greater bond energy compared to C-C bonds, therefore, will not break at temperatures as high as 400°F (200°C) or certain grades up to 575°F (300°C). Silicone polymer molecular structure is highly flexible, resulting in low glass transition temperature (Tg). They are, therefore, flexible and functional at negative or freezing temperatures. The hydrophobic methyl groups in the structure are accountable for its water repellency. Silicone elastomers have unique chemical and physical properties with excellent biocompatibility and biodurability and are ideal for many life-science applications. Other notable characteristics of silicones are excellent resistance to aging, low extractables, and low leachable.

Biocompatibility is one of the desirous characteristics as well as the ability to meet a variety of healthcare and medical industry requirements. Silicones are formulated conveniently to comply with USP Class VI standards and ISO-10993 regulatory requirements, which include:

- Compliant with cleanliness requirements and cGMP requirements
- Sterilizable with steam (autoclave) or gamma irradiation
- Do not contain latex, organic plasticizers or phthalates

Types of silicones

Two types of silicones are frequently considered for life science applications: high consistency rubber (HCR) silicone and liquid silicone rubber (LSR).

HCR and LSR are available in a wide range of hardness. The hardness of silicone elastomers is achieved by the addition of silica and other ingredients into the matrix during a process known as compounding. By altering the silicone compound formulations, formulators design silicone compounds from hardness of 10 Shore A to 80 Shore A. (Shore A scale is a typical scale used to characterize hardness of elastomers.) Further, compounders and fabricators formulate silicone compounds to enhance their inherent characteristics or add new features such as colors, low coefficient of friction, ease of processing, adhesion to surfaces, and so on, as needed for the intended application.

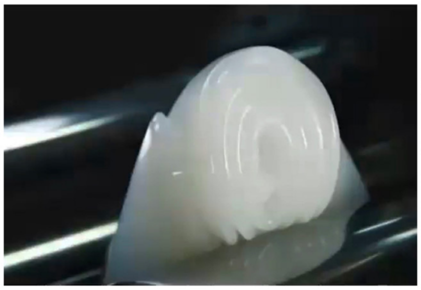
What makes silicone useful and safe for life science applications?

The reason silicones are so widely used in life sciences is the fact that they have such a wide variety of unique properties:

- Non-porous
- Low thermal conductivity makes it resistant to heat and thermally stable in extreme heat or cold
- Flexible over wide temperature range
- Once cured, it contains no plasticizers that can leach or be extracted
- Hydrophobic (water resistant) traits inhibit (but not eliminate) microbial growth

Such unique properties of silicones allow the designers to design products from everything from ventilation masks to catheters to septa to molded grommets to medical tubing to extruded profiles.

Fig. 3. High consistency rubber (HCR) silicone (left) and liquid silicone rubber (LSR) (right)



Methods of Manufacture

Here, we will examine, at a high level, the three different methods of manufacturing silicone for life sciences: profile extrusion, which is quite common to design products; compression molding; and injection molding.

Profile extrusion

There is multi-layer extrusion, co-extrusion, and a variety of different profiles. They can range from solid profiles to hollow profiles that are symmetric to non-axisymmetric. This is a smattering of the types of extrusion that one can find and design for use in life sciences.

There are variations on this term that we use very generally as extrusion or profile extrusion. But for life sciences, there are many different embodiments. For example, single and/or multi-lumen extrusions (see figure 4), complicated, sophisticated extrusions that have multiple working channels, as in catheter assembly or sheathing type applications. Micro lumen work also is unique to life sciences.

Fig. 4. Single and multi-lumen extrusions

There are two general ways that extrusion is performed. On the left of the image below is a schematic of a ram-type extrusion. On the right-hand side is what is typically called screw type extrusion. There are different variants of both of these and different nuances in both of these methods.

One or both of these methods produce typical profiles and many others - from solid to hollow and everything in between. Single lumen and multi-lumen are used for catheters and sheathing applications, and those two methods are used to derive the product form either via ram or screw extrusion.

