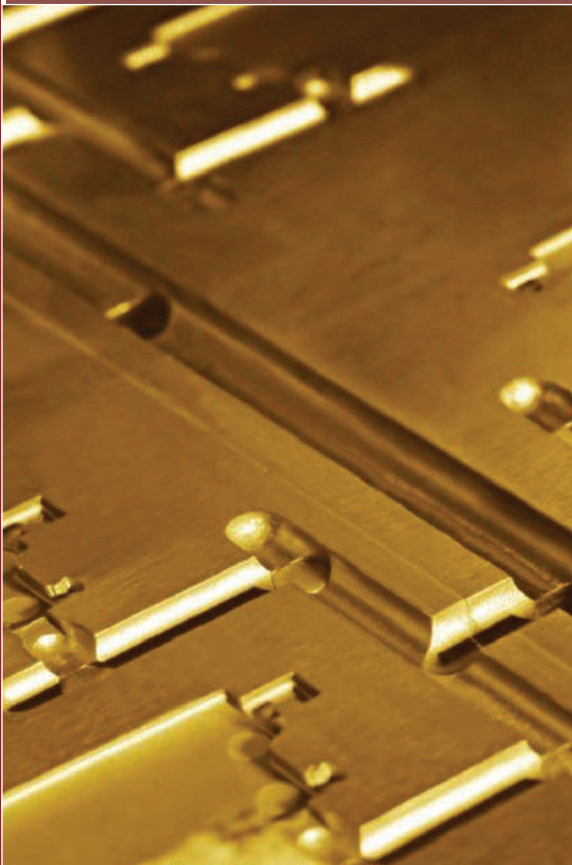


Practical Guide to Rubber Injection Moulding

John A. Lindsay



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<http://www.polymer-books.com>

First Published in 2012 by

Smithers Rapra Technology Ltd

Shawbury, Shrewsbury, Shropshire, SY4 4NR, UK

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ISBN: 978-1-84735-707-6 (softback)
978-1-84735-708-3 (ebook)

Typeset by Integra Software Services Pvt. Ltd.

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Preface

This work is for people and companies who wish to succeed in satisfying their customers in quality and price. It contains knowledge that has been gained over four decades and has required experimentation and lateral thinking to turn those companies who initially believed that rubber and its manufacture was a ‘black art’ into world leaders in the production of rubber and rubber-bonded components, based on a strong and robust technology.

The phrase ‘to be the best’ is now an oft-quoted saying in industry. It is a worthwhile end and it can be achieved by providing a culture within which designers, mould makers, chemists, technologists and production personnel cooperate and listen to one another. It is vital to understand why it is necessary to work in a particular way to achieve the best product. Learning is a two-way process. Watching a process worker and understanding the particular ways in which they work can provide managers with valuable undocumented information and an insight into how processes can be improved.

This book is of value to all areas of a company, from those who purchase raw materials to those working in design, technology and production. It will provide a guide for automotive component buyers and should also be useful to a CEO or board member who is new to the industry.

Practical Guide to Rubber Injection Moulding

1 Market Leader: Introduction

1.1 Perfection of the Process

For those who seek to control and perfect a process it is necessary that the unique features of that process be fully understood and that the peripheral factors are known and also controlled. The purpose of this work is to highlight to the reader the wide range of processes that are encompassed in understanding the complete process of rubber injection moulding so that the end product can be optimised with respect to the desired component properties and ensure that product quality is maximised with the achievement of zero rejection rates.

The effect on quality of the processes involved will depend, to a certain extent, upon the type and end use of the end product. The driving force for high quality in the industry has been, and still is, the automotive industry with a customer driven requirement to provide vehicles that will be trouble free and retain their design characteristics throughout their working lives. For some manufacturers the life span of the vehicle may be more than 20 years and this will be reflected in the component specification and the quality standards that the customer expects. Suppliers know that their company reputation hangs on the fact that their customers have no cause for complaint.

1.2 Historical Background

To understand how quality standards within the industry have changed over the last 60 years it is worth knowing some of the history. Following the Second World War, the Japanese began large scale manufacture of motor vehicles. Initially the product was of poor quality and customers were unhappy with the wide range of faults and the rapid deterioration of the chassis and body due to corrosion. In the USA high volume car production also suffered from a range of similar problems. Deming [1] had studied product variation within his own electronics industry and following earlier work by a mathematician developed formulae that could link complex process variations with product characteristics using a technique now known as regression analysis. Although Deming tried to interest his home industries with his ideas of how this technique could be used to improve quality, it was the Japanese who welcomed his methods;

undertaking detailed study of the process and application of the results to change their methods of working and control. This resulted in a dramatic improvement in product quality with subsequent capture of a much larger share of the world markets in many industries.

1.2.1 Practical Considerations

Regression analysis involves a great number of calculations to be made accurately and in the 1950s computers were not widely available. This meant that a set of regression calculations could take several months to complete; the process was, therefore, not seen as viable in a market where labour was relatively expensive (compared to the situation in Japan where labour was of lower relative cost). It was not until computers became more widely available in Europe and the USA that regression techniques began to gain acceptance. Even then, there was suspicion of the technique by many engineers who believed in the method taught in schools of experimentation by changing one variable at a time. In fact this method works well if all of the variables are linear and show very little or no interaction between one another. In the rubber industry this is rarely the case and for each process involved in the production, the number of variables becomes considerable.

Why should this be a problem? In many industrial (and experimental) processes there is an optimum set of operating conditions under which the product is ideally made. In the rubber industry many process have been found to operate in conditions that are far from ideal, where relatively small changes in the state of one or more variables substantially affects the nature of the product. Over the years the manufacturers of rubber injection moulding machines have improved the accuracy by which they can control the machine settings. If the settings have not been optimised then the process can be unstable.

Today, the process of optimisation can be achieved using software packages to design a set of experiments that will allow all of the perceived variables to be examined in a way that will show possible interactions and find the 'plateau' or setting at which there is the least variation in component properties within designed machine setting variations (see **Table 1.1**). The results can be displayed as charts (**Figure 1.1**) that make it easier for technicians less skilled in mathematics to employ.

Should the reader wish to obtain an optimisation program then it should encompass the following minimum options:

- Sufficient number of variables (≥ 64).
- Screening experiments to establish active variables.

- Experimental plans for five levels of each variable.
- Flexible graphic displays of the computed interactive results.

