9 Molding of Rubber

9.1 Introduction

Many rubber articles are produced by molding, a process in which uncured rubber, sometimes with an insert of textile, plastic, or metal, is cured under pressure in a mold. There are three general molding techniques: compression, transfer, and injection molding.

In compression molding, a pre-weighed, generally preformed piece is placed in the mold; the mold is closed, with the sample under pressure, as it vulcanizes. Cavity pressure is maintained by slightly overfilling the mold and holding it closed in a hydraulic press. Heat is provided by electricity, hot fluid, or steam.

Transfer molding is a form of injection molding. The compound to be cured is held in a heated reservoir, the amount of rubber to fill the mold is forced through sprues or a runner system and into the mold cavities by a piston. Pressure is maintained by the piston and a mold closure system. The mold has to be hot enough to ensure curing of the rubber, but the reservoir has to be at a lower temperature.

Injection molding combines an extruder, which heats and fluxes the rubber, with a reservoir and mold. While the rubber in the mold is curing, fresh rubber is prepared for the next cycle so that molding is a semi-continuous process. The compounds used have to be optimized for injection molding. They must flow through the nozzle and runner system and fill the mold under the pressure available. They should not cure before filling the mold, but cure quickly once in the mold.

A high viscosity compound may not fill the mold properly or may generate too much shear heat, leading to overheating and scorch. A low viscosity compound may not generate enough heat, leading to undercure. These considerations mean that there is a process window within which a specific material can be satisfactorily molded in a given process.

Both compression molding and transfer molding have been used in the rubber industry for many years, whereas injection molding did not become common in the rubber industry until after it had been developed as a standard process in the thermoplastics industry in the 1960s.

9.2 Compression and Transfer Molding

Both compression molding and transfer molding are still widely used in the industry worldwide, even though injection molding has a number of advantages. This is often because the fabricator has an existing press in good working order. When starting from scratch both economic and technical factors have to be considered [1]. The main economic factor is that the capital cost of machines and molds increases in the order compression molding, through transfer molding, to injection molding. A production volume may be too small to justify a high initial capital cost.

In compression molding, Fig. 9.1, the weight, dimensions, and positioning of the charge have to be closely controlled, or the dimensions of the product can vary widely. This is often due to variation in the amount of material lost from the

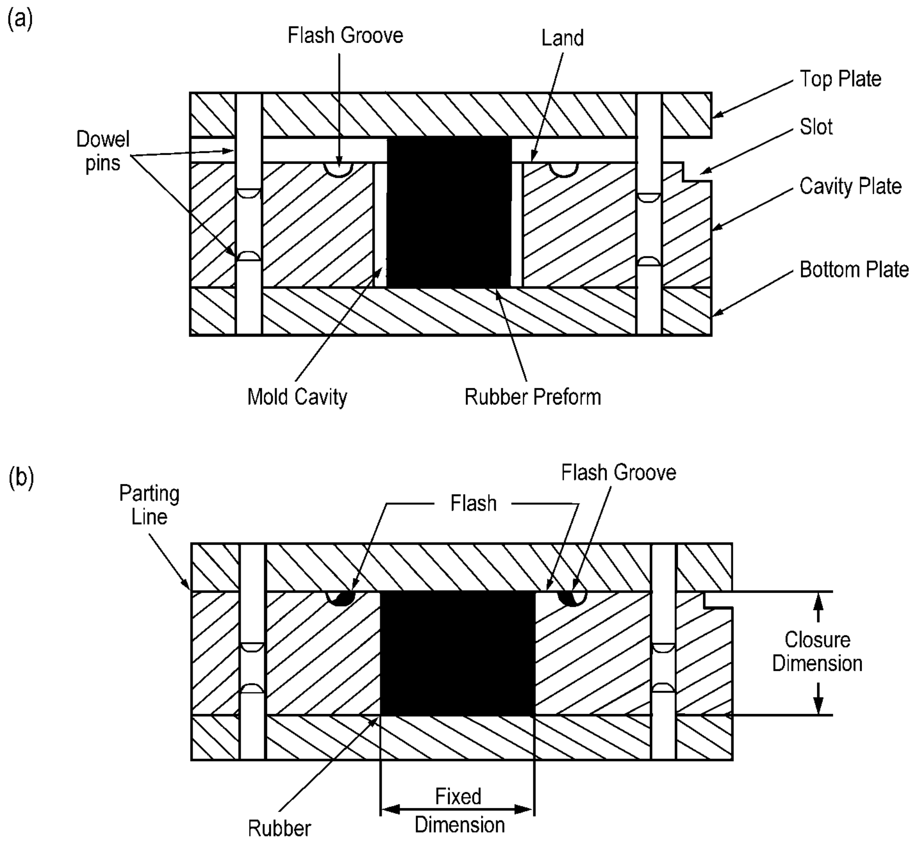

Fig. 9.1 Compression mold containing a rubber preform (a) before closing molding, and (b) after mold closing (courtesy of J. Sommer and Rubber Division ACS [4])

cavity as flash. This can be controlled, rather than be eliminated, by employing a shallow plunger, which, because of close clearances, means that excess rubber can only escape when high pressure is applied, after the mold is completely filled.