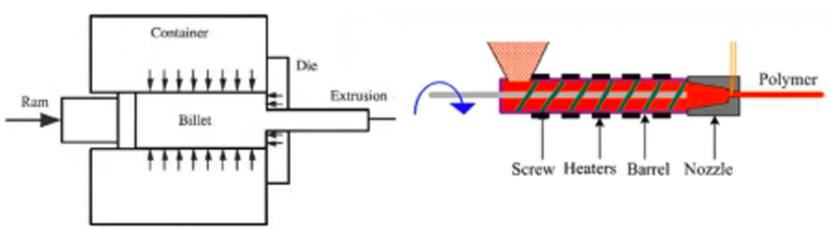
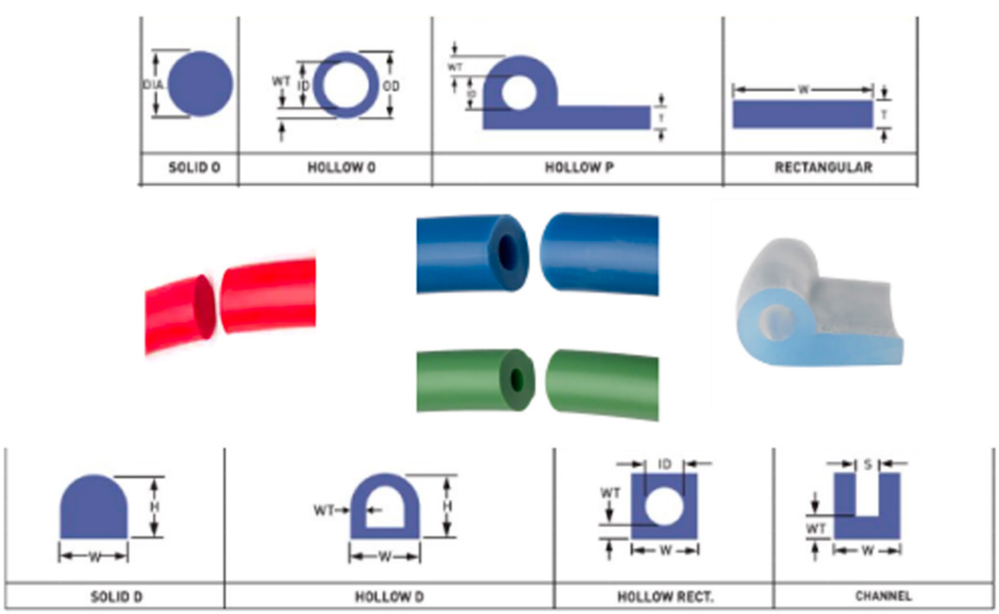


Fig. 5. Ram-type extrusion (top) and screw-type extrusion (right)
Fig. 6. Common profile extrusions (bottom)



Compression molding

The next method of manufacturer is compression molding. And once again, there's a variety of nuanced or variety of specific subsets of this general category of compression molding.

Variations include:

- Compression transfer
- Insert and over molding
- Micro molding (the parts are exceedingly small and almost microscopic, in some instances with very tight tolerances)
- 2K (multi-component molding of dissimilar materials or similar polymers in varying hardnesses)
- Flashless compression molding (sophisticated tooling strategies to result in a finished part that has no flash or material extension)

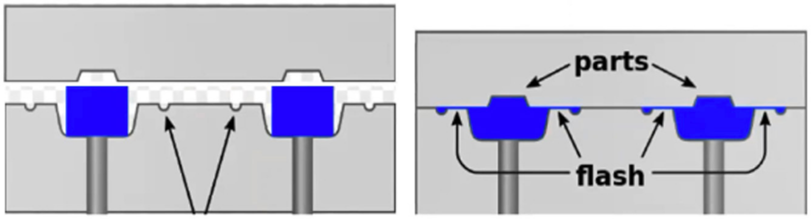


Fig. 7. High cavitation compression tool

Using a high cavitation compression tool allows you to mold a single cavity, one part at a time, or thousands of parts, hundreds of thousands of parts, depending on their size and geometry, at one time. Shown right is similar to a book, referred to as a book mold. Sometimes called two-plate molds where there's a top and a bottom, and that parting line or that mating interface is where that flash does occur.

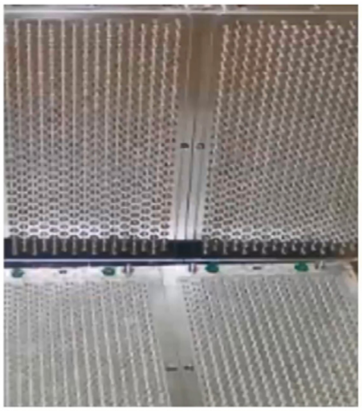


Fig. 8. Book mold

Fig.9. Compression molded silicone profiles

Injection molding

As with the previous types, there are many variants of injection molding as a type of process or method of manufacture. There are pros and cons to each type.

