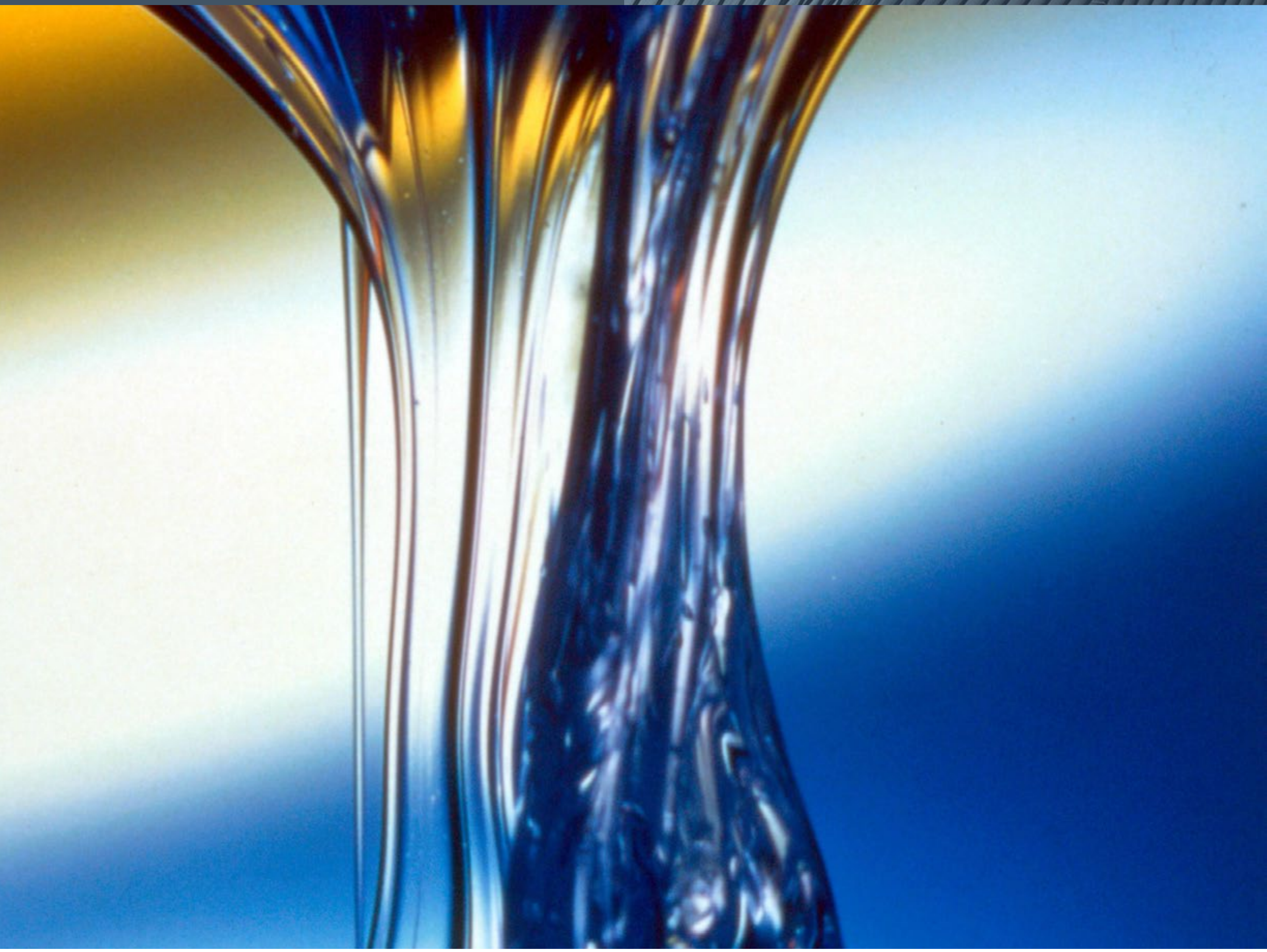
CONSUMER SOLUTIONS

Liquid injection molding:

Processing guide for SILASTIC™ Liquid Silicone Rubber (LSR) and SILASTIC™ Fluoro Liquid Silicone Rubber (F-LSR)



Preface

Injection molding of liquid silicone rubber (LSR) is often the preferred choice of producers of rubber parts. That is because LSRs offer better end-product performance, and the injection molding technique offers high levels of automation and almost 24/7 production. LSRs also are ideal for rubber parts in general applications, as well as for specific market demands.

Now, in addition to the wide range of SILASTIC™ LSRs from Dow, manufacturers can take advantage of a new liquid silicone rubber product – one that can withstand extreme temperatures and highly aggressive solvents and other chemicals:

SILASTIC™ Fluoro Liquid Silicone Rubber (or SILASTIC™ F-LSR for short) is an LSR with the performance characteristics of FSR. This makes it ideal for the automotive and aerospace industries and for other extreme applications.

This brochure discusses the basics of injection molding using SILASTIC™ LSRs and F-LSRs and what manufacturers need to know to fully exploit the associated time savings and productivity improvements.

For further information on SILASTIC™ LSRs and F-LSRs, please contact your nearest Dow sales offices.

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SILASTIC™ LSR and F-LSR

General

Description

SILASTIC™ Liquid Silicone Rubber (LSR) was pioneered by Dow and introduced to the rubber fabrication marketplace in the late 1970s. More recently, Dow has introduced a new LSR that is fluorinated: SILASTIC™ F-LSR. This new rubber is a true LSR but with the performance properties of an FSR. This means it can withstand the extreme temperature conditions and aggressive solvent environments of modern automotive and aerospace engines.

Today, the processing and product advantages of SILASTIC™ LSRs are exploited in many existing and new applications. A broad product line is available both for general applications and for specific requirements. Moreover, many new applications are rapidly emerging to take advantage of the new SILASTIC™ F-LSRs.

Key elements of SILASTIC™ LSR and F-LSR

SILASTIC™ LSRs and F-LSRs are liquids with viscosities that vary from easily pourable to paste. These two-component materials are mostly used in a 1 to 1 ratio and consist of polysiloxane polymers or copolymers, which are vulcanized by polyaddition. In addition, F-LSRs are fluorinated.

Packaging

SILASTIC™ LSR and F-LSR are supplied as lot-matched kits in 200-liter drums or 20-liter pails. The exact packaging weight varies, depending on the density of the product. For detailed information, please refer to the individual product data sheet.

Usable life and storage

When stored at or below 32°C in the original unopened containers, Dow guarantees the usable life of these products until the date indicated on the packaging, and they will have a usable life of at least 6 months when shipped. This date is shown by the letters: EXP. (meaning "expire") followed by four digits, which stand for the month (last day) and year.

Example: EXP. 03/21 means use by March 31, 2021.

Handling precautions

A product safety data sheet should be obtained from your nearest Dow sales office prior to use.

Attention: Before handling, read the product information, product safety data sheet and container labels for safe end use and physical and/or health hazard information.

Advantages of SILASTIC™ LSR and F-LSR

Easier processing

- No cure decomposition products (unlike peroxides)
- Long pot life at room temperature, yet very fast vulcanization above 150°C
- SILASTIC™ LSRs are easier to mix and to process than SILASTIC™ HCR
- F-LSRs are easier to mix and to process than high consistency FSRs
- Easy to pigment, providing end product flexibility
- SILASTIC™ F-LSRs can be overmolded onto plastics that have a lower melting temperature

Faster cycle times

- SILASTIC™ LSRs and F-LSRs are fully compounded, ready to process
- Just two components, mixed 1:1
- Automated injection molding process similar to thermoplastic injection molding
- Easy demolding with good hot tear
- Rapid curing at elevated temperatures
- Flashless molding with tight part size tolerance control
- Post-curing frequently not needed

Better end-products

- Good direct bonding to specific insert components
- Superior clarity, as well as low odor and neutral taste
- SILASTIC™ LSRs are usable over a wide temperature range from -60°C to +180°C for continuous use; F-LSRs are usable from -82°C to +180°C for continuous use
- Good elastic properties
- Very good UV and ozone resistance, as well as atmospheric aging stability
- Low moisture pick-up
- SILASTIC™ LSRs are resistant to many solvents
- SILASTIC™ F-LSRs are resistant at extreme temperatures to fuels, oils and other aggressive fluids
- Good dielectric properties over a wide temperature range

Applications

SILASTIC™ LSR

SILASTIC™ LSRs are widely used in injection molding, fabric coating, dipping and extrusion coating processes. Application areas are numerous, including the automotive, aerospace, appliance, business machine, electrical and consumer industries.

SILASTIC™ F-LSR

Due to their FSR-like performance characteristics, SILASTIC™ F-LSRs can be used in injection molding to produce parts that must withstand fuels and oils at extreme temperatures – for example, rubber seals, gaskets, diaphragms and other parts within modern engines. Because SILASTIC™ F-LSRs are true liquid rubbers, they offer faster, easier production cycles than manufacturing techniques that use FSR, HNBR, Urethane, GFKM or AEM rubbers. They also offer a more precise manufacture.

Extrusion and flat textile coating

LSRs are very suited to these processes for reasons of:

- Solventless with low and versatile viscosity
- Easy mixing and pigmentation
- Rapid processing compared to solvent dispersions and usually allows a complete coating to be applied in a single pass
- Primerless adhesion to glass and certain other substrates

Meter-mixed SILASTIC™ LSR can be dip-coated or fed to a crosshead for supported extrusion coating. Standard techniques are used for flat textile coating.