Table 1.1 Example of experimental component optimisation			
Design reference D8/3			
Variable		Level (−1)	Level (+1)
Sulfur level (pphr)		0.8 (low)	1.2 (Medium)
Cure temperature (°C)		163	175
Cure time (s)		220	250
Experiment design			
Run number	Sulfur level (pphr)	Cure temperature (°C)	Cure time (s)
1	0.8	165	220
2	1.2	165	220
3	0.8	175	220
4	1.2	175	220
5	0.8	165	250
6	1.2	165	250
7	0.8	175	250
8	1.2	175	250

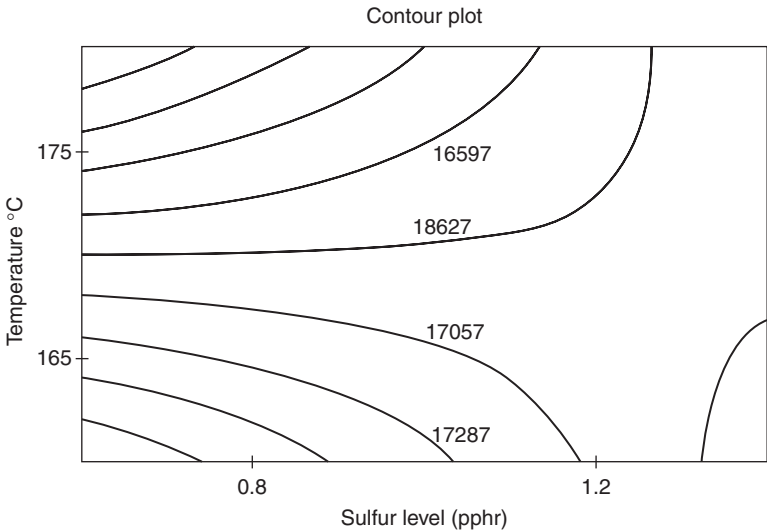


Figure 1.1 Example of an optimisation plot

With this process it is possible to screen a very large number of variables to discover which have the greatest effect and then fine tune those with the greatest influence on the final properties with a more detailed experiment. This technique has been used with great effect to optimise compound properties and cure conditions in the development of all new components over a period of more than 10 years in the author's last place of employment. Coupled with similar techniques in mould design it has allowed the company to maintain a reputation for excellence with customers in the quality automotive field.

Similarly, ingredient sources can be examined to establish compounds that are more cost effective. Operational information gained by the use of these techniques over more than two decades is discussed in the ensuing chapters. It deals with many aspects of the production of vulcanised elastomeric engineering automotive components and includes bonding of elastomers to various substrates.

Reference

1. W.E. Deming, *Out of the Crisis: Quality, Productivity and Competitive Position*, The MIT Press, Cambridge, MA, USA, 1988.

2 Setting the Parameters: Initial Stages

2.1 The Quality System

The customer rightly expects that the product ordered will be delivered in accordance to schedule, at the agreed price and to the agreed specification. To achieve this, and to strive to exceed expectations, it is essential that an effective quality system be in place. The requirements of ISO 9001 [1] form a sound basis upon which to operate. Intelligent interpretation of the component specification and dedication to its maintenance provide the injection moulding company with that rock on which a successful business may be built. Automotive companies have individually adapted ISO 9001 to produce their own standards. More recently a new standard, ISO/TS 16949 [2], has been introduced in 'an effort to provide harmonised quality systems within the automotive supply chain, resulting in a focused and consistent approach' that could be adopted by all automotive manufacturers.

When a company receives an enquiry about manufacturing a rubber component, the first stage of the quotation process is an assessment of the process and materials needed to satisfy the customer. The information supplied by the customer should contain all the key elements that will enable decisions to be made. It is necessary to examine four issues.

2.2 Shape

The shape to be manufactured needs to be systematically examined to determine that a mould design is possible, and that the required size tolerances are practical. Customers unfamiliar with rubber may need help with the design to ensure that a commercial product is possible. Try to avoid deep undercuts, which make the component difficult to demould, and tolerances that are greater than 0.30 mm. Tighter tolerances are possible, but they demand much in terms of mould design and operation.

2.3 Polymer Compatibility

The polymer specified must be compatible with the factory processes. Whist it is possible to process almost any combination of polymers, some, such as the silicones

and fluoroelastomers are very sensitive to contamination from other polymers and special care must be taken to ensure that the processing equipment does not introduce contamination.

The requirement to use butyl rubber in a factory more used to the processing of natural rubber (NR) and styrene-butadiene rubber could pose similar problems. These are best avoided by the selection of bromobutyl or chlorobutyl rubber recipes that show tolerance to minor contamination from general-purpose rubber. Acrylate-based rubbers also place limits on contamination and add problems of smell. Use of these polymers may make the manufacturer unpopular with both the work force and the immediate neighbours of the factory.

2.4 Production Volume

The volume of product to be manufactured is of prime importance and relates to existing and future machine capacity. Modern injection moulding machines are expensive and high volumes are required to support the necessary capital outlay.

2.5 Start of Production

The time scale for production to start affects forward planning of the existing production program. Machine availability or the need to purchase new equipment must be established. Time must be allowed for mould design and manufacture, and for the development of the compound and product to meet all the engineering specifications.

The prospective supplier must be satisfied that these questions have been addressed and the answers suitably recorded. The wise purchaser will determine that the supplier has the necessary systems in place through careful audit of the company.

2.6 Component Design

2.6.1 The Enquiry Stage

Vehicle manufacturers often provide prospective component suppliers with a drawing of the item required. In some cases a preferred supplier will be given an overall space and asked to produce a component that will fulfil the customer's requirements for installed performance and service life. Together with the drawing are details of

the expected component performance specification and any customer rubber test requirements. In addition to this there may be details about any included bonded inserts of metal, plastic or other materials. In this enquiry stage it is necessary that all of these details are considered as a whole. This requires consideration of expected component quantities, a practical moulding tool design, the availability of a suitable injection moulding machine or its sourcing and manufacturing lead time of it and the mould(s), any inserts, the rubber compound, the expected cure time and the overall cycle time. In the event of an order the successful supplier will then be ready to proceed.

2.6.2 Finalising the Component Shape

Although the component drawing shows the suggested profiles of the moulded part, the customer will expect the supplier to ensure that the shape is optimised for its best resistance to fatigue and that the shape does not make the moulding process difficult or impossible. Of these the former used to be a matter of experience and trial. Today the component designer will use finite element analysis with three-dimensional design software to reduce highly stressed zones by significant changes to flex radii and section shapes. Shape can be optimised on the computer using designed experiments similar to that shown in Table 1.1.

2.6.3 Compound Design

The design of the compound for the majority of automotive components depends on a number of factors relating to the product environment.

2.6.3.1 Oils and Solvents

The part may need to be in contact with service fluids such as mineral and vegetable based oils. The selection of the correct polymer depends on the exact nature of the fluid and the service temperature. For mineral oils a polychloroprene or acrylonitrile - butadiene copolymer based compound may be appropriate but small variations in lubricant constituents make it worthwhile to measure the changes that can occur at operating temperatures to properties such as modulus and tear resistance. For solvents it may be more viable to use a physical sheath of an impervious material such as polytetrafluoroethylene. Swelling or shrinkage is strongly influenced by the nature of fillers and oils used to compound the rubber.

2.6.3.2 Gases

General purpose polymers such as NR and styrene-butadiene polymers do not withstand the action of oxygen, and ozone (especially close to electrical generators), which attack the polymer chains and create cracks that soon cause failure. These effects can be suitably avoided by addition of antioxidants and/or antiozonants, often with certain microcrystalline waxes.

2.6.3.3 Water

Prolonged immersion in water will swell many polymers, the effect varying greatly according to the actual polymer and the compounding ingredients added to it. The more highly polar the polymer the less will be the swelling effect of water. Rubber compounds that are to be used where there is continuous immersion in a fluid of any kind need to be carefully screened in the laboratory to measure the physical effects of the fluid over a suitable range of temperatures and over a lengthy period of time. Experience has shown that swelling is rarely linear and is best measured on a logarithmic time scale. Swelling or shrinkage is strongly influenced by the nature of the fillers and oils used to compound the rubber.