(a)

(b)

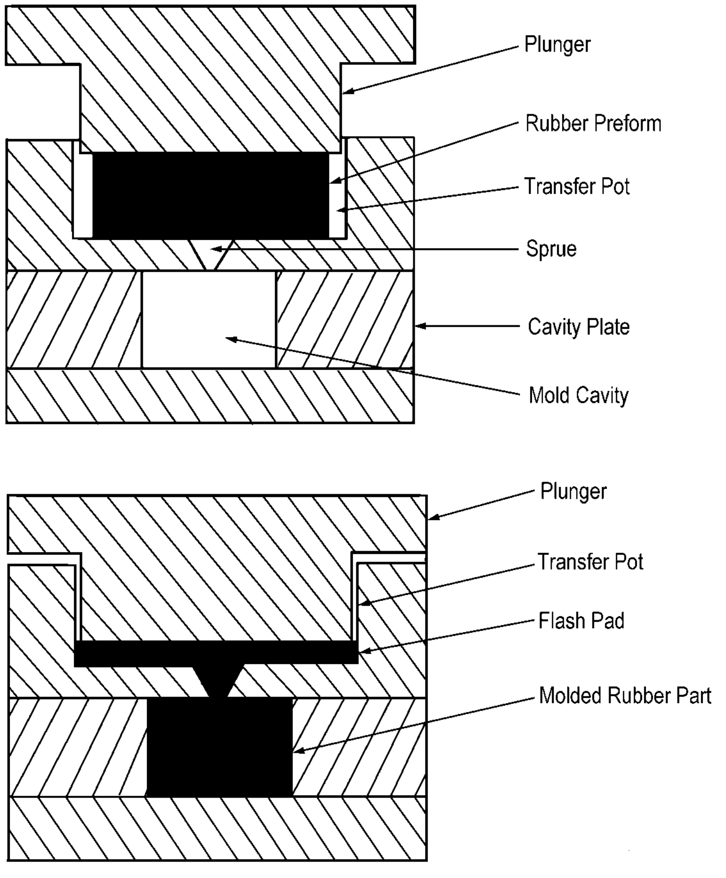

Fig. 9.2 Transfer mold showing (a) preform in transfer pot before closing mold, and (b) after closing mold

In transfer molding, Fig. 9.2, rubber flows from a separate reservoir through a narrow flow channel, called a sprue, into the mold. There are three advantages over compression molding [1].

1. As the mold is closed before the rubber charge is forced into it, closer dimensional control is achievable.
2. In the transfer process, fresh rubber surfaces are produced, and this allows development of a strong rubber-metal bond with any insert in the mold.

3. Unit production costs are lower due to shorter cure times as a result of heating the rubber due to flow through sprue, runner, and gates and shorter downtime between runs, as only one charge blank is necessary, even if a multicavity mold is used.

9.3 Injection Molding of Rubber

Injection molding is now a well-established fabrication process in the rubber industry. Its advantages in most situations over the older processes of compression and transfer molding have been amply demonstrated [1 to 7]. These advantages comprise reduced labor costs, shorter cure times, better dimensional control, and more consistent mechanical properties of the product.

This chapter will give an overview of the injection molding process and of the equipment used. More detail can be found in the references, which are the sources of much of the information in this chapter.

The operation of an injection-molding machine requires: feeding, fluxing and injection of a measured volume of compound, at a temperature close to the vulcanization temperature, into a closed and heated mold; a curing period; demolding; and, if necessary, mold cleaning and/or metal insertion, before the cycle starts again. For maximum efficiency, as many of the above operations as possible should be automatic.

There are three main types of injection machine: the ram type, the in-line reciprocating screw type, and the out-of-line non-reciprocating screw type (Figs. 9.3–9.5) [2 to 8].