Pigmenting SILASTIC™ LSR and F-LSR

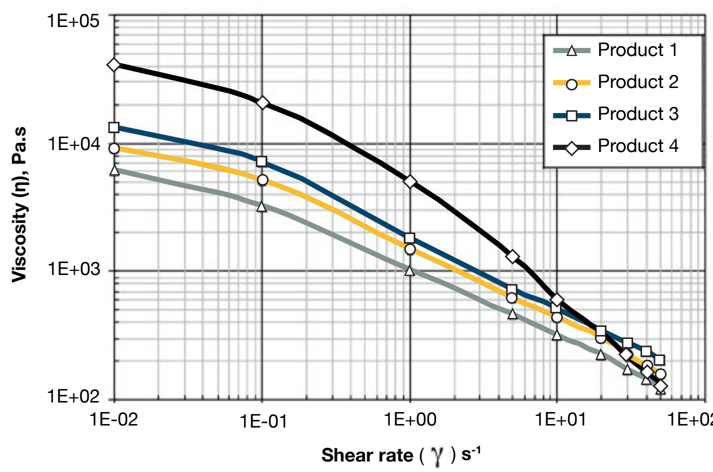
This is best done with SILASTIC™ LPX crosslinkable pigment masterbatches. Full details are available from Dow.

Injection molding of SILASTIC™ LSR and F-LSR

Viscosity of SILASTIC™ LSR and F-LSR

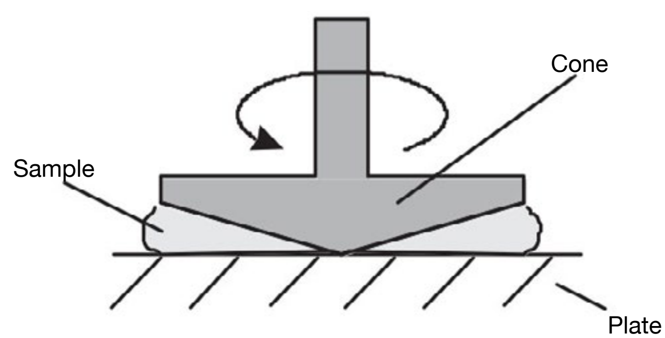
Like many polymers, SILASTIC™ LSR and F-LSR are shear-thinning materials. This means that their viscosities depend on the shear rate; as the shear rate rises, the product becomes lower in viscosity.

This is good news for injection molding manufacturers, because even rubber parts with a very high L/D ratio can be filled with low injection pressure.

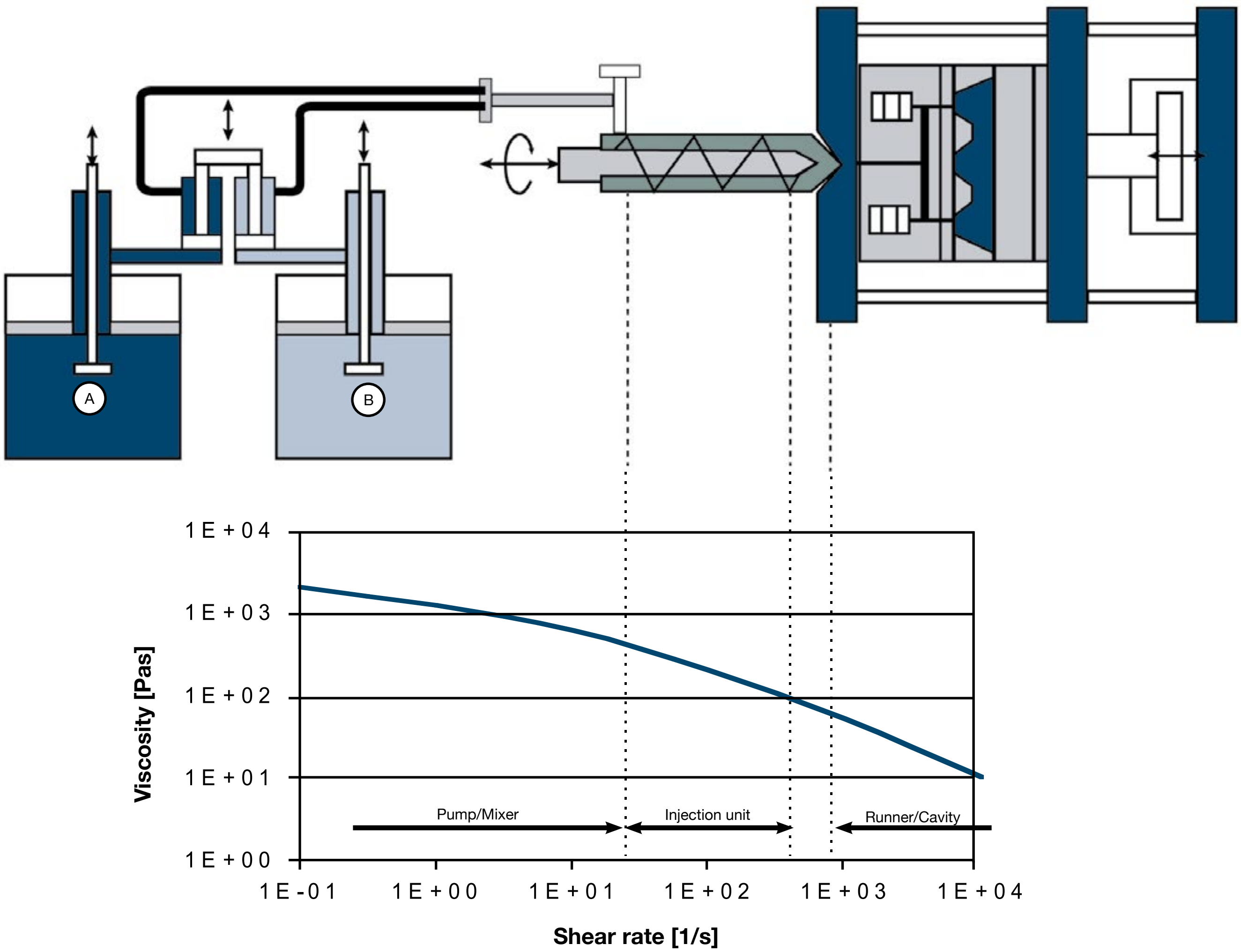


The graph above shows typical viscosity versus shear rate of some SILASTIC™ LSRs. These figures were measured on a cone/plate viscometer at 25°C. The electrically conductive SILASTIC™ LSR (Product 4) has a higher viscosity at low shear rates than the standard SILASTIC™ LSR. However, at shear rates occurring during the injection molding process, its viscosity is lower than the others. Therefore, it is not possible to extrapolate from the viscosity at low shear the actual viscosity during the injection process. Though this material can only be metered with a high consumption of energy, the injection pressure should, however, be kept fairly low in order to avoid flash.

SILASTIC™ F-LSR has a higher initial viscosity than regular LSR. However, at the shear rates occurring during the injection molding process, its viscosity reduces – making it as easy to process as LSR.



The shear rates that occur during the process are shown in the following diagram:



The shearing rates are highest at the gates and in the cavities, with values ranging up to 1 × 10-4 1/s. Viscosity here is often 10 to 100 times lower than in the pumps. These low viscosities allow the SILASTIC™ LSR and F-LSR to reach even the smallest gap during the injection process. Therefore, it is particularly important that all venting channels and other gaps are less than 5 to 7.5 µm; otherwise, flash will occur.

Injection

The injection pressure depends mainly on the geometry of the runner. It normally ranges from 100 to 1000 bar. Filling times for both SILASTIC™ LSR and F-LSR are approximately 0.5 to 3 seconds for a part size of 10 cm^3. To ensure that the material is not scorched, the injection speed profile should provide enough material to fill the cavity before it begins to vulcanize.

Holding pressure

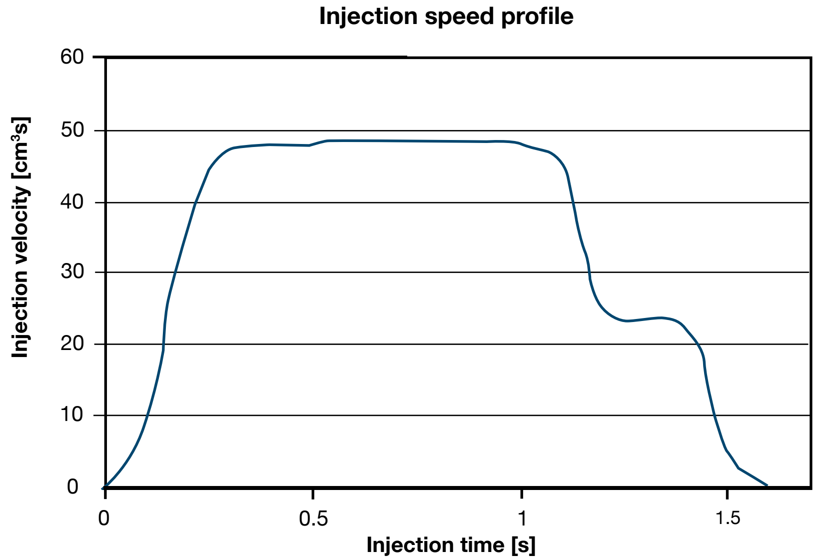
The switchover to holding pressure is best adjusted according to distance or volume. Holding pressure ensures that when the liquid silicone rubber expands within the mold (with the rising temperature), it is not pushed out of the cavity.

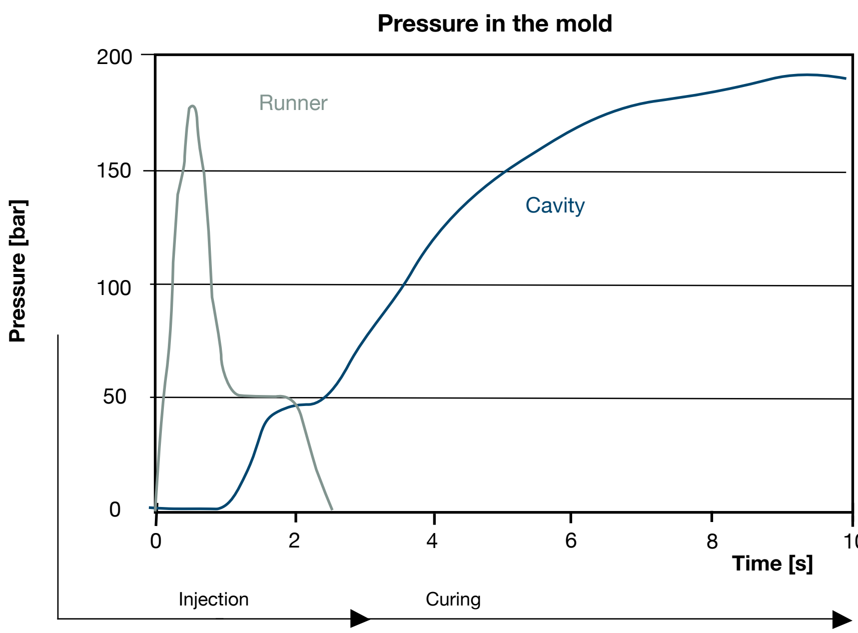
This is in contrast to thermoplastic injection molding, which applies holding pressure to counteract shrinkage caused by the cooling down of the melt in the cavity.