2.6.3.4 Temperature

Temperature either above or below ambient levels can have a significant effect on the life expectancy of the component. The effect will depend upon the polymer selected and the recipe used in the formulation. Many synthetic compounds have medium to high damping characteristics at 20 °C but as the temperature rises damping reduces so that at 120 °C there is much less difference between them. Unfortunately for the automotive designer components need to operate over a range of temperatures that may be as wide as -40 °C to +170 °C. In such cases the vehicle designer often opts to keep rubber components as remote from heat sources as possible or utilise heat shields. This may limit exposure to perhaps 140 °C, an upper limit for NR with suitable compounding.

2.6.4 Engineering Requirements

2.6.4.1 Resilience or Damping

In automotive design these terms describe the ability of the rubber component to isolate or absorb vibrational energy. The polymer of choice is NR for where low

damping/high resilience is the requirement. This may be successfully employed from ambient temperatures up to 140 °C although special attention to compounding is needed for temperatures above 70 °C. Low damping compounds often display greater resistance to compression set/creep.

Where high damping is required polymers such as ethylene-propylene-diene terpolymer, butyl, chlorobutyl, bromobutyl and acrylonitrile butadiene copolymer can be considered.

2.6.4.2 Fatigue Resistance

During their life cycle many rubber components are subjected to forces that produce relatively high deflections or strains within the rubber. The component designer will attempt to minimise these strains but for the best life expectancy the rubber compound must also be optimised for the application. This will be discussed in **Chapter 3**.

References

1. ISO 9001, *Quality Management Systems – Requirements*, 2009.
2. ISO/TS 16949, *Quality Management Systems – Particular Requirements for the Application of ISO 9001:2008 for Automotive Production and Relevant Service Part Organizations*, 2009.

3 The Rubber Compound

The basic requirement for the rubber compound is that it will meet the customer's requirements in terms of physical properties and service life. In reality it is necessary to look beyond these bounds. The manufacturer must consider a number of aspects before committing to produce any item.

The producer of rubber injection moulded components will either have access to in-plant rubber compounding facilities or will purchase compound from a trade supplier. In both cases the control of the process is vital. If the process is in-house, control is then a matter of company policy. If a trade compounder is used, there needs to be a close liaison between the supplier and the injection moulding company to establish quality principles.

3.1 Specification

It is essential to determine the relevance of the details supplied to specify the product. The customer expects the manufacturer to be the expert. It is essential that the manufacturing company is able to reconcile the stated specification with the proposed end use of the component. This must be the first step. It may be very costly to correct at a later stage. In some cases the drawing is unaccompanied by any detailed specification. In this instance the supplier needs to agree standards for the component with the customer.

3.2 Selection of Polymer

The class of polymer required for the product is of considerable importance. The choice may affect the materials used in the construction of the mould and the barrel and screw of the injection moulding machine. For example, it is necessary to use special alloys for continuous use with halogen-containing polymers, as the halogen by-products are highly corrosive [1, 2]. The choice of polymer may also determine the feasibility and commercial success of the project, depending upon the type of injection moulding machine available for the impending production.

3.3 Hardness or Modulus

The hardness of a compound will affect its suitability for injection moulding. Very hard formulations generally give rise to compounds of high viscosity, and poor flow properties. This can be a problem with the narrow runners and gates often used with injection moulding equipment. To deal with such jobs successfully it may be necessary to make significant modifications to the formulation in order to reduce the compound viscosity to a level at which it will fill the mould without scorching. This may be done in combination with suitable mould modifications. However, compound modifications may adversely affect the service capability of the component. It is necessary to test the effect of all such changes thoroughly.

3.4 Compound Design and Cost

For any given application it may be possible to show reductions in the cost of a compound per kilo, by the use of cheaper replacement ingredients, or the addition of extending fillers and oils. Some manufacturers who want to offer the customer a lower price per kilo may encourage this. The approach is perhaps justified where the component has little to do in service but to fill a hole.

However, it must be remembered that higher specific gravity compounds produce heavier components. The higher weight gained by extending the compound with fillers imposes hidden costs in terms of added inventory items, and of increased energy use for transport and waste disposal. In applications that depend upon the elastic characteristics of the compound, the use of extenders will usually serve to shorten service life. There may also be additional problems during processing such as a greater incidence of mould fouling, damage during de-moulding operations and higher fume levels (see **Chapter 7**).

3.5 Factors that Adversely Affect Processing

Before discussing moulds and machines, it is necessary to understand the factors that influence the quality of an injection moulding. These factors affect the ability of the manufacturer to produce mouldings without defects and at minimum cost to the customer. The first to be considered is scorch.

3.5.1 Scorch

All rubber processing will generate heat within the rubber and the effect of this heat needs to be measured, understood, and controlled. Scorch is the industry term used

to describe the premature crosslinking or vulcanisation of rubber due to the influence of heat. The process is continuous and cumulative, the rate of scorching varying positively with increasing temperature.

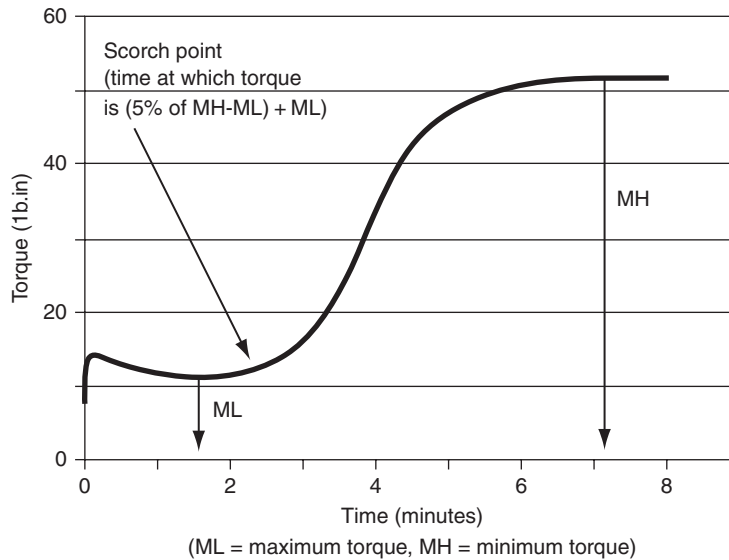


Figure 3.1 Rheometer cure chart

The behaviour and appearance of the rubber compound at different points in the injection moulding process are diagnostic of where scorch is occurring (See **Table 3.1**).

Table 3.1 Effects of scorch	
Site of Scorch	Effect
Injection barrel	Long injection times. Rubber may appear as if filled with crumb.
Injection nozzle	May block injection process.
Runners and gates	Crumb may appear in the moulding. The runners are distorted.
Moulding	Mild scorch causes rippling of the mould walls.

For control purposes it is convenient to apply a percentage scale to the amount of crosslinking, or scorch, suffered by the rubber. For the injection process it is appropriate to define 5% crosslinking prior to complete filling of the injection mould, as 100% scorch, and the time required for this to occur is the scorch time. If the amount of crosslinking has reached 5% before the rubber has completely filled the mould cavity, then there is a probability that the resultant mouldings will contain defects (See **Figure 3.1**). Poor control of scorch is the main cause of moulding defects.