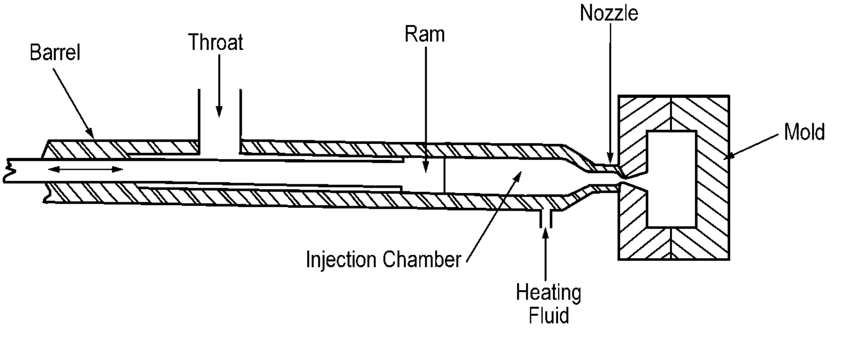

Fig. 9.3 Ram type injection molding machine (courtesy of J. Sommer and Rubber Division ACS [4])

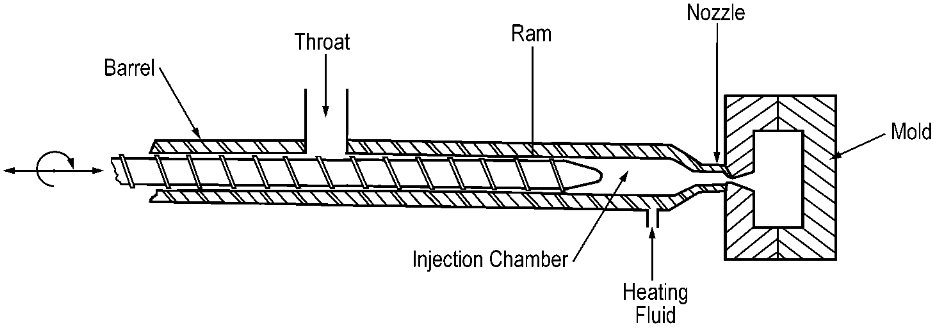

Fig. 9.4 Inline reciprocating screw machine for injection molding (courtesy of J. Sommer and Rubber Division ACS [4])

Simple ram machines cost less than screw machines and because the ram can be made to fit very tightly in the cylinder, they can develop very high injection pressures. However, as the mix receives heat only by thermal conduction from the barrel, high injection temperatures and thermal homogeneity are difficult to achieve, and they are not widely used.

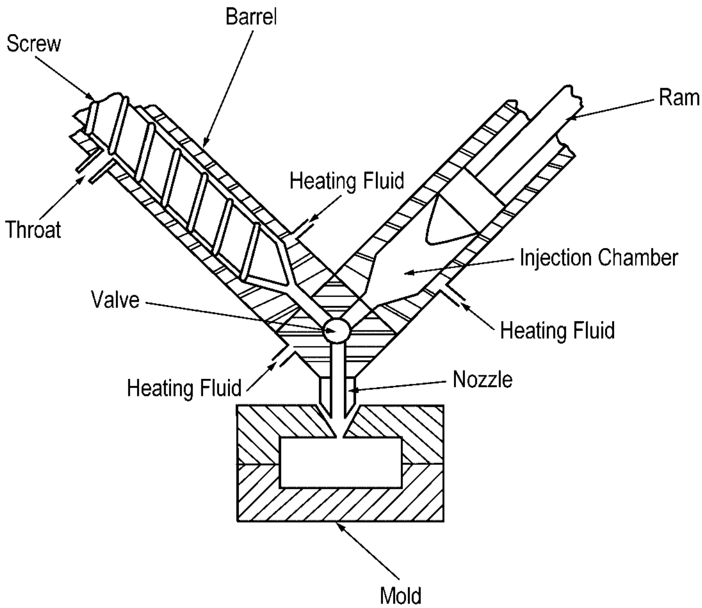

Fig. 9.5 Injection molding machine with separate ram and screw (courtesy of J. Sommer and Rubber Division ACS [4])

The screw in the in-line reciprocating screw type acts both as an extruder and a ram. In this type of machine, the mix is heated and plasticized as it progresses along a retractable screw. When the necessary shot volume has accumulated in front of the screw it is injected by a forward ramming action of the screw. With this system, a more uniformly controlled feeding of the material can be achieved, together with more rapid heating of the stock from mechanical shearing, additional distributive mixing from the rotational screw action, a greater degree of thermal homogeneity, and a temperature 20 to 30 °C higher than the jacket temperature. However, during the injection stage, when the screw is acting as a ram, there is inevitably some leakage back past the flights and this limits the achievable injection pressure.

The out-of-line non-reciprocating screw machines have separate screw and injection chambers and combine the advantages of the above two types. The screw plasticizes the compound and delivers it through a non-return valve into a separate injection chamber. Machines of this type can generate injection pressures of up to 200 Mpa and can efficiently mold high viscosity mixes and effectively fill large volume molds.