For LSRs, a 1- to 4-second holding pressure is normally sufficient for the silicone to cure at the gate, ensuring the silicone cannot flow back. For F-LSRs, a 3- to 6-second holding pressure is normally sufficient.

Material cushion

To avoid overloading, we advise that the material cushion is driven towards zero.





Pressure in the cavity – Avoiding flash

Cavity pressure commonly measures up to 300 bar. It rises gradually as the injected silicone expands upon rising temperature – but this rising pressure occurs before vulcanization starts. This means that you can fill the cavity up to 98-99%, and the remaining space is filled by the expanding liquid silicone rubber. This helps to avoid flash, because the cavity pressure does not rise much compared to when it is fully filled.

Material supply

SILASTIC™ LSR and SILASTIC™ F-LSR have two components that are delivered at a rate of 1:1 from either a 200-liter drum or 20-liter pail. Hydraulic or pneumatic reciprocating pumps are used to feed the liquid silicone rubber through flexible pipes to a static mixer. Here the pressure in the silicone measures 150-220 bar.

At this point, 0.5 to 6% color additive can be added. If more than one color is frequently used on the same machine or if more than one injection unit is supplied from the same pump, further additive pumps.

Mixing

The two main components and possibly an additive are delivered through a static mixer, which is a pipe with staggered mixing vanes inside. This ensures they are thoroughly mixed into a homogeneous suspension.

Dosing

The pressure of the material delivered through the pumps is reduced to 30-70 bar before it reaches the injection unit, which has been specially developed for liquid silicone rubber injection molding. The injection unit often has just one feeding screw for processing SILASTIC™ LSR or F-LSR. This means the proportion of compression is 1:1. To guarantee optimal mixing, feeding screws with an additional mixing unit in the metering zone are sometimes employed. Some special machines use a dynamic mixer combined with an injection piston to dose the material.

Special attention should be given to the non-return valve. It must be equipped with an exact and reproducible closing mechanism to avoid variations in the final volume caused by leakage flow.

Due to the very low viscosity (compared to thermoplastic melts), standard non-return valves are often too inert and do not always close immediately when the screw begins the injection process. Good results can be achieved with spring-loaded rings or with non-return valves that have very small closing distances for the particular application.

The dosing speed should be chosen to:

- Minimize the cycle time
- Avoid partial curing of the material in the injection unit

Back pressure

The specific back pressure should be adjusted to 5-30 bar.

Overmolding opportunities

SILASTIC™ F-LSRs are particularly good in overmolding thermoplastic: their fast curing time at lower temperature will not damage the thermoplastic insert. This allows a broad range of thermoplastic material to be overmolded.

Vulcanization speeds and cycle times

The vulcanization speed of liquid silicone rubber depends on four main factors:

- Temperature of mold, temperature of possible inserts
- Temperature of the silicone upon reaching the cavity
- Geometry of the part (relation between surface area and volume)
- General vulcanization behavior and the chemistry of the curing (see also page 17)

Cycle times can be reduced (and therefore productivity increased) by:

- Increasing the mold temperature
- Pre-heating the injection barrel and cold runner to 40-80°C with the use of a temperature controller
- Using a faster-curing material can be linked up.

Pre-heating the silicone that is about to be injected is recommended only for fully automated processes making larger items with a small surface-volume ratio.

If the machine is interrupted in its cycle, the cooling system must be activated immediately to prevent the material from curing.

At this point, it is important to note that the vulcanization time is often not the decisive factor for the overall cycle time. Demolding the rubber part often takes much longer.

Also, the dosage of the liquid silicone rubber in the injection barrel can be a major factor in cycle time. If a mold with a high number of cavities is being run (which as a single item would only need a short vulcanization time), the dosing unit may not be able to load the necessary shot volume fast enough; if this is the case, dosing time will extend the cycle.

To achieve the highest possible productivity, the machinery must be adjusted very precisely. However, the times for processes using air ejection of the rubber parts should not be too short– if they are too short, they may wrongly activate the mold protection after a few cycles because some parts were not ejected.

In many cases, the curing time can be assessed at the planning stage, using a total vulcanization time of 4 to 6 sec/mm. This becomes longer with larger thicknesses of parts. More precise calculations can be made with the help of simulation software on a computer.

Curing behavior of SILASTIC™ LSR/F-LSR

Vinyl- and hydrogen-functional polysiloxanes are cured using a platinum catalyst. This reaction can take place at room temperature but is much faster at higher temperatures. Once mixed, SILASTIC™ LSR or SILASTIC™ F-LSR, when stored at room temperature, has a minimum usage time (pot life) of three days.

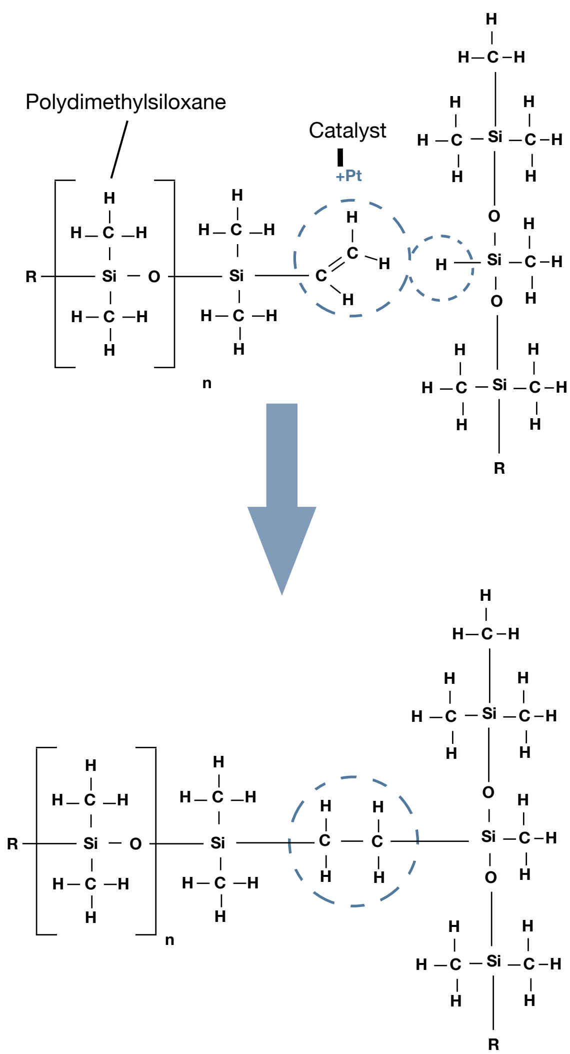
When the curing of a liquid silicone rubber is measured on a rheometer, the torque is shown as a function of the test time.

The graph shows the various stages of cure. In the beginning, the sample is mainly plastic and shows very little resistance to the deformation caused by the testing equipment. When the liquid silicone rubber begins to absorb the heat of the chamber, the torque begins to rise along with the start of vulcanization.

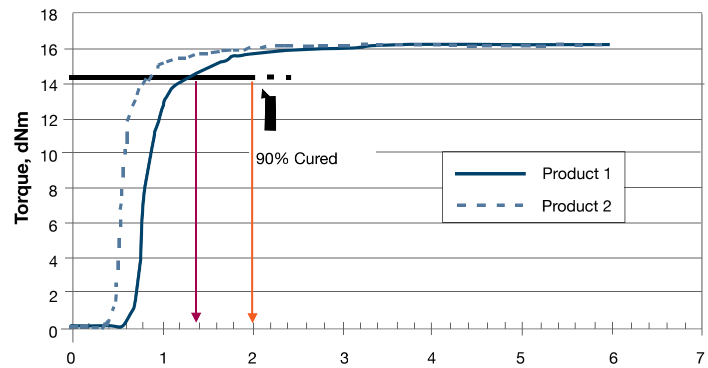
The 'TC 2' value shows when 2% of the maximum torque is reached during the test, and therefore indicates when curing starts.

The 'TC 90' value also is important. Here, 90% of the maximum torque is reached, and the curing is so much advanced that demolding is possible.

At 25°C, it takes several weeks for the material to become completely vulcanized. At temperatures above 120°C, however, this reaction takes only a few seconds.