Unfortunately factors that will affect scorch occur at all stages of the process and are influenced by compound design, mixing, rubber storage conditions, the injection machine, mould design and operating conditions.

3.5.2 Effect of Temperature

The temperature at which rubber is processed affects the level of scorch, the cure profile through the component, the overall cure time and the degree of reversion of the crosslinked rubber. Rubber compounds are poor conductors of heat. This fact has to be borne in mind when experimenting with the curing conditions to find the optimum temperature for pre-plasticising, injection and moulding.

Because temperature is critical in processing, it is important to exercise very tight control. Mould cavities should be within ± 2 °C of the experimentally determined optimum working temperature. For general rubber mouldings, where the rubber modulus has little bearing on service requirements, a wider tolerance may be acceptable, albeit at the expense of profit! Components with high technical specifications need carefully controlled conditions.

The temperature and time at which it is cured influence the modulus of rubber. As the temperature in the mould cavity is adjusted, significant changes occur to the nature of the crosslinks formed. The aim is to achieve 90-100% crosslinking of the rubber to attain the highest modulus. However, if the rubber is heated for too long or at too high a temperature, reversion commences and the degree of crosslinking is reduced. The magnitude of these changes is influenced by the type of rubber formulation in use and is less with recipes containing low sulfur (<1 pphr) levels compared to those with greater amounts. The belief that curing for longer, at lower temperatures, or a shorter time at higher temperatures will give equivalent results is wrong. If such changes are made to the cure conditions it is necessary to evaluate the resulting components for deflection characteristics (stiffness), dynamic properties and fatigue life, since all of these can be affected.

A secondary effect of short, high temperature cures is to narrow the time window within which the rubber can produce components that maintain the design parameters. This can be satisfactory for fully automated systems where the operator has no influence on the cycle time. For semi-automatic operation it is necessary to exercise great care that the mould opening times are consistent. Due to the poor rate of heat transfer from moulded components, it may also be wise to consider how they are stacked or placed whilst they cool, since this will add to the heat history of the rubber. This is especially true for components bonded to inserts of high heat capacity.

Where consistency of a product is of the utmost importance, the rubber compound should be selected to contain as low a sulfur level as is possible, consistent with

the service life of the product. High sulfur levels can give excellent fatigue life but low robustness with respect to static and dynamic stiffness. Such problems may be mitigated by the use of cavity temperatures in the range of 140-150 °C (see **Figure 3.2**).

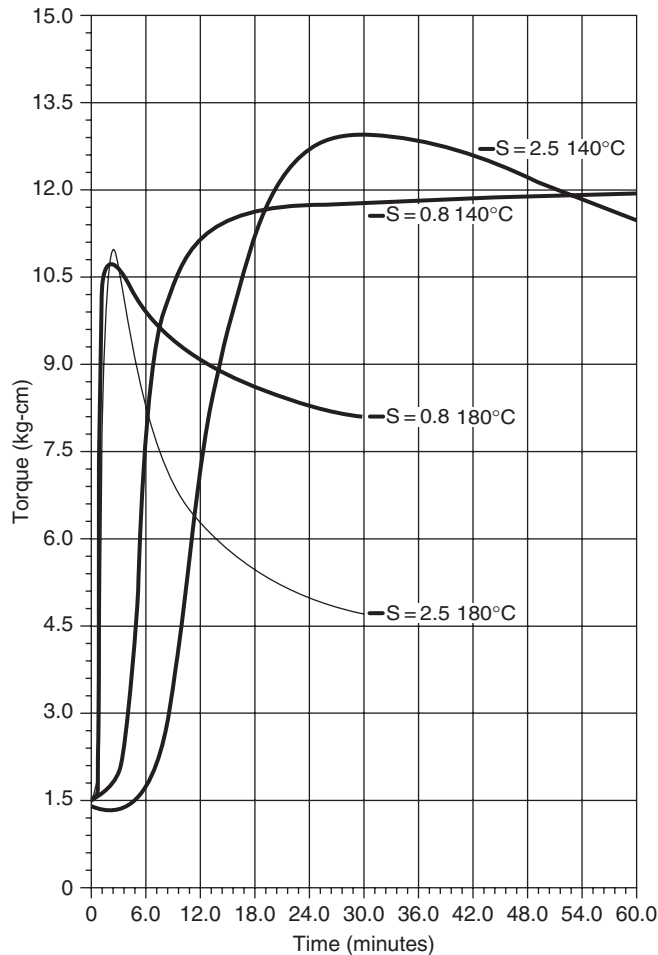


Figure 3.2 Effect of cure temperature and sulfur level (pphr) on modulus

Use of factorial experiment design (FED) is especially beneficial for the determination of optimum moulding conditions.

3.5.3 Compound Viscosity

Compound viscosity has a profound effect on processes in rubber manufacturing systems. This is certainly true for rubber injection moulding, where plasticised material must pass through narrow pathways, under pressure, to reach the mould.

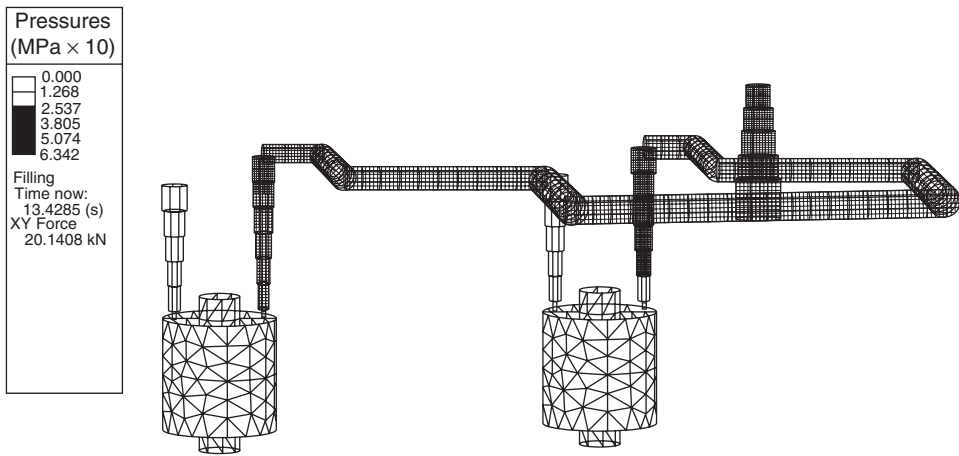


Figure 3.3 Illustration of the pressure gradient in a mould with “high” viscosity compound A

Figure 3.3 shows the calculated pressure gradients during filling of a mould using a compound (A) of relatively high viscosity. When the same mould is filled using a rubber (B) compounded to give a lower viscosity, the maximum pressure reached during filling is reduced, allowing all the cavities to fill evenly.