In the standard injection process described above, the compound is injected into a closed mold; there are two variations on this:

- *Injection-compression molding*: The mold is partially opened and a vacuum applied to the cavity area which is sealed by a compressible silicone gasket. A measured amount of rubber is injected into the partially opened mold. The mold is then closed and the excess rubber is forced outward to flow off channels. This process is used for articles such as precision O-rings, where runner marks are unacceptable.
- *Injection-transfer molding*: The rubber is injected into a transfer chamber and then forced from the transfer chamber into the mold. This combination process uses the plasticization and heat generation advantages of the injection unit with the controlled flash pad and cavity layout advantages of the transfer press.

All of the above systems have been in use for many years. The equipment manufacturers are constantly improving the design, operation, and control of their machines, but in general, available equipment is based on the systems described above. The equipment manufacturers' concentration has been on data acquisition and process control systems to enable the processors to implement on-line statistical process control. This has been in response to the end-users demands, especially from the automobile industry, for defect-free products.

Another major pressure on suppliers to the automotive industry is cost. This, in turn, is reflected onto equipment manufacturers to provide cheaper, more efficient machines to allow the processors to make parts more cheaply, but with no loss in quality.

9.3.1 Injection Molding Equipment

In specifying an injection molding system it is necessary to decide on the type of injection machine, the size of the machine in terms of shot capacity, platen size, pressure, the number of mold cavities per platen, and the layout and size of runners and gates.

There are a number of manufacturers of injection molding equipment, and details of design, operation, and control are obtainable from them. Merely an overview of important aspects of equipment design will be given here; from delivery to the injection nozzle, passage through the nozzle, runners and gates to the mold, ejection of parts, and deflashing.

9.3.1.1 Delivery Systems

The three main types of injection molding machines were described in Section 9.3. They differ mainly in the way in which they heat, plasticize, and deliver the mix, using a simple ram, reciprocating screw, or separate screw and ram. Screw extruders provide better temperature control and homogeneity and are now generally preferred to the simpler systems.

Simple Ram Machines

Whelan's summation [2] of the advantages and disadvantages of these cannot be improved upon and therefore it is quoted directly.

> "These cost less than other types and deliver mix efficiently to the mold as a result of the ram fitting very tightly in its cylinder. One disadvantage is that, depending on the ratio of the shot volume to the barrel volume there may be three, four or five shots in the barrel, all of which need to be pressed forward to deliver one shot. This causes an undesirable pressure drop and heat generation in the nozzle region of the barrel where it cannot be used to advantage.
>
> Another disadvantage is that the mix is heated slowly by the thermal convection or conduction from the barrel of the machine. It cannot become hotter than the barrel until it is forced through the nozzle into the mold. For products having thin section, these machines may be adequate."

One modification is the insertion of an unheated torpedo in front of the nozzle to conduct heat away from the nozzle region. The separation necessary between torpedo and chamber walls depends on the viscosity of the mix.

Reciprocating Screw Machines

Most of the early screw machines were of the reciprocating type but it is now generally accepted that the use of the pre-plasticizing screw as the injection ram is only possible for low shot volumes (< 500 ccs) or very soft compounds [8]. The advantage of screw machines in feeding material efficiently plasticized and thermally homogeneous, can only be realized if there is constant intake of feed compound into the feed port. In other words, it is important to ensure that the feedstock is not severed when the screw, acting as a ram, moves forward to inject the shot into the mold. This can be achieved by having a positive drive arranged so that the feed strip hangs freely over the barrel opening [9]. Another method is to machine a short tangential tunnel undercut at the front of the base of the feed throat where the material feeds into the barrel bore. This acts as a reservoir, or buffer, and smoothes out variations in the feed flow. It eliminates choking or balling up of the material in the feed throat.

Screw Machines with Separate Injection Chambers and Rams

These are the preferred basic design for rubber injection molding machines because they combine the advantages of both screw and ram machine [2]. In the standard "V" configuration the plasticated compound is fed through a check valve into an accumulation chamber. One disadvantage of this is that the first rubber fed through the check valve is actually the last rubber to be injected. This can lead to adhesion and build-up of rubber on the face of the injection piston, which can cure, break off, and cause rejects and molding problems. Two modifications have been developed to circumvent this. In the "first-in-first-out" system, the screw and ram, although separate, are in line. Initially, the injection ram is in the forward position and the injection chamber is empty. As compound enters through the ram, it is forced backwards by the incoming material until a limit switch controlling shot volume is activated. Injection then takes place through a special ball-type torpedo, which completes the plastication and thermal homogenization. As the material does not reach the final injection temperature until it reaches the nozzle, temperatures earlier in the system can be relatively low (~70 °C). Such inline systems have gained in popularity in recent years [5].