The variants include

- Direct inject (the material is injected directly into the mold cavity
- Injection compression (a variation where you inject into a pool, and then it's considered a compression process where the mold plates come together into that pool)
- Injection transfer
- Liquid injection (commonly referred to as liquid injection molding or "LIM")
- Multi-stream liquid injection
- 2K (multi-component)
- Micro-molding
- Gum/HCR injection

Figure 10 (top right) is a schematic of the archetypical liquid injection molding using LSR (liquid silicone rubber). Typically, two-part systems, two-component systems, usually are mixed in a one-to-one ratio. There are variation possibilities, especially in multi-stream liquid injection molding when injected into an injection press, the material is mixed actually in that screw. It's an extrusion process of sorts that then gets introduced into a mold cavity and an injection mold cavity.

One of the unique characteristics of liquid injection molding is that you can design and manufacture for those that are complex, complicated, and difficult to compression mold or certainly extrude. In many cases, it can be used for the impossible to extrude geometries and configurations with undercuts, and a variety of design features that would not be possible in other methods of manufacturing can be achieved. However, as the name signifies, they tend to be overly complex. As part complexity goes up, so does, in exponential ways, the complexity of designing these injection molds.

Figure 11 below shows some examples of how complex these molds might be. They are much more difficult to design and manufacture than book molds or two-plate molds.

Fig. 10. Archetypical liquid injection molding using LSR (liquid silicone rubber)

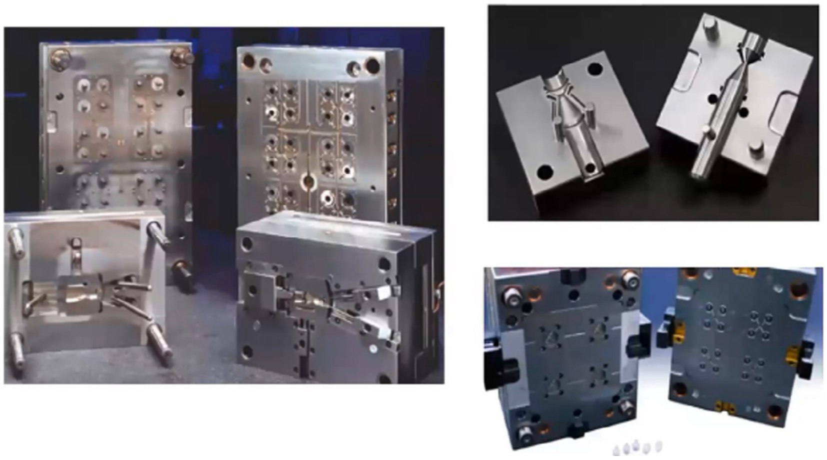
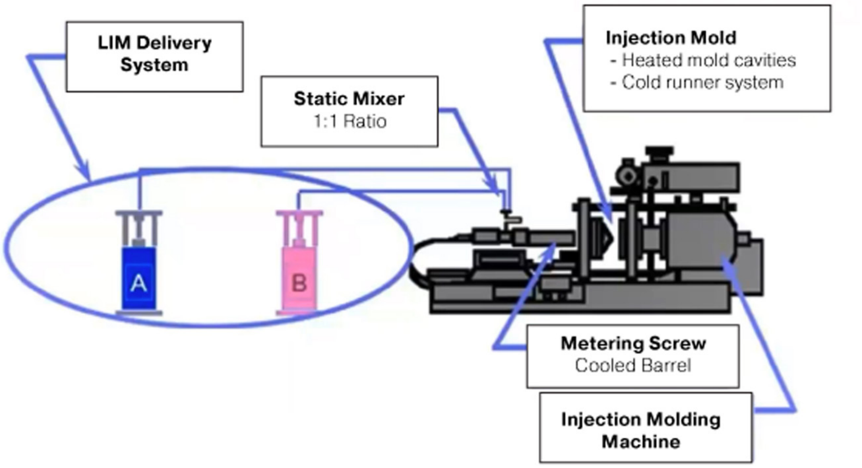


Fig. 11. Complexity of liquid injection molds



Tooling

A few words about tooling, as the devil is in the detail: we talk about prototype tooling or sometimes soft tooling, hard tooling, and hybrid tooling (which is, as the name signifies, a combination of both soft tooling concepts as well as hard tooling concepts). Sometimes hybrid tooling is called insert tooling. You might think of that as where you would have "soft tools," which are essentially hybrids. Also, prototype tooling sometimes is used interchangeably with soft tooling. Production tooling is sometimes used interchangeably with hard tooling, and it is a continuum in between these.