SILASTIC™ LSR curing time as a function of temperature

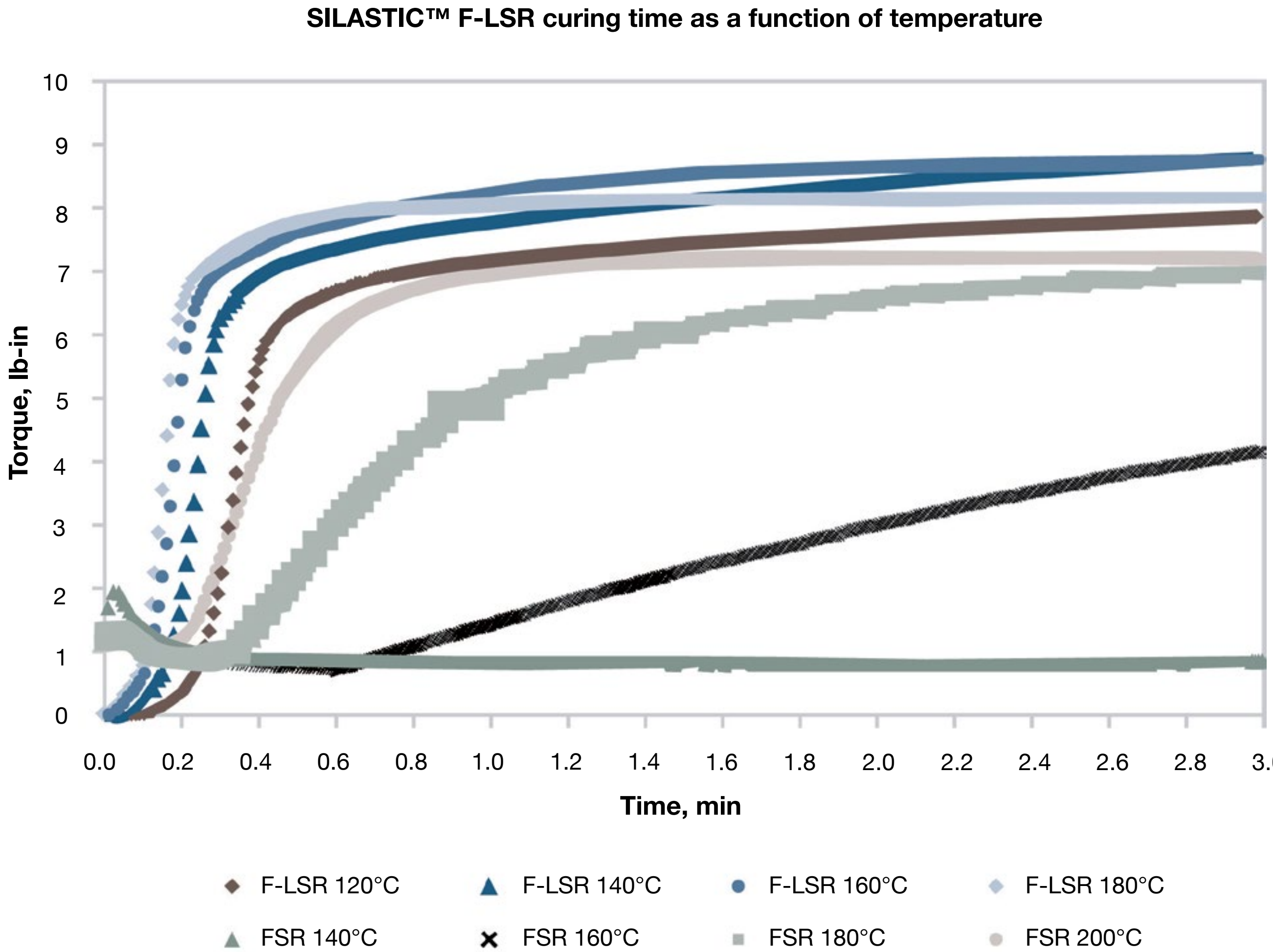


Measured with MDR at 120°C

At molding temperatures of 170°C to 210°C, SILASTIC™ LSRs cure very quickly, leading to a highly productive process.

This graph shows a close link between the cure kinetics of SILASTIC™ F-LSR with higher temperatures. Temperature is a key factor: It should be low enough to allow injection without scorch but high enough to minimize cure time.

SILASTIC™ F-LSRs have a very fast cure time at a lower temperature than a typical LSR. This means you can increase production output. Rubber parts with 2.8 g weight and 1.4 mm thickness have been successfully molded at temperatures lower than 140°C with cure times of 15 seconds. Rubber parts also have been molded at temperatures slightly higher than 160°C with cure times of 4 seconds – but at these temperatures, scorching may occur. If this happens, simply change the molding conditions – for example, by increasing the injection speed.



Post-curing

If the finished rubber parts must meet certain guidelines such as BfR* or FDA, post-curing is essential. In this case, volatiles escape from the molded part.

When post-curing parts made with SILASTIC™ LSR or F-LSR, it is necessary to supply a fresh air flow of 80 to 110 liters per minute and per kilogram of silicone rubber.

Post-curing also can help achieve some particularly high mechanical properties required from the silicone rubber.

A typical post-curing process takes place at 200°C over a period of 4 hours in an oven with fresh air supply. Depending on the required properties of the finished rubber parts, post-curing times and temperatures may be reduced. To fulfill the requirements of BfR* with respect to volatile content, the post-curing should be fine-tuned using experimental trials.

* BfR: Bundesinstitut für Risikobewertung

Principles of mold design for SILASTIC™ LSR and F-LSR

The design of injection molds for liquid silicone rubber is generally similar to the design of molds for thermoplastic parts. Nevertheless, some important differences in the behavior of silicone should be noted.

Due to the relatively low viscosity of SILASTIC™ LSR and F-LSR, the filling times of the cavity are very short – even at low injection pressures. In order to avoid air entrapments, a good venting of the mold is necessary.

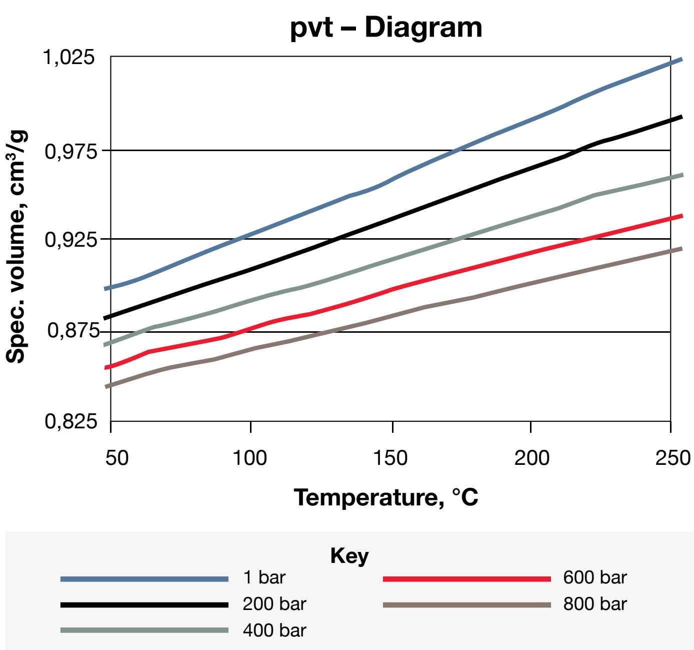
SILASTIC™ LSRs and F-LSRs expand in the hot mold – unlike a typical thermoplastic material, which shrinks. Therefore, the rubber parts do not necessarily remain on a core or more generally on the positive side of the mold as desired. Usually, the rubber parts remain in the cavity half with the larger surface area.

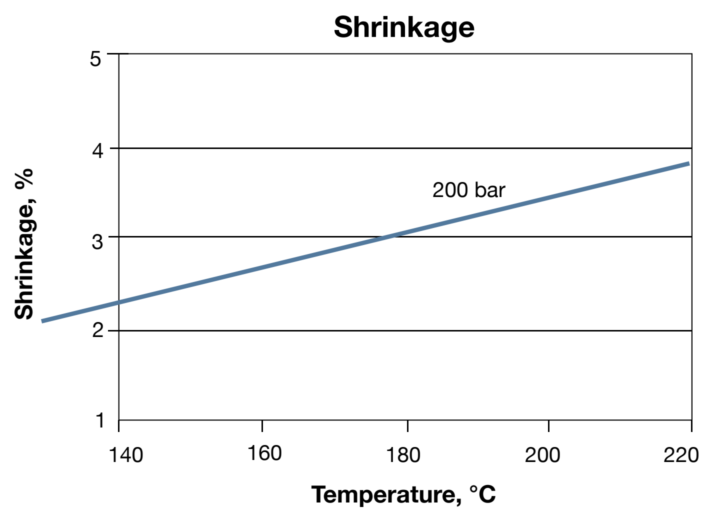
Shrinkage

Even though the rubber parts do not shrink in the mold, they will shrink after the demolding during the following cooling process. SILASTIC™ LSRs typically shrink 2.5 to 3%, and SILASTIC™ F-LSRs typically shrink 3 to 3.5%.

This shrinkage during the cooling depends on several factors:

- Tool temperature and demolding temperature
- Pressure in the cavity and, consequently, the compression of the materials
- Location of injection point (shrinkage in the direction of the material flow is usually higher than shrinkage perpendicular to the direction of flow)
- The dimension of the part (the shrinkage of thicker rubber parts is lower than that of thinner rubber parts)
- Post-curing the rubber part causes additional shrinkage of about 0.5 to 0.7%





Parting line

Deciding where the parting line should be is one of the first steps in the development of the injection mold. The venting, which is necessary for the material flow, takes place through special channels inserted into the parting line. The parting line should therefore be located in the area that the material reaches last. This avoids air entrapments, and the mechanical strength of the rubber part is not reduced along the weld line.

On the molded part, the separation from the mold is always recognizable later on. This area is very sensitive due to the low viscosity of the silicone and can easily bring about flash.

Demolding the rubber parts at a later time is influenced by the geometry of the rubber part and location of the parting line. Under cuts here can help ensure that the rubber part remains in the desired cavity half.

Venting

The air that is enclosed in the cavity is first compressed by the injected silicone and then expelled through the venting channels. If the air cannot escape entirely, air entrapments in the rubber part will occur, which can often be recognized by a white edge along the rubber part.

Special venting channels with a 1 to 3 mm width and a depth varying between 0.004 to 0.005 mm are inserted into the parting line so the air can escape. Optimum venting is created by a vacuum. To produce such a vacuum, the mold stops during the closing movement at 0.5 to 2 mm before it is completely closed. A gasket is built into the parting line, so a vacuum pump can draw the air from the cavities. Only when the vacuum has reached a certain reduced pressure or a time cycle has come to its end will the machine close the mold completely and the injection process is restarted.