Shuttle Press and Multi-Station Rotary Press

One disadvantage of the single-station machines is that the injection system is idle during the curing and demolding stages. Shuttle presses are designed for applications where the time to inject and cure is approximately the same as the time required to unload, clean, and service the mold. It is especially useful for the production of items containing inserts of tall moldings and of moldings with a long stripping time. The press is equipped with two sliding bottom platens, which are individually heated. After the press has opened, both bottom heating platens and molds shuttle, positioning the mold that was inside the press into the unloading station while simultaneously positioning the other mold inside the press.

The main advantage to this format is that unloading takes place on one mold while injection and curing takes place on another mold. Therefore, the time needed for stripping and loading inserts remains entirely outside the cycle time.

A logical extension of two-station shuttle presses is a multi-station rotary press. Several equipment manufacturers produce such systems, which have one injection unit that feeds a number of molds, carried on a rotating carousel. The economic, and practical, number of mold stations depends on capital costs of machine and molds, required production rate, and curing and stripping times. Such machines may have automatic ejection of parts and runner system, cleaning and spraying of the molds, and automatic loading of metal inserts.

9.3.1.2 Nozzles, Runners, and Gates

Nozzles

The rubber is injected into the mold through the nozzle and, obviously, with multi-station systems, its shape and outside dimensions have to be such that it mates positively with each mold. As the inside nozzle diameter is increased, the pressure drop, injection time, and temperature rise, decrease. Nozzle diameters are chosen to give a temperature rise of ~25 °C and an injection time of 5 to 10 s. This balance is adjusted, if necessary, to avoid scorch during mold filling. Nozzle diameters may range from 3 mm for a shot volume of 500 cm^3, to 10 mm for a 4,000 cm^3 shot volume. Nozzles usually have a reverse taper of 4 to 5 degrees and as short a land as possible. The nozzle bushing on the mold also has reverse taper and an inlet bore the same or slightly smaller than the nozzle.

Runners

These are the channels provided to convey the rubber from the injection point, the sprue, to the mold cavities; in cross section, they are usually trapezoidal, half-round, or round. They should be as short and direct as possible, and streamlined to reduce pressure loss [8]. The thickness of the molding at the gating point governs the cross-section size of the runner. For multi-cavity molds, the lengths of runner channel between the sprue and each cavity should be the same so that all cavities are filled at the same rate and have the same effective pressure. If the product has to meet close tolerances, this requirement becomes essential. Where the flow branches there should always be a blind wall at 90°, this gives balanced flow as the leading edge of the flowing rubber hits the wall and divides equally.

If the runner system is extensive, venting the runners is advisable, to help reduce the volume of air and gases which have to be removed via the cavity vents and flashlines.

A reduction in scrap can be achieved by using a “cold” runner system. This depends on having a temperature-controlled platen containing the runners, which are constantly full of rubber at a temperature below that at which it will cure. From here, it is injected into the rest of the mold, from which the cold channel platen is effectively insulated. Obviously sufficient heat has to be generated in the hot channel run to raise the rubber temperature to the required level for curing.

Gates

These are restrictive passageways from the runner to cavity which are sized to allow easy flow of the rubber into the cavity and at the same time raise its temperature to the final desired level. Generally they are full-round, fanned, with a bore one-half of that of the feed runner and as short as possible. The final sizing of gates is usually done by carrying out a practical molding test.

The gate position is often more important than the size or type of gate. It should be positioned so that it feeds the thickest section of the molding, preferably in the non-stressed area of the molding. If weld lines are likely to be a problem, the gate position is critical.

9.3.1.3 Molds

Obviously, the major design consideration with a mold is the shape and size of the required molding. However, within this restriction, there are a number of points that have to be considered in determining the optimum mold design for a particular product. Turk [3] lists general mold design requirements, which are summarized here.

- Molds should be rigid enough to avoid deflection under pressure, which can cause flashing.
- Guide dowels and bushes used in lining up the mold halves should mate easily and lock rigidly. They should also be sized to allow for thermal expansion.
- The working faces of the mold, particularly on the split line or closure faces, should be kept as clear as possible of screw fixing holes and joints.
- The use of good quality toughened steels is advisable, particularly for the areas that come into contact with rubber, to reduce wear.
- All surfaces coming into contact with the rubber should be polished and the cavities and core pins should be plated. This ensures good surface finish on the molded product.
- Shrinkage allowances must be made in the cavities and on the core pins. These depend on the type of rubber compound and such processing variables as mold surface temperatures, injection pressures, and cure times. Allowances should be made in the mold

manufacture so that the final sizing of the cavities and core pins can, if necessary, be carried out after initial testing and proving.