Fig. 12. Silicone molded medical device products

If we're going to design a part and go to the extent of making production tooling, then that certainly will require going through some design iterations prior to that. Hence this continuum and how to describe arriving at a single prototype from an idea to form, fit, not necessarily function, and then further -- all the way -- progressing to a production tool.

Remember the concept mentioned previously, both in injection molding as well as compression, of flashless tool design. Injection molding tooling, especially with production tooling, tends to be flashless.

Generally speaking, flash extension, with that little bit of leftover material from the molding process, can be eliminated with the design of injection tools that will result in a zero-flash extension or, essentially, a zero-flash extension.

There are also tooling nuances associated with the extrusion process. Those are typically called extrusion dies or die tooling or extrusion die tooling. It's much simpler, more cost effective, and easier to design and produce. However, you cannot design all part geometries to be processed in the extrusion process for obvious reasons.

Design for Manufacturability

Balancing product design and economics to reduce risk

Let's now explore how front-end support incorporating design for manufacturability (DFM), process development and validation services help medical device companies balance product design with economics to explore options that reduce risk and ensure your devices meet expectations.

Customers come to Parker in different phases of product development. When customers engage us early in the product development cycle, they leverage Parker's expansive range of expertise. This is of tremendous benefit to customers as it allows greater freedom in exploring design for manufacturability options that balance product design with economics while reducing risk, thereby optimizing profitability.

Our comprehensive DFM review is backed by the entire CSS Division engineering staff, including product, chemical, quality, manufacturing and process engineering teams. With our support, customers can balance product design and economics while minimizing potential defects through Finite Element Analysis (FEA) and mold flow analysis simulations.

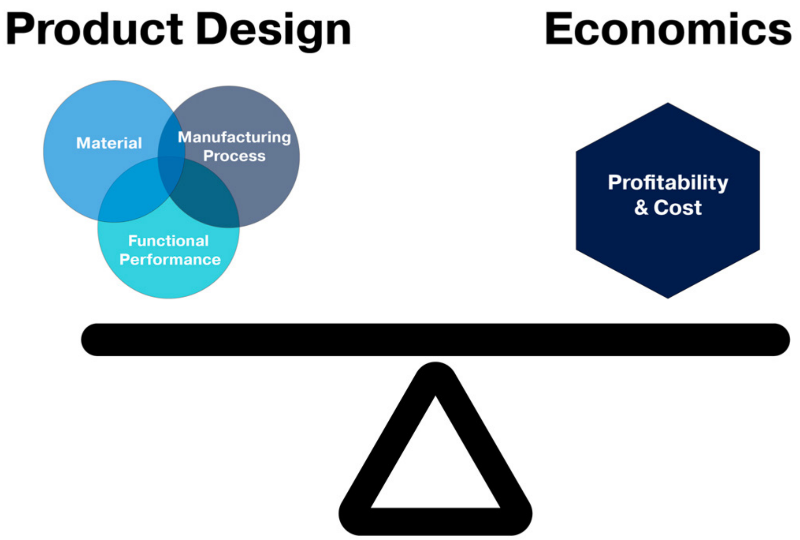


Fig. 13. Design for manufacturability (DFM) aids in balancing product design & economics to reduce risk

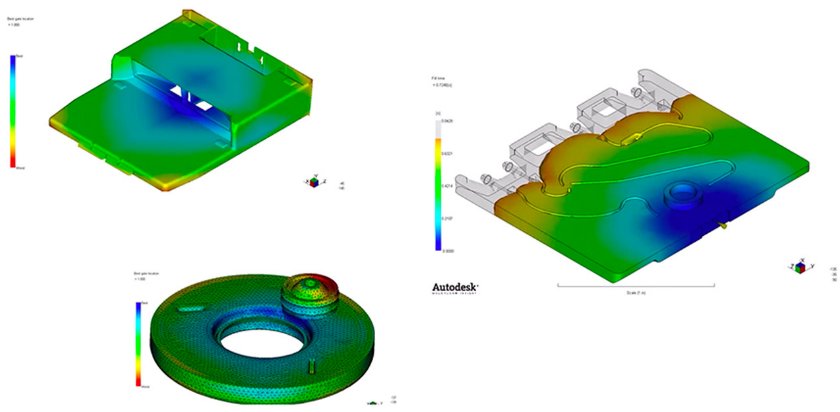


Fig. 14. Finite Element Analysis (FEA) mold flow analysis

> *Having our own tool rooms allows us to respond quickly to issues on current parts as well as new program introductions, allowing us to continuously reduce downtime, improve quality, and increase yield.*
>
> — **John Thomas, tooling manager, Composite Sealing Systems Division**

Factors To Consider When Selecting a Manufacturing Process

Common inputs affecting material selection and method of manufacture for medical devices include budget, volume/scale, time constraints, functional, aesthetic and regulatory requirements.