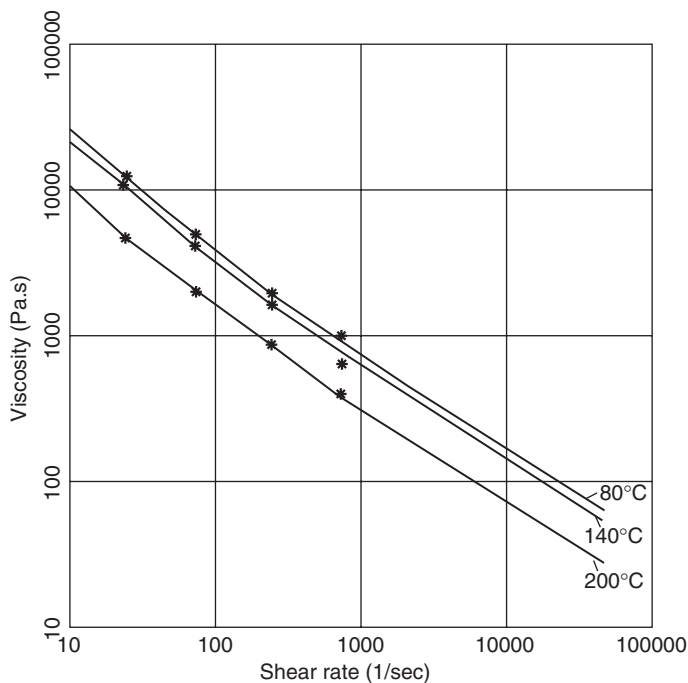


Figure 3.4 Viscosity/shear for compound A

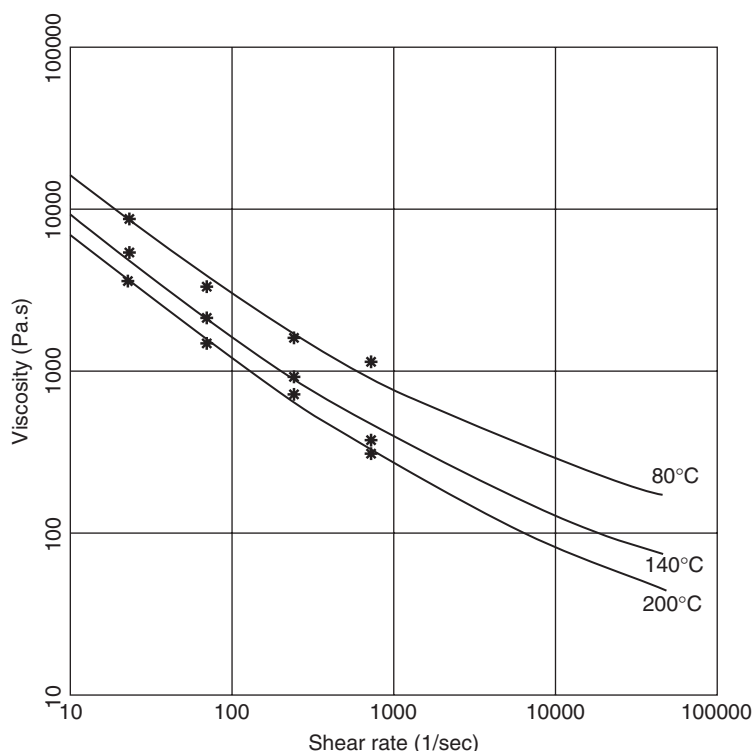


Figure 3.5 Viscosity/shear for compound B

Figures 3.4 and 3.5 demonstrate the change in shear rate with viscosity at different temperatures of compounds A and B. The shear rate in injection moulding varies through the system according to the design of the machine and mould, and may range from 100 to >10,000 sec^{-1} . The addition of small amounts of a process aid and variation of the mixing procedure for the two compounds have brought about these differences in properties. This demonstrates that it is possible to compound and process rubber compounds to suit moulds through diligent selection of polymers, fillers and process aids.

In general it is best to aim for a compound viscosity that is sufficiently low and yet remains compatible with the specifications of the component.

For natural rubber (NR) it is preferable to use a controlled viscosity grade, rather than attempt to reduce a variable, non-controlled grade to a lower viscosity by pre-mastication. Not only is the product less variable, it is also less expensive in terms of labour and machine utilisation. Synthetic rubbers offer a wide availability of viscosity grades and are designed to allow for ease of processing. Whatever the polymer, it is important to ensure that it has been kept dry and free from the gelling effects of sunlight.

3.5.4 Moisture

Moisture can generate serious in-process problems, especially where bonding to prepared inserts is part of the process. As little as 0.5% moisture will cause porosity or blistering of the component, and affect the acceleration system by hydrolysing the accelerators. The net effect is to reduce the number of possible crosslinks and, hence, the overall stiffness and modulus of the component. It is therefore important to choose materials that are of inherently low moisture content and that are essentially non-hygroscopic. Where moisture has become an inherent problem it is sometimes possible to counter the effect with the addition of a predispersed desiccant at 3 to 5 parts per hundred of rubber. This should not be seen as a routine addition and every effort needs to be made to tackle the source of the moisture.

3.5.5 Gel

Rubber consists of two phases, 'sol' and 'gel'. The gel phase is insoluble in solvents such as hydrocarbons. The gel has a complex structure involving the carboxyl groups of the rubber molecules and non-rubber contaminants such as proteins. Rubber molecules with a high branching density tend to form gels. The gel content of rubber varies. Gel formation affects viscosity and will influence rubber flow adversely. It is often difficult to recognise unless the rubber viscosity is measured over a range of shear rates. Simple measurement of compound Mooney viscosity is not usually enough. Some polymers produce gel structures under the influence of external factors such as sunlight and compounded rubbers can increase in viscosity with age. This effect is more evident with polymers containing halogens that can slowly crosslink at ambient temperatures.

3.6 Mixing

Whatever the compound, it is vital that it is produced in such a way that there can be no question as to its composition or processing characteristics. The rubber is often the least understood part of the injection moulding process and will be the first thing to be questioned if injection moulding process problems of any nature are encountered. The best formulations are usually the most simple. The average rubber formulation need contain no more than 11 or 12 ingredients.

3.6.1 Weighing of Ingredients

Ingredients should be weighed accurately, i.e., equal to, or better than one part in 500. This simple precaution will reduce mixing rejects significantly and minimise

stock level discrepancy! Ingredients can be automatically weighed and transferred to low-melt bags, made of polyvinyl acetate blended with low molecular weight polyethylene, which are then heat sealed to maintain weight integrity. Such bags will disperse completely within the rubber and have no measurable effect on the compound properties.

3.6.2 Mixing Cycles

To control compound cure rate and viscosity, the rubber batches should be mixed to a temperature profile with close control over machine start and dump temperatures [3]. The choice of mixing machines is usually governed by the machinery that is already being used by the factory (see Table 3.2). The addition of the ingredients is best governed by a pre-determined cycle derived from experimental optimisation.

Table 3.2 Types of mixing equipment			
Type	Usage	Typical cycle time (minutes)	Comments
Open two-roll mill	For low volume production	20 to 40 depending on formulation	Low melt bags should not be included in the mix.
‘Banbury’ style internal mixer	High volume production	2 to 4	Mix temperatures are generally high and rotor wear affects shear rate.
‘Intermix’ style internal mixer	High volume production	3 to 4	Continuous contact with mixing chamber walls limits heat build up.
‘Herschel’ type high-speed powder mixer	Mostly used for plastic mixing and for thermoplastic rubbers	1 to 2	Requires ‘powdered’ polymer. Mixes can be directly fed to a suitably modified injection machine. Difficult to control the level of parting agent used on polymers.