- In the design of the molds, the transfer of the mold into and out of the machine has to be considered. Suitable tappings, holes, etc. should be provided for the attachment of lifting devices.
- Shallow grooves from the cavities to atmosphere on the split line of the mold and on the opposite side to the gate or feed points should be provided to allow escape of air and volatiles.
- Trim or tear off grooves should be provided around the cavities to give clean moldings and minimize extra after-trimming operations. The rubber is allowed to flow out through very narrow lands between the cavities and the trim grooves, the thickness of the rubber across the land being so thin that on removal of the moldings it is possible to tear off the excess rubber anchored to the moldings and formed by the groove cavities. To minimize flash, it is essential to achieve a good bite between the split line faces of the mold when clamping force is applied. This can be achieved by providing land faces around the feed runner, gate, and cavity areas.

9.3.1.4 Automatic Ejection

To take full advantage of the short cure cycles obtained with injection molding, an automatic ejection system is required [2,8].

Thin sections can be stripped from the mold by a compressed air jet. Simply shaped and flat parts can be removed by a rotating brush. Delicate parts can be removed by a robot pulling device, which places each part on a turntable, rather than ejecting it into a tote box. Many rubber moldings, however, do not lend themselves to automatic ejection, but assistance in removal can be provided by mechanical or hydraulic mechanisms, which retain the molding in the most suitable part of the mold for easy stripping. Ejection is better suited to thick moldings with good hot tear strength and those with bonded metal inserts. When ejector pins are used to push directly on the rubber, a mushroom or miter type of pin is recommended in preference to a straight pin, which may be inhibited in its action by rubber stretching.

9.3.1.5 Deflashing

The ideal mold design would produce either no flash or would make flash removal simple, as pointed out above. However, some parts, especially multi-cavity molds, will need deflashing. There are a number of techniques for deflashing. The most efficient involves chilling to –150 °C and then tumbling or shot blasting. The latter will handle complex parts, even items with inaccessible internal flash.

9.3.2 The Injection Molding Process

During injection molding, rubber compounds are subjected to more severe processing conditions than during compression or transfer molding. Temperatures, pressures, and shear stresses are higher, though cure times are shorter. Control over process variables can be more precise. The cycle time can be minimized by independently controlling barrel temperature, screw speed, mold temperature, cure time, and injection pressure. Compounds with widely differing flow and cure characteristics can be molded into a variety of complex shapes. The skill lies in the optimization of the process; this depends on close interaction and understanding between rubber compounder, mold designer, and processor.

The highest productivity is achieved when the compound is injected at a temperature close to the curing temperature, into a mold at a slightly higher temperature, because these conditions minimize both injection and cure time. Scorch safety of the compound is the limiting factor in the process, and the effect of machine variables on compound temperature needs to be understood if high injection temperatures and short injection times are to be achieved without scorch. Equally, it allows adjustments for batch-to-batch variations in viscosity, cure rate and scorch safety to be made, if necessary [2].

Thus, to a large extent, controlling the injection molding process reduces to a question of homogeneity of temperature and heat history of the compound at each stage in the process [2]. The temperature of the mix in the injection chamber, prior to injection, is determined by the temperatures of the extruder and injection chamber, by the screw speed, screw design, and by the applied back pressure. The injection, or mold filling, time and temperature depend on the temperature of the mix, as determined by the above factors, the injection pressure, the dimensions of nozzle, runners and gates, and the viscosity response of the compound. The cure time depends on the mold temperature and the temperature of the compound as it enters the mold. A full analysis of the process is given by Whelans [2] for an out-of-line reciprocating machine.

9.3.2.1 Injection Temperature

Cold feed extruder designs have been optimized to enable control of the amount of frictional heat generated, and to maximize the overall heat-transfer rate by constantly exposing fresh rubber surfaces to both barrel and screw. Proper flow also ensures thermal homogeneity of the entire volume of compound in the injection chamber, whose temperature is kept as high as possible without scorching.

9.3.2.2 Screw Speed

Screw speed and design can both significantly affect heat generation in the extruder. In a given machine, screw design is fixed, and thus screw speed is the primary control factor. Plasticization time also depends on screw speed, and a high screw speed can be used to minimize heat history by having the screw rotate only for the time required to fill the injection chamber.

9.3.2.3 Back Pressure

Back pressure is controlled by the pressure against which the screw must work whilst filling the injection chamber. Elevated back pressure raises the temperature of the mix and is only normally needed for low viscosity compounds that might not otherwise generate sufficient shear heat in their passage through the extruder.