Some modern injection molding machines offer variable clamping forces. Here, the mold is held together with low force until the cavities are filled to 90-95%; the low clamping force allows the air to escape more easily through the parting line. Then, switching to the necessary clamping force avoids flash caused by the expanding silicone.

Injection point

The type of gate depends on a number of factors. Using a system of cold runners fully exploits the technical advantages of liquid silicone rubber and also maximizes productivity. The aim is to produce the rubber parts without having to remove any sprue, which can be very labor-intensive. Avoiding sprue removal also saves considerable amounts of material and leads to faster cycle times.

Some injection nozzles can open and close with the help of a needle. These needles shut off nozzles that are built into the mold or, in some special cases, are fixed to the injection barrel instead of the standard nozzle. Nowadays, pneumatically controlled needle shut-off nozzles can be obtained as a standard mold part and, as such, can be built into various positions of the injection mold by the toolmaker.

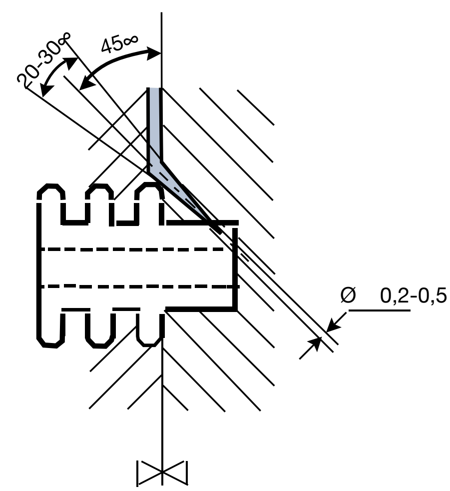
Some moldmakers specialize in the development of open cold runner systems. Due to their small size, the open cold runner systems can provide many injection points in very limited space. This technology also enables the production, even on small injection molding machines, of large numbers of high-quality rubber parts where no sprue gate needs to be removed.

When such cold runner systems are employed, it is necessary to separate the temperatures between the hot cavity and the cold runner. This ensures that the material does not start to cure if the cold runner is too hot. Furthermore, if the cooling is too strong, too much heat is drawn from the hot mold in the gate region – which, in turn, causes that area of silicone to insufficiently cure.

If the rubber parts are injected in a more conventional sprue (such as submarine or cone gate), small diameters should always be selected in the beginning. This is because in these areas, the low-viscosity material can easily flow and does not need large diameters. The diameter of the feed point is between 0.2 and 0.5 mm.

It is important to balance the layout of the whole runner system in such a way that all cavities are filled evenly. Filling studies can be used to confirm this information, or you can use filling simulation software to design the runner during the development of the mold.

Heating of SILASTIC™ LSR through dissipation: $\Delta T \cong \Delta p/(\rho \times cp)$



Δp pressure gradient
ρ density SILASTIC™ LSR
cp heat capacity SILASTIC™

For SILASTIC™ LSR, the increase is approximately **4-6 K/100 bar applied.**

NOTE: The warming resulting from the friction during the injection may be neglected.

Demolding and ejection systems

Vulcanized liquid silicone rubber sticks to metallic surfaces. The silicone rubber molded part also is flexible. These two factors can sometimes make demolding particularly difficult. However, the high hot tear resistance of SILASTIC™ LSR and F-LSR makes it possible to easily demold rubber parts – even with big undercuts – without damage.

The demolding technologies most used are:

• Stripper plate

• Ejector pin

• Air ejection

• Roller sweep

• Draw-off plate

• Robotic handling

When ejection systems are used, they must have narrow tolerances. Flash will occur if there is too much clearance between ejector pin and bushing guide or if this has been enlarged by wear over time.

Good results are achieved with mushroom-shaped or tapered ejectors where an improved sealing effect is favored by increased contact pressure.

Mold materials

When developing molds for highly abrasive materials, ensure that the high-wear areas can be exchanged separately – this avoids having to replace the whole injection mold.

• Retainer plates are fabricated from unalloyed tool steel.

Steel-No.: 1.1730

DIN-Code: C 45 W

• Molding plates exposed to temperatures between 170 and 210°C should be constructed from tempered steel.

Steel-No.: 1.2312

DIN-Code: 40 CrMnMoS 8 6

• The mold plates containing the cavities are preferably produced from forged steel, tempered later and possibly nitrided.

Steel-No.: 1.2343

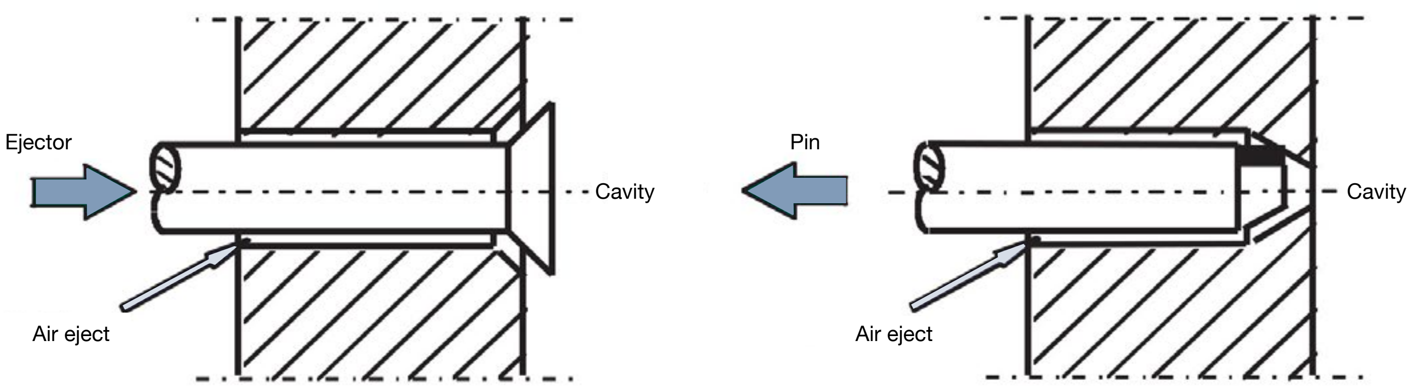
DIN-Code: X 38 CrMoV 5 1

• For highly filled SILASTIC™ LSR and F-LSR, such as oil-resistant grades, it is recommended to use even harder materials, such as steel-plated with flash chrome or powder metallurgy steel developed specifically for this application.

Steel-No.: 1.2379

DIN-Code: X 155 CrVMo 12 1

Mushroom-shaped and tapered ejector pin:



Cavity surface finish

Surface roughness:

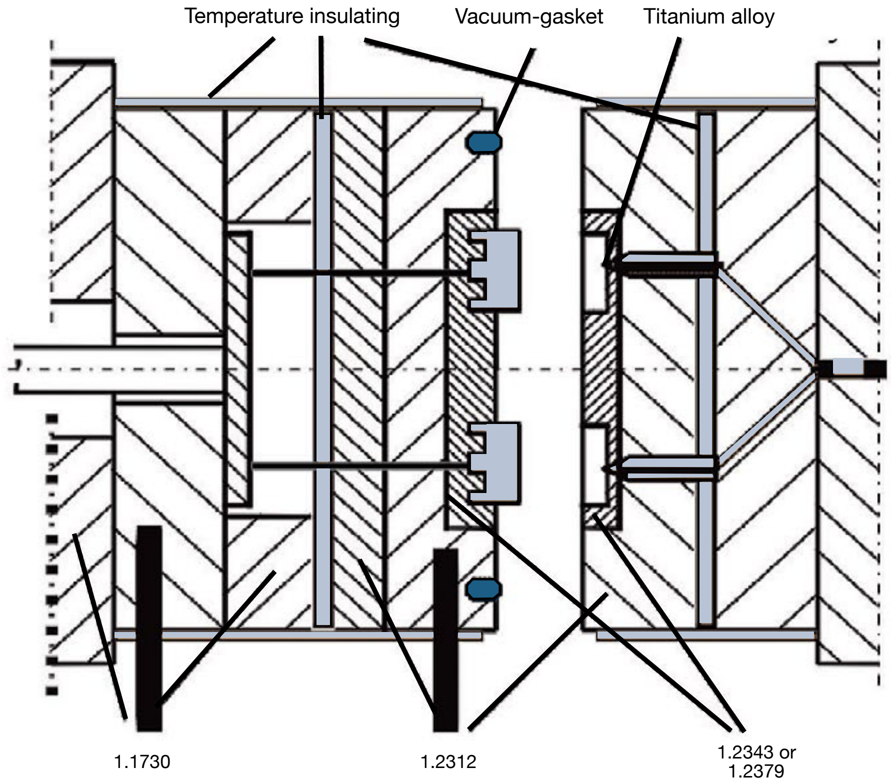
Spark erosion: 0.5-3.5 μRa

Grind, polish: 0.05-1 μRa

The surface of the cavities influences the process in different ways:

- The rubber part exactly duplicates the surface of the steel, hence this surface fulfills various optical requirements. Polished steel must be used for the production of transparent rubber parts.
- An eroded surface normally provides less adhesion between the liquid silicone rubber and the mold than a polished surface, so demolding may be specifically designed.
- Steel with a Titanium/Nickel-treated surface has a very high wear resistance.

Sketch of a cold runner mold for SILASTIC™ LSR and F-LSR



Temperature control

PTFE/Nickel makes demolding easier.

Injection molds are preferably heated electrically with the use of cartridge heaters, strip heaters or heating plates. A homogeneous distribution of temperature is desirable to maintain the same conditions for the liquid silicone rubber in all places. To get an even temperature on larger molds in the most cost-effective manner, it is recommended to use oil temperature-controlled heaters. It also is advisable to case the mold in insulating plates to reduce the thermal losses.

Required heat energy: ≈ 50 W/kg

Unheated cores can be exposed to great changes in temperature due to prolonged break times or from the blow-off air. When the temperature falls too low at this point, the material cures at a slower rate, and this may cause demolding difficulties because of the stickiness of liquid silicone rubber.