For a more detailed description of mixing equipment see Wood [3].

3.7 Compounding Ingredients

Before making decisions on the ingredients to be used it is worthwhile taking into consideration facts about the materials available that may not be readily discovered by persons new to the industry. These factors are suggestions designed to:

- Eliminate variation of ingredient quality,
- Ensure an even distribution and dosage,
- Maintain a constant viscosity and cure rate, and
- Ensure no variation in the rubber modulus.

It has been found, from unfortunate experience, that cutting costs through the use of a short-term buying advantage will result in unexpected results and components failing to meet zero defect targets.

3.7.1 Polymers

3.7.1.1 Natural Rubber

NR is variable according to the source, manner of its collection from the tree and the subsequent coagulation, drying and baling. Some producers supply controlled viscosity (CV) grades that have much less variation than the standard grades. This does come at an added cost but this is more than offset by the reduction in power used for mixing and the consistency of the injection processes and the moulded product. The formulations to be found in the appendices use Standard Malaysian rubber (SMR) of controlled viscosity (CV) at 60 Mooney units. The dirt content of SMR CV60 is stated at 0.02% maximum and this is an important feature where fatigue, thermal ageing and life expectancy of the product is concerned. Dirt content is one measure of the amount of sand that can be embedded in some sources of the NR. It can be assessed by passing a sample bale through a mixing machine and then through an extruder equipped with a 44 µm mesh inside the die head. Examination of the mesh from some of the lower price grades, often favoured by the logistics team, shows a resemblance to rough sandpaper! This sort of contamination hastens the wear of all the processing equipment and leads to blocked injection ports and products that will have a short fatigue life. The metallic content (tin, iron and so on) associated with the grit has a severe effect on the resistance of the rubber to thermal ageing. To minimise variation some manufacturers of critical components limit the choice of NR supply to particular estates.

3.7.1.2 Synthetic Polymers

For synthetic polymers, dirt content is seldom an issue although there are occasions when the odd piece of the polymerisation plant may appear as an inclusion in a polymer bale. The source of all polymers, and other ingredients, should be assessed on the basis by which the process is controlled and monitored. Incoming batches should be accompanied with test certificates that are routinely checked for conformity to an agreed specification. The latter may be in accord to the supplier's general specification or a special agreement to meet process demands within the user's factory.

Polymer bales should always be stored away from sunlight, as this is a cause of gel formation in the uncompounded polymer.

Polychloroprene (PC) rubbers should not be stored for more than three months and when compounded are best used within three weeks. This is due to a slow crosslinking action that produces unacceptable levels of scorch in PC as well as in chlorobutyl and bromobutyl compounds.

3.7.1.3 Peptisers

The use of a peptiser is recommended to minimise mix cycles and keep final plasticity low. This applies even when using SMR CV60. The type and amount are best determined by FED. Of all the types available the zinc salt of pentachlorothiophenol has been found to give the most consistent results.

3.7.1.4 Zinc Oxide

Zinc oxide has been used in the industry for many years as an activator in cure systems. The standard grade used is one with a surface area of about 2 m²/g and is generally used at a dosage of about 5 pphr. The material is relatively expensive, fluctuating in price with the commodity market for zinc metal. Laboratory and works experiments (FED) were conducted using an active grade of the material with a surface area of 9 m²/g. Equivalent physical properties of the cured compounds were obtained using an optimised dosage of 1.7 pphr. It was found that the active grade disperses more quickly into the rubber and was less prone to 'cake' on to the surface of the mixing surface. Adoption of the active grade for all compounds was successful and resulted in a saving of cost and a reduction in the density of the product and a saving of warehousing space. Where high temperature resistance is required higher levels are used (5 pphr with active compared to 10 pphr for the standard grade).

3.7.1.5 Stearic Acid and Activation

Stearic acid is used with zinc oxide as part of the activation system. Lindley at MRPRA (now TARRC) working with others on reducing stress relaxation in rubber springs found that the stearic acid could be beneficially replaced with (ZEH). This chemical is much more soluble in NR and allows for the development of compounds that have low relaxation. Trials with this material proved successful and helped with development of engineering components for automotive customers. ZEH is a viscous liquid and it proved necessary to find a supplier who could reliably produce a drimix version at 75% activity. The material is relatively expensive as a universal replacement for stearic acid but it was found that long chain unsaturated hydrocarbon zinc soaps, readily available in lenticular form, are also effective in reducing stress relaxation effects as well as being effective as agents to reduce compound viscosity.

3.7.1.6 Fillers

Avoid where possible the use of fillers that generate high viscosity. All reinforcing fillers increase viscosity with the volume used, and increase the tendency towards shear-induced crystallisation. A disadvantage of using large amounts of non-reinforcing fillers is their tendency to reduce the hot-tear strength of the rubber, which can lead to problems during demoulding operations. For example, using large amounts of clay filler may leave fine flash on the mould surfaces and fragments of rubber in awkward corners of the mould. They also increase the density of the product.

Silica-filled systems will produce higher viscosity compounds when compared to the use of carbon black although this effect can be moderated through the use of silane coupling agents. The mixing process with silanes must be very well controlled to avoid wide fluctuations in processing and end component properties.

Carbon black filled rubbers have excellent wear and tear resistance. Select grades of carbon black that will provide the desired end-use properties with the minimum volume of filler. The filler volume has the greatest effect on viscosity and damping properties. In general, the finer black particle sizes lead to increased viscosity, and require longer mixing times. The use of finer grades may permit the use of higher injection temperatures. Carbon black affects the flow of rubber by forming physical and chemical links with other black particles, and with the polymer (carbon 'gel'). Avoid grades that have long storage times at the supplier's premises especially if stored in bulk bags, rather than metal silos. Carbon black is hygroscopic and capable of absorbing a great deal of moisture. When first produced the moisture content is low, but the manufacturers place a generally agreed maximum limit of 1% to allow for storage uptake. Rubber made from filler with a high level of moisture would be

unsuitable for most injection moulding processes (see **Section 3.5.4**). The author has used grade N330 very successfully as a 60% masterbatch in NR (SMR CV60), blending with additional rubber to achieve the desired filler content. The use of masterbatch gives excellent control over the filler content and eliminates material losses (see **Section 3.7.12**).

3.7.1.7 Process Aids

Process aids are often used to reduce compound viscosity. There are many proprietary chemicals and mixtures available, but their selection should be made with great care and use made of them only after carefully controlled experiments. The quantities recommended by the suppliers of these materials are not necessarily going to give the desired result in every formulation, and may not work at all in the required way! Peptisers provide a useful way of significantly reducing compound viscosity and aid the process of incorporation of the other ingredients.

3.7.1.8 Process Oils

The use of process oils and waxes to reduce viscosity may alter other properties of the compound. For example, lowering the amount of viscosity with oils can reduce the injection temperature, unless the injection nozzle diameter is narrowed accordingly. Waxes, naphthenic and aromatic oils, depending on type and amount, often contribute to an increase in mould fouling. Oils will increase damping and reduce hot tear strength. If they need to be used, to reduce cost for example, in non-critical applications, they should be injected under the mixing ram in doses sufficiently small to prevent slippage during mixing (known as ‘going to sleep’). If carbon black is to be added the oil can be added at a time when most of the black has become incorporated. If carbon black masterbatch is used it can be added with the remaining ingredients before addition of the curative.