9.3.2.4 Injection Pressure

The work done by the ram in injecting the compound through the nozzle and runners is dissipated as heat, and this can boost the material temperature by over 40 °C above that in the injection chamber. Thus as high an injection pressure is used as possible, consistent with freedom from scorch.

9.3.2.5 Summary

In summary, for safe, that is scorch free, injection molding the barrel and injection chamber temperatures, screw speed and back pressure are raised until the mix in the injection chamber is at the maximum safe temperature for the time it must remain there waiting to be injected. A nozzle diameter is then chosen that will permit a 5 to 10 s injection time. Injection pressures and speeds as high as possible are then used consistent with freedom from scorch in nozzle, runners, gates, and mold together with minimum mold filling times. Finally, mold temperatures can be raised to achieve minimum cure times. Thus it is clear, as stated earlier, that scorch safety of the compound is the limiting factor in injection molding. Compounds generally need to be scorch safe to 130 °C.

9.3.3 Monitoring and Modeling the Injection Molding Process

In injection molding, the two most critical parameters are flow at the high shear rates that occur, and scorch time. Most reported work has concentrated on these and ignored other less significant factors.

The approach taken by many operators of injection molding machines is to determine the effect of machine controls on mix temperature at each stage, and to determine how to achieve high injection temperatures and short injection times without scorching or underfilling. Equally, this approach allows adjustments for batch-to-batch variations in viscosity, scorch time, and cure rate. This technique forms the basis of most trouble-shooting charts published by equipment manufacturers.

At the other extreme, in terms of sophistication of approach, is to measure various properties of the compound that are relevant to flow, temperature rise, and curing of the material at various stages in the process. For example, one study assessed the

- Behavior during heating in the screw section by use of a Defometer
- The cure time using a Brabender Plasticorder
- The change of viscosity with time at different temperatures and the resistance to scorch at low shear using a Mooney viscometer
- The behavior during injection using a capillary viscometer
- The duration of induction period and the rate of cure using a Monsanto Rheometer

Such a complete evaluation would be time consuming and uneconomical for a molding shop to undertake for each compound, machine, and mold and the authors found that for most purposes the Defometer measurements were sufficient.

Another approach is to generate an “operating window” for the injection molding process, using a capillary rheometer. This defines those combinations of inject time and inject temperature at a given mold temperature, which should produce completely filled unscorched parts [7].

There have been a number of attempts to analyze and model the injection molding process. To be able to design an efficient injection-molding system, a model must be able to predict the flow rate of the material, the pressure drop over the mold network, the temperature of the material, and the forces that develop in the mold network [10]. Theoretical models for the filling stage to the injection molding cycle, which enable prediction of the above variables, have been developed.

The aim is to develop a mathematical model of mold filling that can predict the temperature distribution of the rubber compound as it fills the mold. This temperature distribution, together with the rheometer data, could then be used to predict the onset of cross-linking and help set up optimized injection molding conditions.

9.3.4 Control of the Injection Molding Process

Equipment manufacturers offer microprocessor control systems and software packages with their injection molding machines. These can be very simple, such as an individual control on a press to monitor and control cure time/cure temperature/

mold pressure. At the other extreme are systems integrating the monitoring and control of several machines, providing data for SPC and plant information systems, such as maintenance planning, optimal machine use, recording data, etc.

There are a number of cure simulation and control systems available from companies that are not equipment manufacturers. One of the first was the FillCalc system from RAPRA Technologies, which, unfortunately is no longer being marketed. Others are Smart Trac from Signature Control Systems, the Vacam System from Vacan Ltd, and Sigmasoft from Sigma Engineering.

Rubber processors are demanding still more automation of the injection molding process to improve consistency and reduce labor costs. Once again, the thrust is for lower costs and higher quality.

9.3.5 Compounds for Injection Molding

Quality control for injection molding compounds has to be tighter than for those that are compression molded because the injection-molding process itself can be more precisely controlled and is therefore more sensitive to variations in compound properties. Compounds must have sufficient processing safety (scorch safety) to flow through the nozzle, runners, and gates without scorching, but still cure rapidly in the mold. Thus, the balance of viscoelastic and curing characteristics of the compounds are extremely important.

Designing rubber compounds for injection molding has often been a trial and error process because the processor usually does not have data on the behavior of such compounds at the temperatures, pressures, and shear rates involved in injection molding. In fact, most rubber compounds that will compression mold can be satisfactorily injection molded provided that they flow well enough and are not too scorch sensitive, and that the machine controls are properly adjusted. However, for maximum productivity, the compound has to be injected rapidly into the mold at near vulcanization temperature. It is in this area of optimization that laboratory tests, properly interpreted, can be of value in delineating an operating window of time, temperature, and pressure, within which a particular material will flow well and cure effectively without danger of scorching.