The distance between heating cartridges and the parting line should be high enough that they cannot bend or deform the plate. Uneven plates may prevent a flash-free process.

If the mold is equipped with a cold runner system, an exact separation between hot and cold mold must be provided. Here, special titanium alloys, such as 3.7165 (Ti Al 6 V4), can be used as these have a much lower thermal conductivity than other types of steel.

For molds that are heated entirely, heat-insulating plates should be placed between the mold and mold plates to minimize heat loss.

Selection of machine

Clamping force

Before selecting a machine, the clamping force must first be calculated. The expansion of the silicone rubber in the hot mold causes the cavity pressure to rise up to 400 bar. The force needed to clamp the mold can be calculated by multiplying the projected surface of all rubber parts with the cavity pressure.

$$A_{circle} = D^2\pi/4$$

Example: 6-cavity baby nipple mold

Nipple diameter = 39 mm

Projected surface $A = 6 \text{ r } (39/2)^2 \text{ r } \prod = \mathbf{7167.54\ mm^2}$

Cavity pressure ≤ 400 bar

400 bar = 40 N/mm^2

$F = p \text{ r } A = 40\ N/mm^2 \text{ r } 7167.54\ mm^2$

F = 286,702 N clamping force is required.

This corresponds to an injection molding machine with a designated clamping force > 290 kN (or the equivalent of a 30-ton weight).

Injection unit

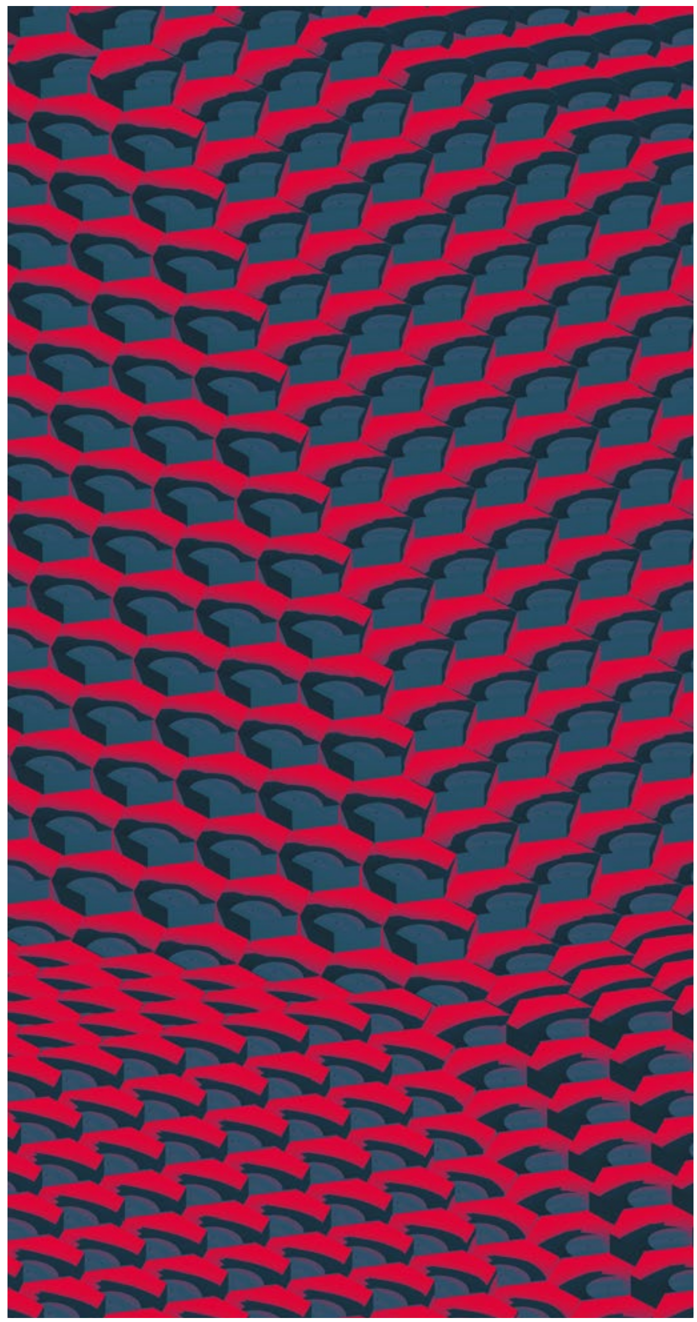
The diameter of the injection screw should be chosen in such a manner that the stroke of the screw ranges between 1-5 D. This guarantees a stable operating process for the injection unit. With a stroke of less than 1 D, the mixing of the screw is insufficient and the movement control for the machinery is not precise enough.

Meter mixer

There are different types of meter-mixing units. Hydraulic and pneumatic driving cylinders are the main differences. The meter-mixing unit can pump the material from 20-liter pails or 200-liter drums.

Equipment adjustment

SILASTIC™ F-LSRs have higher viscosity and exceptionally fast cure rates; therefore, it is recommended to use 1-inch (25.4-mm) diameter hoses to supply material from the feeding pumps to the static mixer. In addition, a static mixer larger than ½ inch (12.7 mm) should be used. These changes will help ensure that the injection screw can refill before the next cycle begins. It also is recommended not to use a screen pack – but if a screen pack is used, make sure it is bigger than 300 micron.



Other injection molding technologies

Two-component injection molding

Many parts made from liquid silicone rubber are assembled after the production in an additional step – causing extra work and cost. But in some cases, it is possible to produce the SILASTIC™ LSR and F-LSR rubber part directly in the place required for its final use.

For example, producing a gasket of silicone rubber on a housing of nylon once entailed making both parts (housing and gasket) on separate injection molding machines and then connecting them in an extra assembling process. But with SILASTIC™ LSR or F-LSR, you can produce products like these in a high-quality and cost-efficient way with two-component injection molding.

For this, two main procedures are commonly used:

1: Two separate injection molding machines

The first part will be injected with thermoplastic on a standard injection molding machine. Depending on the degree of automation, the demolding is done by automatic handling or manually. Afterward, the thermoplastic part is placed directly in the injection molding machine for the liquid silicone rubber, which is standing just next to the first machine. The thermoplastic part represents a part of the cavity during the following injection molding process. The actual injection mold provides the outer shape of the liquid silicone rubber gasket.

Parallel to the molding of the liquid silicone rubber, the machine for the thermoplastic starts the next cycle.

The advantage of this system is that you can use both machines independently for different projects. It also is much easier to control the thermal conditions. For example, the tool temperature for a technical thermoplastic such as glass-fiber-reinforced nylon PA-GF or polybutylenetheraphthalate PBT is approximately 70 to 110°C (check the recommendations of the raw material supplier). The residual heat of the injected thermoplastic part is high enough to reach a fast enough curing in the hot (170 to 190°C) SILASTIC™ LSR mold.

The bonding of both materials can be achieved mechanically by undercuts or chemically with the use of a primer. In some special cases, it may be possible to use a self-adhering SILASTIC™ LSR.

2: Two-component injection molding machine

Alternatively, you can use a two-component injection molding machine. In this case, both materials will be injected on one machine with two injection units. This machine has only one mold that contains both cavities: one for the thermoplastic and one for the liquid silicone rubber.

Moving the molded parts to the respective injection point is done by rotating the mold plate or by using a turning or sliding table.

It is difficult to set up the optimum temperature profile for each material. One possibility is to vary the temperature in the mold: cold for the thermoplastic and hot for the liquid silicone rubber. But this requires a high investment in the mold structure and in its temperature-control unit.

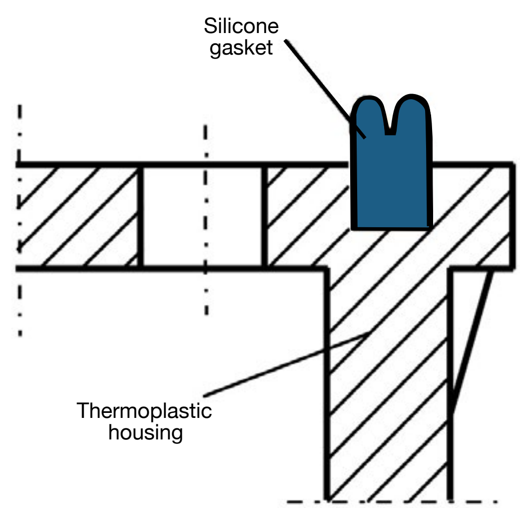
The mold temperature also can be adapted in such a way that the thermoplastic part cools down sufficiently to enable demolding without deforming the part while simultaneously allowing the temperature to still be high enough to achieve an efficient enough curing of the liquid silicone rubber. A tool temperature range of 110 to 130°C for SILASTIC™ LSR gives good results with this method.

Due to the need for faster curing, a liquid silicone rubber should be used. This type of SILASTIC™ LSR vulcanizes at lower tool temperatures fast enough to achieve an efficient process.

It is certainly possible to produce other two-component rubber parts in this way or with similar procedures:

- Silicone with silicone for multicolor rubber parts
- Electrically conductive silicone in combination with insulating ones for high-voltage applications
- Injection of silicone gaskets on aluminum housings

CIPG (Cured In Place Gasket)



The composition of various silicones, as for the high-voltage technology example, gives the advantage that the welding line of both materials is almost as stable as the basic material.

Injection molding of HCR (High Consistency Rubber) as opposed to LSR (Liquid Silicone Rubber)

The oldest way to produce silicone rubber parts is still widely used today: injection molding of high consistency rubber.

The silicone rubber is fed as an endless rope preform or as a block via a special stuffing piston to the injection unit. Compared to liquid silicone rubbers, there are more bases to compound together to achieve specific final properties. This makes it possible to produce small numbers of rubber parts with a custom-developed material that fulfills these special requirements.

Using these newly developed products, you can overcome the disadvantage of the low productivity caused by the much slower curing time of peroxide-curing materials.

The use of a platinum-catalyzed addition-curing system reduces vulcanization time by up to 70% compared to peroxide-curing silicone.