In arriving at a method of manufacture and type of silicone material, Parker and its customers discuss a list of topics during development phases.

1. What is the estimated annual usage?
    - LSR ->High volume (millions of parts)
    - HCR -> Medium to lower volume (thousands of parts)
2. What is the desired lead time, and how quickly does it need to launch?
3. What is the capital spend budget for tooling, presses and other equipment?
4. What material specifications need to be met?
    - Mechanical requirements
    - Cleanliness requirements
    - Physical characteristics, including chemical compatibility
    - Aesthetics
5. What are the functional requirements of the device?
6. Are there regulatory requirements governing manufacture, assembly, or secondary operations?
7. What processing concerns do you have?
    - Cycle time
        - Shorter cycles times on LSR
        - Longer cycles times in HCR due to curing time
8. Automation
    - LSR is capable of full automation
    - HCR – compression/transfer molding is a manual process, not well-suited for automation

Expert Guidance for Optimal Manufacturing Outcomes

Parker will guide you through choosing the right process, providing front-end design for manufacturability support, process development and validation to ensure medical device components and finished devices meet your specifications. Our broad range of capabilities includes:

Tooling capabilities

We work closely with reputable tooling houses to ensure rapid design and prototyping, as well as thorough testing of tools. Our three West Coast locations boast fully-equipped tool rooms, with expertise in compression transfer, injection, thermoplastic, and Liquid Silicone Rubber (LSR) molding. Our focus on tooling capabilities results in reduced downtime, fewer defects, and increased yield.

Validation services

Our validation services help customers tailor their validation master plans to suit their specific needs. The validation process includes Installation Qualification (IQ), Operational Qualification (OQ), and Performance Qualification (PQ) procedures. These steps ensure that all equipment is calibrated and installed properly, tests the limits of the process window, and confirms that the production run meets customer requirements.

Tool management system

Our tool management system maintains cycle counts and preventive maintenance schedules, ensuring tools remain in optimal condition. This system also keeps track of component inventory, notifying customers when it's time to restock. Furthermore, we conduct annual tool assessments to provide our customers with valuable insights into their tool's performance.

Project management

Every project at Parker CSS is assigned to a dedicated engineer and project coordinator, ensuring close monitoring and follow-up throughout the development process. Our team conducts weekly or biweekly meetings with customers to update them on project progress and maintains internal meetings to keep all departments aligned with project timelines.

Build-to-print contract manufacturing

Customers seeking traditional "build to print" contract manufacturing can rely on Parker's expertise with medical molding and extrusion technologies for medical LSR and HCR materials. We can deliver high-quality components and finished medical devices that meet all required dimensions and specifications.

Conclusion

Versatility combined with unique qualities make silicone a material of choice in medical device and life science industries. The three main methods of manufacture for medical silicone components and devices include profile extrusion, compression molding, and injection molding. Customers can optimize profitability and reducing risk by leveraging Parker's design for manufacturability (DFM) capabilities and expertise.

About Parker's Composite Sealing Systems Division

Parker's Composite Sealing Systems Division is a global, FDA registered, ISO 13485 certified, cleanroom manufacturer of custom molded and extruded components, assemblies and finished devices for the medical, pharmaceutical and life science industries. We offer complete end-to-end management of customer projects from idea to project launch.

We work as a valuable source of innovation, using our engineering, manufacturing and quality planning expertise to critically evaluate design concepts for optimal manufacturability and functional performance.

- Early supplier involvement with our customers allows
- Upfront discovery of potential design discrepancies and supply chain constraints
- Assurance that production will meet feasibility requirements
- Certainty of compliance with regulations governing production

We provide products and services that consistently meet customer expectations of quality and value. A central element of our culture is an unwavering commitment to quality and continuous improvement.

For more information on medical grade silicones or to start a discussion on silicones for your medical device, call **619-661-7000** or contact us online.

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