3.7.1.9 Accelerators

Many accelerators are available as dust free dispersions, preferably in an ethylene-propylene diene terpolymer/polyvinyl acetate blend. These have the dual advantage of zero loss as dust when the pellets are crushed as they are mixed, and rapid incorporation into the compound due to their low melting point. These materials are of particularly value when the melting point of the dispersed chemical is relatively high and all show generally rapid dispersion rates, giving high batch-to-batch consistency.

3.7.1.10 Sulfur

This material has a melting point of approximately 113 °C and needs to be very well dispersed into the compound in a short cycle time without any loss. In practice it has been found that the cost of buying sulfur in pre-dispersed pelleted form is justified due to the beneficial results of batch consistency with respect to cure rate and modulus of the cure rubber.

3.7.1.11 Anti-ozonants

N-(1,3-dimethylbutyl)-*n*'-phenyl-*p*-phenylenediamine is a very powerful agent against the effects of flex cracking and ozone. Experience has shown that it is best used in conjunction with a microcrystalline wax having a melting range of 50 °C to 54 °C. Although a number of suppliers offer these materials it should be noted that there are minor variations, in the form of impurities that can affect performance.

3.7.1.12 Masterbatching of Compounds

Masterbatching of compounds provides a major saving of inventory cost and allows greater control over the conversion process. All of the masterbatched compounds shown in the appendices are designed to be dumped at a maximum temperature of 115 °C, depending on filler content. This feature results in compounds of unvarying cure rate and gives a firm basis for a zero reject rate throughout the injection moulding and bonding processes (provided that the other guidelines are followed).

3.7.2 Characterisation of Materials

It is a wise precaution to ensure that all material can be checked against a known internal company standard. These may be a simple test such as melting point but where blends of materials are purchased such a test is not useful. A good, almost universal, test method, that yields a quantitative result, is produced using differential thermal analysis. With careful selection of the temperature profile it is often possible to measure moisture content, detect phase changes and the ratio of various components.

3.7.3 Example Compound Formulations

Examples of working formulations can be seen in the Appendices.

3.8 Stock Presentation

The uncured rubber, or stock, must fulfil several requirements to allow its successful presentation at the injection press. Most injection units are fed with strip rubber. The strip has to be of regular section and appropriate size. It should not be distorted or kinked and it should show little tendency to stick to itself. These are all features that are controlled by the choice of dump mill take-off machinery and selection of anti-tack agents. The latter should add sufficient coating to the surface of the rubber to leave the strip dry and dustless. Commercially available soap solutions have been found to be almost universally suitable for this purpose.

Zinc stearate based anti-tack systems should not be used for nitrile rubber as they may cause poor melding of converging fronts in the moulding. Extreme care should be exercised in the selection of any anti-tack materials for all of the synthetic rubbers other than styrene-butadiene rubber. For synthetic polymers there is less need for high levels of anti-tack.

The use of pelleted material has to be approached with caution. To prevent the pellets solidifying into an unusable mass during transit and storage it is often necessary to use significant levels of dusting powder during the pelleting operation. Levels of 10 to 15% *w/w* have been measured with NR-based compounds and this amount will have a significant affect on the final rubber properties. Health and safety issues may arise from the dust generated during the transfer of material to the injection moulding machine.

There are two further constraints to be considered. These relate to the hardness or viscosity of the strip and to the stack height of the strip in its container. Uncured rubber is thermoplastic and will flow under the pressure of its own weight. This flow behaviour can lead to strip adhesion problems on the lower levels of the stack. The effect is time and temperature related, and must be controlled through the size of container and accurate scheduling to avoid prolonged storage of the prepared rubber. Failure to control properly the stock presentation will provide the press operator with extra work separating strips, and cause component rejects.

To reduce the time taken for strip production it is possible to arrange that two or more stripping knives are used, depending on the width of the dump mill.

Rubber stock must not be placed upon wooden pallets or on the floor, no matter how clean it is thought to be. Such practice will cause mouldings to contain pieces of everything to be found in a press shop and will certainly lead to unseen and unsuspected damage to the injection machine.

3.9 Storage of Uncured Rubber

Prolonged storage of stripped rubber before the moulding operation usually results in some flow and storage stiffening that will render the material difficult to feed to the injection machine. Exposure to a temperature below 10 °C will cause NR stocks to crystallise, rendering them unsuitable for use. The condition is reversible, although it will be necessary to warm the material to above 15 °C to effect the recovery. Storage at temperatures in excess of 23 °C will accentuate sticking problems and increase scorch. The ideal storage temperature is therefore in the range of 15–23 °C.

For most factories the best solution to storage problems is an effective planning system that allows the rubber to be produced just in advance of the time it is required for moulding!

References

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4 The Injection Machine

4.1 The Parts to Understand

Although it is possible to produce rubber mouldings on virtually any machine with little knowledge of the equipment or technology, there are features of the equipment that need to be understood in terms of their function and interaction with the whole process. It is through this understanding that process analysis and prevention of failure is achieved, often referred to as failure mode effect and analysis (FMEA). It is a vital component in the selection of the injection moulding machine, and in the quality control of the process. It is not the intention here to catalogue all of the many machine configurations that are currently offered by machinery manufacturers, but to highlight the basic components that need to be understood and considered prior to the selection of the 'perfect' machine for the job.

The injection moulding machine consists of five basic parts:

- The pre-plasticising and injection unit
- Mould clamping mechanism and ancillaries
- Hydraulic power pack
- Heating/cooling system
- Control system

4.2 The Pre-plasticising and Injection Unit

Pre-plasticising is the term given to the conversion of uncured rubber to a hot, soft (relative), and homogeneous, plastic mass. This is achieved by the rotation of a metal screw within a heater-jacketed barrel. The relationship between the temperature of the pre-plasticised rubber and that of the jacketed barrel is dynamic, as the hot rubber exchanges frictional heat to the barrel walls or, depending on the heater setting, gains more heat. Rubber strip is fed to the throat, or inlet to the screw where it is sheared

between the wall of the barrel and the screw flights. The plasticised rubber is forced by the screw past its tip and into the heat-jacketed injection barrel, where it is held pending the injection stroke. The plasticising action is controlled by:

- The design of the screw (length, depth of flight, screw pitch)
- The speed of rotation of the screw
- The gap between the screw and the containing wall
- The screw and barrel temperatures
- The ease with which the rubber can move from the screw into the injection barrel. Pressure applied against this movement of the rubber is known as 'back-pressure'. Adjustment of the back pressure has a significant effect on the frictional heat developed and hence scorch and viscosity.
- The rubber compound(s) to be used.

The relationship between these variables is complex and needs to be fully understood through use of factorial experiment design for each type of machine used in the factory. The unit must allow the rubber to be processed uniformly without scorch. There must be a smooth pathway for the rubber, free from 'dead zones' where there is little or no rubber flow. Rubber that collects in these zones will soon cure to form hard 'nibs' that will grow in size until they re-enter the material flow, impede the injection, and produce moulding faults. This problem exists in many existing machines where the first rubber to pass into the injection barrel is the last to be injected, and may be partially retained for many cycles. The design of the injection unit is therefore crucial to the operation of the machine.