SILASTIC™ HCR, which is delivered as a stable-to-store, one-component ready-mix, offers shorter curing times and, thereby, much higher outputs compared to the use of peroxide-curing compounds.

Thanks to its vulcanization behavior, SILASTIC™ HCR is not so sensitive to tool temperature variations as peroxide-curing silicones are – even with short curing times. Thereby, deformations caused by the demolding process can be prevented even with a lower tool temperature. This makes it possible to produce rubber parts with narrow tolerances.

Addition-curing silicones are uninhibited by oxygen, making the demolding easier. The surface also feels drier than with peroxide materials. As with SILASTIC™ LSR, during the production using SILASTIC™ HCR, no peroxide decomposition products escape from the material, and there is none of the typical peroxide odor during production.

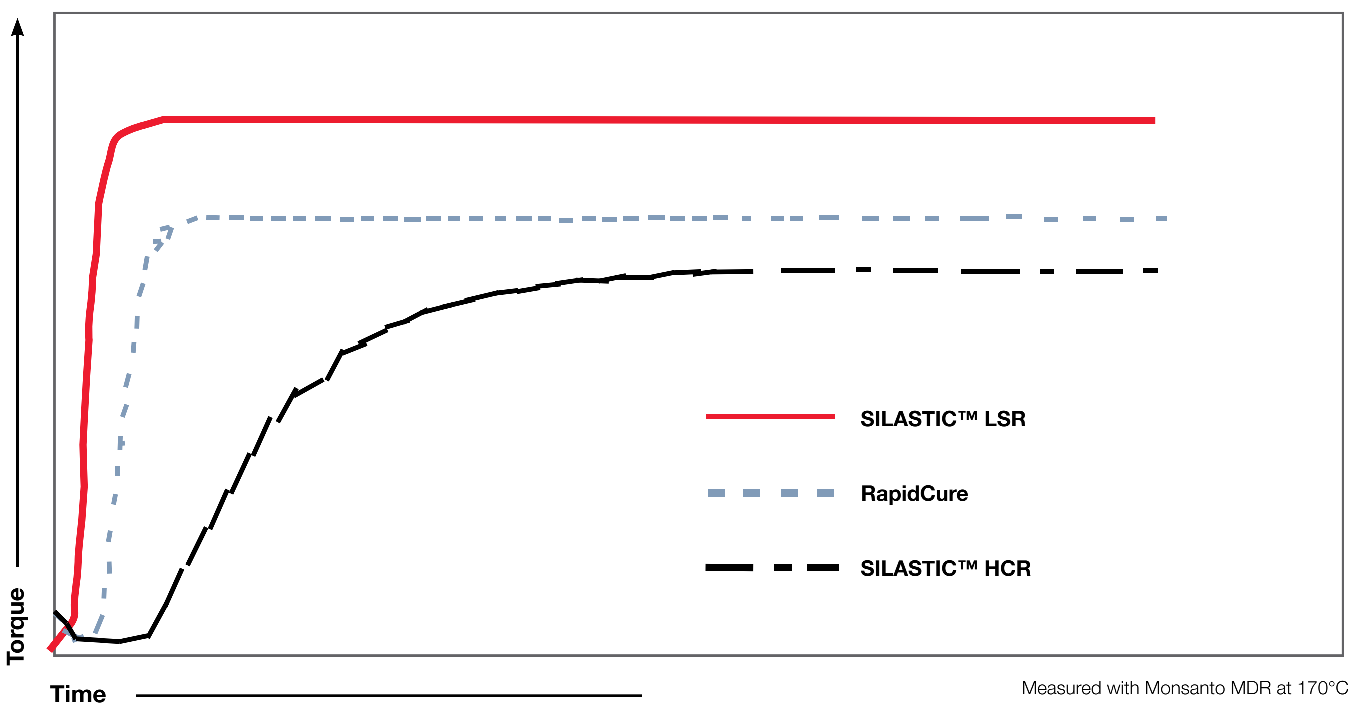
The production and tool design for SILASTIC™ HCR silicones is generally comparable with the guidelines for liquid silicone rubber. The injection barrel is designed specifically for the use of these materials. Various machine constructions are developed by machine suppliers to cover this wide range of applications. The use of a compression screw is common with the various injection molding methods, and a non-return valve is similar to the ones used for thermoplastic injection molding.

The runners and the injection points should have slightly larger dimensions due to the higher viscosity of SILASTIC™ HCR compared to SILASTIC™ LSR. As a result of the higher viscosity, flash also is not so critical. Thereby, the venting channels may have a size of 0.01 mm.

The total curing time depends on the mold temperature and the geometry of the rubber part:

- For SILASTIC™ HCR with a peroxide curing system, a typical curing value is about 15 sec/mm.
- For a rubber part made with addition-cured SILASTIC™ HCR, a typical curing value is between **5 to 7 sec/mm.**

Curing behavior of SILASTIC™ silicone rubber



Measured with Monsanto MDR at 170°C

Starting the production with SILASTIC™ LSR and F-LSR

Temperature preset

Before operating the injection molding machine, all traces of spray for mold or other rust-prevention coatings must be thoroughly removed. The injection unit and the cold runner should also be cooled to 20 to 25°C.

When heating a mold for production, the temperature for a SILASTIC™ LSR is generally 175 to 200°C, and for SILASTIC™ F-LSR 125 to 180°C.

Before starting the first cycles, the temperature should be within the desired temperature range for 10 to 20 minutes. If the mold is kept closed during the heating phase, the loss of heat at the parting line is significantly lower, and the temperature of the cavity surfaces rises uniformly with the mold temperature. This guarantees the desired temperature in all mold parts – even those that are not heated directly.

With some machines, the zero point of the mold may change due to the thermal expansion. It makes sense, therefore, to adjust the zero point only at working temperature or to check it again when the working temperature has been reached.

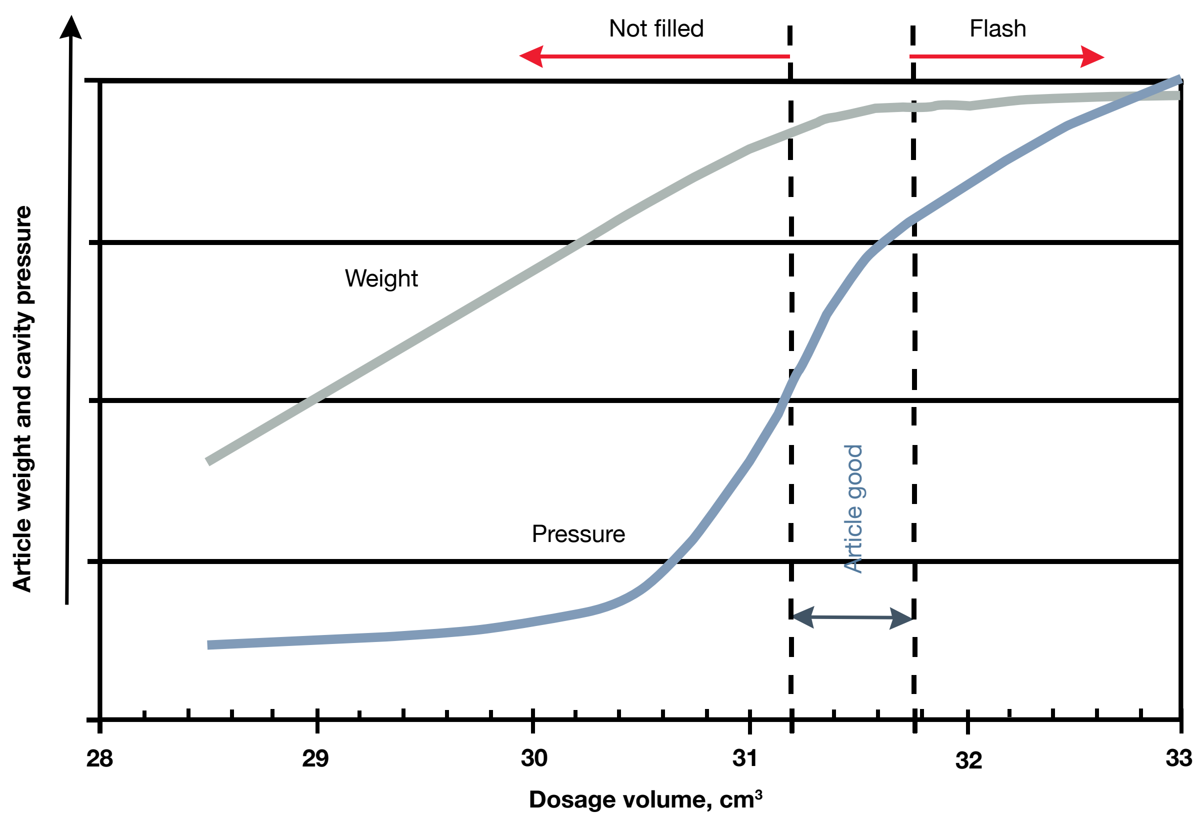
Injection stroke and flow

If demolding makes it possible, it is good to try to underfill the first injection molded part so that an overload is avoided. In the following cycles, the dosing volume can be gradually increased to the final shot size.

Best results are achieved when the cavities are filled precisely to 98-99% of the cavity volume.

The thermal expansion of the liquid silicone rubber fills the cavity completely during the curing time. This can be examined, for instance, by weighing the finished rubber parts. To prevent an overload, all parameters should be kept low for the first injection.

The injection speed and the maximum injection pressure should then be chosen in such a way that the cavities are filled in a period, of 0.5 to 3 seconds. Towards the end of the filling period, the injection speed should be reduced to enable the air enclosed in the cavity to escape through the vents.



Switchover and holding pressure

During the injection molding of liquid silicone rubber, holding pressure ensures that no material is pushed back from the cavity out of the gate. Pressures of 50 to 200 bar (specific material pressure) are sufficient.