The three major areas in which data on a compound are required are rheological behavior, rate of vulcanization, and heat flow into and through the compound.

9.3.6 Problems in Injection Molding of Rubber [1 to 5]

In addition to the operating problems discussed earlier, there are a number of problems that do not become apparent until the mold is opened and it and the product are examined. Some of these are briefly described below.

Shrinkage and Part Dimensions

On cooling, both the mold cavity and the molded part contract, usually by a differential amount because the metal and rubber have different coefficients of thermal contraction. Shrinkage is usually defined as the difference between the dimensions of the mold cavity and those of a molded part, when both are measured at room temperature. It might be more exact to refer to the difference between the hot mold and the cold part but the above definition is easier to use in practice.

The amount of shrinkage has to be allowed for in mold design, but it is itself variable, being affected by batch-to-batch variance in the compound, cure time, temperature and pressure, and so there must be adequate dimensional tolerance allowed in the specifications for the part.

Adhesion

Adhesion in injection molding has two aspects: Adhesion to the mold surface, which is not wanted, and adhesion (bonding) to a metal or plastic insert in the part, which is wanted. Mold release agents are used to prevent the one, and adhesion promoters to ensure the other.

Release agents, often silicone based, are sprayed onto the mold surfaces between shots. With complex molds this can be time consuming, and it is difficult to ensure thin, even coating on all surfaces. There is also a problem of pollution from the spray carrier. One improvement on this is to deposit a layer of diamond-like carbon on the surfaces by a plasma vapor deposition system. This leaves a semi-permanent easy release surface, which does not wear readily.

Rubber-to-metal bonding agents have been used in the industry for many years, and there are many types available. Most of these depend on a two-coat system. The first coat, or primer, applied to the clean metal surface is usually halogenated polymer with heat-reactive resin, either dispersed or dissolved in organic solvents. The metal bond is the result of van der Waals forces and is described by standard adhesion theory. Second layers, or cover cements, depend on the base polymer being used. They are usually chlorinated, brominated, or chlorosulfonated polymers, with appropriate cross-linking systems, which form cross-links with the rubber part and with the primer layer. Concern about environmental pollution due to the solvents used in the traditional systems and, in the USA, government regulations on volatile organic compounds (VOCs) and chlorine containing solvents, has led to the development of water-based adhesive systems, which are replacing solvent ones.

Backrinding

This is the term applied to the torn or gouged look that occurs at the mold parting line of compression molded parts, and at the gates of transfer and injection molds. It is caused by thermal expansion of the rubber after cross-linking, which can force the cross-linked rubber into the space at the parting line or gate, causing it to rupture. The smaller the surface area/mass ratio of the part, the worse it is (i. e., a sphere is the most severe case). The best way to minimize backrinding is to minimize the shot weight commensurate with filling the cavity, of course. Increasing scorch time can also help because it ensures that the mold is filled before curing begins, as the injection temperature can be raised.

Mold Fouling

The build-up of material in a mold, especially in corners, is a major problem. The more severe it is, the fewer the number of cycles before the surface or sharp edges of the part are affected and the mold has to be taken out of service and cleaned. The cause is usually deposition of chemicals and perhaps their subsequent oxidation or degradation. These agents may originate in the rubber, in fillers, curatives, waxes, etc. or from release agents. Thus, there are a wide variety of deposits whose severity varies from compound to compound and also depends on injection rate and mold temperature. One of the major concerns in compounding for injection molding is to minimize mold fouling. Costs of downtime and mold cleaning can be considerable.

Mold cleaning is often done by blasting with some abrasive particulate material such as glass beads, plastic, or metal beads. One effective, clean, but expensive and noisy process is blasts with solid carbon dioxide. Other techniques use liquids such as detergent solutions or hydrocarbons, often with ultrasonics. When the deposit is volatile at higher than curing temperatures, heating in a salt bath, fluidized bed, oven, or by induction can be used.

Orange Peeling

This is usually caused by the initial layer of rubber in contact with the heated mold surface having cross-linked before succeeding layers have filled the mold. The cure is usually to increase the scorch time of the compound.

Porosity

This is due to undercure and the presence of volatiles, especially water, in the compound. Higher injection and mold temperature or longer mold closed time should resolve this.

Blisters

Air entrapped in the rubber is the usual cause. This can be eliminated by a higher back pressure, slower injection rate, or effective venting of the mold.

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