The holding pressure time depends mainly on the type and geometry of the gate. If a needle shut-off nozzle is employed, holding pressure time can often be less than 1 second as the discharge of the material is hindered by the needle shut-off.

With open cold runner systems, however, holding pressure must be maintained until the liquid silicone rubber is so far vulcanized at the gate that no material can escape from the cavity. Holding pressure time depends largely on the geometry of the gate and is commonly 0.5 to 4 seconds for SILASTIC™ LSR and 3 to 6 seconds for SILASTIC™ F-LSR.

The switchover from injection to holding pressure should be chosen in such a way that the holding pressure sets in very late and fills the cavity a little. This facilitates a flash-free injection.

Curing time

The curing time for the first trials should be selected in such a way that the liquid silicone rubber cures securely and can be demolded without damaging the rubber part and without uncured rubber remaining in the cavity. A typical curing time is between 3 to 5 sec/mm.

However, the curing time can be incrementally reduced until problems such as deforming or stickiness occur. Then, the curing time should be raised by about 5 to 10% to ensure a safe process.

Demolding

At the start of production, the rubber parts may tend to stick on the mold steel. However, this will improve after several cycles as siloxanes escape from the liquid silicone rubber and deposit a layer of siloxane on the steel section. To prevent sticking at the initial cycles, a silicone free release agent can be used as a demolding aid.

A mixture of water and liquid soap, which can be wiped on with a cloth or sprayed on thinly with a diffuser, is often efficient and economical.

Production end and clean-up

If the heaters are turned off at the end of production, the cooling systems for the cold runner and for the shut-off nozzle of the injection unit must continue to run. This prevents parts carrying mixed liquid silicone rubber from being warmed by radiating heat, which causes a shortening of the pot life. If the machine is interrupted in its cycle, shortly afterward the cooling systems must be turned on to prevent the material from curing.

If the machine stands still for three days, as for instance on the weekend, no special measures need to be taken, as during this time the mixed liquid silicone rubber vulcanizes only slightly in a cooled barrel. That is because at temperatures below 35°C, mixed material will remain processable for a minimum of three days, unless otherwise stated.

If the machine stands still for longer than three days, the mixer, the injection unit and the cold runner should be flushed with the B-component. Parts that carry mixed material also can be kept in a freezer to prevent curing for a longer period of time.

Even if the production runs almost without interruption, about every six months the mixer and the injection unit should be cleaned thoroughly. This ensures that cured particles in the mixing unit do not detach themselves and thereby plug up the cold runner or enter the mold cavity.

Cured SILASTIC™ F-LSRs have high solubility in polar solvent such as ester- or ketone-based solvents. Use of such fluid will help remove easily cured material.

Troubleshooting for injection molding of SILASTIC™ LSR or F-LSR

1. Rubber part is underfilled		- Part is short - Uneven surface - Underweight part
Cause		**Solution**
a.	Injection speed or pressure is not optimal	• Raise injection velocity and possibly injection pressure
b.	Dosage insufficient	• Enlarge dosing volume
c.	Poor venting	• See “3. Bubbles/burners”
d.	Tool temperature too high	• Lower tool temperature
e.	Switchover and holding pressure not correct	• Delay switchover • Increase holding pressure
f.	Machine fault	• Check radial screw clearance and non-return valve
g.	Cold runner or sprue dimensions faulty	• Check sprue system for soiling or precured area • Check dimensions of sprue and possibly enlarge
h.	Uneven filling of cavities	• Balance runner and gate
i	Precuring in injection unit or supply lines	• Clean system

2. Flashing of mold		- Silicone film at parting line
Cause		**Solution**
a.	Shot size too large	• Reduce dosing volume • Check for even dosing volume
b.	Injection speed or pressure is not optimal	• Reduce injection velocity and possibly injection pressure
c.	Switchover and holding pressure not correct	• Set switch point earlier and reduce holding pressure
d.	Venting channels too big	• Reduce size of vents
e.	Tool temperature too low	• Raise temperature and check on even mold temperature • Check heaters and thermocouples
f.	Tool damaged or soiled	• Check parting lines and movable parts for wear and repair or rework • Clean parting line
g.	Clamping force too low	• Raise clamping force or switch to larger machine if necessary

3. Bubbles/burners		- Blisters visible in finished parts - Wedges
Cause		**Solution**
a.	Injection speed or pressure too high	• Reduce injection velocity and possibly pressure
b.	Tool temperature too high	• Reduce tool temperature
c.	Venting channels soiled or not properly dimensioned	• Clean mold • Deepen vents • Reduce clamping force
d.	Vacuum insufficient	• Check vacuum pump • Check gasket for defect spots • Prolong time for building up vacuum
e.	Air in meter mixer	• De-air the unit • Check gaskets
f.	Uneven filling	• Balance runner and gat

4. Silicone not cured		- Rubber part sticks in the cavity - Rubber part feels tacky
Cause		**Solution**
a.	Vulcanization time too short	• Prolong vulcanization time
b.	Tool temperature too low	• Raise temperature • Check heaters and thermocouples • Check if temperature is even • Shorten break time
c.	Mixing proportion not 1:1	• Check meter mixer for fluctuation of pressure • Clean supply lines and mixer from precured particles and areas
d.	Curing inhibited	• Check that no sulphur or tin are contaminating the SILASTIC™ LSR unit (occurs often when organic rubbers are produced close to SILASTIC LSR)

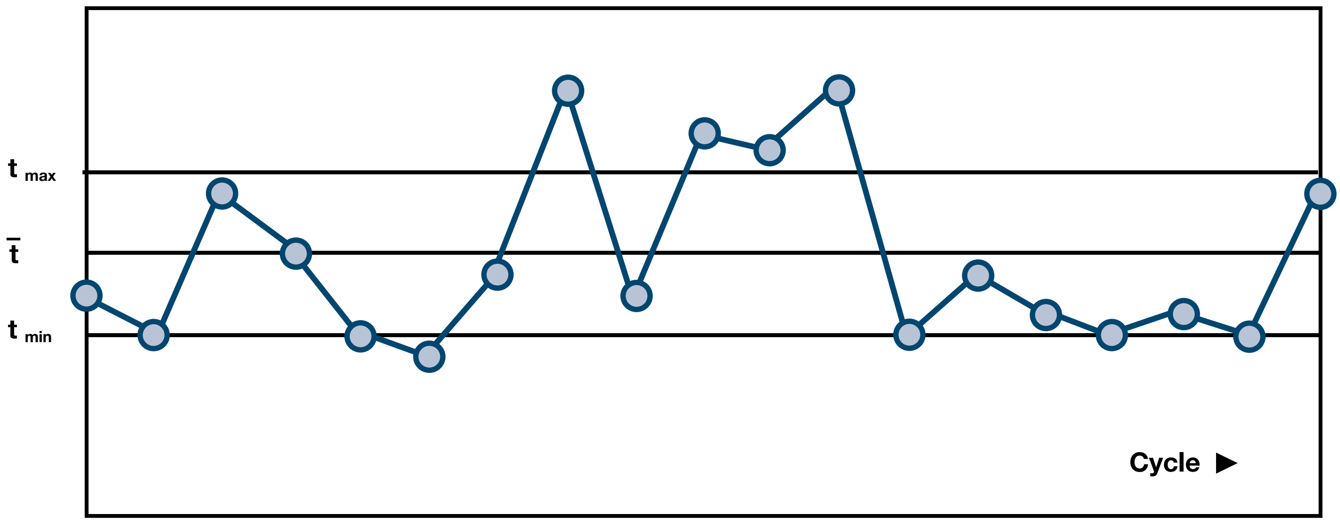
5. Scorch; precuring of the material during the injection process		- Part shows streaks - Strongly appearing flow lines - Orange skin
Cause		**Solution**
a.	Injection speed too low	• Raise injection velocity and possibly pressure
b.	Tool temperature too high	• Lower mold temperature and possibly cold runner temperature

6. Precured particles in finished article		- Cured particles appearing in the part - Cured sprue visible in article
Cause		**Solution**
a.	Temperature of cold runner at injection point not low enough	• Control or improve cooling of cold runner • Lower tool temperature at the gate
b.	Material leaks from the injection point	• Decompression of material in the cold runner with open system insufficient • Shut-off needles have too much clearance
c.	Precured particles are spooled out from the injection unit or mixer	• Clean mixed material leading areas

7. Problems with demolding		- Article not ejected from cavity - Runner is not separating from part
Cause		**Solution**
a.	Tool temperature too high	• Lower mold temperature
b.	Holding pressure too long or too high	• Reduce holding pressure or time
c.	Curing time too long	• Shorten vulcanization time
d.	Tool construction not perfect	• Optimize undercuts • Treat mold surfaces or adjust roughness • Combine ejector-pins, -brushes, -plates with air eject and/or roller sweep

8. Incorrect dimension of part		- Article is deformed after demolding - Part dimensions out of range
Cause		**Solution**
a.	Curing insufficient	• Prolong vulcanization time • Control and optimize temperature of mold
b.	Shrinkage changed	• Check for even tool temperature • Adjust injection parameters to get required cavity pressure

9. **Irregular cycle times**	- Varying cycle times during the production



	Cause	**Solution**
a.	Dosing time varies and is sometimes longer than curing time	• Adjust pressure in the pumping unit evenly • Remove precured material from the mixer • Increase dosing speed • Optimize back pressure • Control hydraulic system of the machine • Check non-return valve
b.	Injection time irregular	• Control injection parameters • Lower temperature of cold runner • Control for even dosing volume • Check non-return valve

10. **Potlife material cures in injection unit**		- Starting difficulties after a longer production break - Longer injection and dosing times at production start
	Cause	**Solution**
a.	Material in the mixer and the injection unit begins to cure	• Check cooling of injection unit • Spool unit with A-component before a standstill of more than three days • Disconnect injection unit from the hot mold, even at short breaks • Continue cooling of cold runner after switching off he tool heating

For more information

To learn more about liquid silicone rubber solutions from Dow, visit **www.dow.com/lsr**.

Contact information

www.dow.com/contactus

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