To avoid much of the problem, some machine manufacturers have reverted to the inline reciprocating screw design first used, in the 1970s and now called 'first in, first out' units, or 'FIFO'. With this design, the screw is forced backwards by displacement with the rubber that it has plasticised. The plasticising barrel becomes the holding unit for the plasticised rubber. Injection is then achieved by hydraulically forcing the screw back into the barrel (see **Figure 4.1**).

The temperature of the screw cylinder, plunger, injection cylinder and nozzle need to be regulated. This is best achieved with jackets of oil circulating around each zone at precisely regulated temperatures. This same system must also be able to provide emergency cooling to prevent scorching of the rubber in the event of a prolonged delay in the moulding cycle. Some older machines are equipped with electric barrel

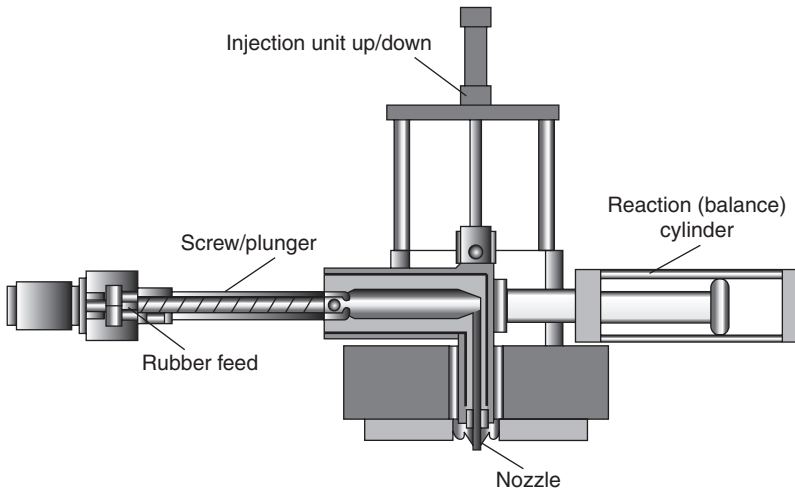


Figure 4.1 FIFO injection unit (courtesy of Klockner Desma)

heaters, which need to be regularly monitored. For these machines the barrel will need to be emptied of rubber at any pause in the process and may even require to be cleaned with purging rubber (see **Appendix 7** for examples of suitable purging compounds).

The way the rubber feeds into the screw has a significant influence on product quality. Designs that allow the rubber to be cut off in the feed zone (throat) by the screw flight cause extra work for the operator, and will give rise to an increase in screw speed as the ‘starved’ screw empties itself of rubber. This results in a rapid build-up of scorched material in the unit and, if it is not immediately detected and corrected, there will be insufficient rubber in the components (‘light parts’). A number of design features may be adopted to overcome rubber strip feed problems. Three solutions are regularly adopted, either alone or in combination:

- Motorised rollers to maintain positive contact between the rubber strip and the screw. Control measures ensure that the device is working only when there is a call for material feed.
- A localised increase of the distance between the screw and the barrel wall at the throat, allowing an initial contact between the screw-flight and the wide face of the strip.
- Teeth-like notches cut into the screw flights in the feed zone.

The type of rubber to be used may require that special metals are selected for the construction of both screw and barrel. Halogen containing polymers can generate extremely corrosive breakdown products and their proposed use must certainly be discussed with the machinery manufacturer.

Some compounds contain fillers such as silica and silicates that have a significantly abrasive effect on the screw and barrel. Special steels may be appropriate to minimise wear, and additionally, the amount of wear should be measured and recorded on a regular basis (at least annually). Changes in machine performance can then be avoided by planned replacement of eroded machine parts. If wear goes unchecked then the performance of the injection machine will change and affect product quality. The first sign of this could be an onset of moulding rejects.

The final part of the unit is the nozzle. This part of the machine has been given the least attention by machinery manufacturers but is very important to efficient operation of the unit. The design of the nozzle and the control mechanism of the injection unit mechanism, affect the quality of the compound as it leaves the injection unit and is the final point of departure for the rubber from the injection unit. It channels the rubber directly into the mould through a hemispherical mating face to the top of the sprue bush in the mould and then leads to the centre of the runner system. Most machine manufacturers design the nozzle with a parallel bore at its exit. For minimum pressure drop through the nozzle it is desirable that the nozzle is made with a smooth conical path to its end (**Figure 4.2**). This channels the pressure to where it is required - in the mould! The mould design should always include a matching nozzle that has an exit diameter at the point of contact to that of the sprue bush. Designers often make the mistake of under sizing the nozzle and sprue bush in the belief that they are saving the company money by minimising the volume of compound used for each shot. Under sizing will lead to a reduction in the pressure available in the cavity and an overall increase in the time needed to fill the cavity.



Figure 4.2 Section through an injection nozzle

4.3 The Press Unit

The press comprises a machine that will:

- Open the various sections of a mould,
- Allow the placement of inserts,
- Close the mould sections, and
- Close and securely clamp the mould sections together during the ensuing injection and curing cycle.

The selection of the press is directly related to the type of product and the size of mould to be used. The scale of everything fitted to the press is controlled by these factors. The choices to be made are as follows:

- Horizontal or vertical opening.
- Hydraulic or toggle closing, opening and clamping mechanism.
- Various 'ejector' systems to manipulate the mould.
- Mould loading devices for inserts.
- Component unloading tools.
- Access requirements for mould fitting and changing.
- Operator position and reach.
- Safety features.

These choices can only be made prior to purchase. They are of the utmost importance to ensure that the injection moulding machine will produce high quality products. The decision making process must also consider the effect each feature will have upon the cycle and the machine operator. The aim must be to ensure an operation that will be consistent and cause the minimum of stress to the operator.

Press manufacturers in Europe produce a wealth of different press configurations and will also produce presses to suit the needs of individual customers. However, it should be remembered that the press manufacturer is an expert in engineering but may not be an expert in all of the aspects of processing.

4.3.1 Horizontal or Vertical Opening?

Presses with horizontal openings have usually been designed for short cures and fast cycle times. They are useful for rubber products that do not require inserts. Although inserts may be positioned in the vertical open mould face, press operation movements will cause significant dislodgement, producing components without the required insert, 'light' parts, and mould damage.

Horizontal presses occupy greater floor space than their vertical counterparts but less headroom. The press shop layout and construction is therefore an important consideration. One great advantage of horizontal presses is the accessibility of the screw, barrel, and nozzle unit to the operator.

4.3.2 Hydraulic or Toggle Clamp?

Hydraulic mechanisms have proved the favoured means of press operation within the rubber industry for a number of reasons. Historically, before the advent of the injection process, rubber moulding was accomplished using compression or transfer techniques with hydraulically operated presses. These presses could be manufactured cheaply and run using water as the hydraulic fluid, with a simple accumulator system to develop the necessary pressure. The same water supply was used to raise the high steam pressure that was used to heat the platens. The operators required to set up these simple presses could be easily trained and needed no special engineering skills. The rubber industry was therefore conditioned to the use of hydraulic presses, well before the advent of injection moulding. In time the hydraulic systems were refined and changed to oil.

A toggle operated press is one where the opening and closure is effected by folding and straightening sets of hinged bars that connect the moving platen to the end frame of the machine. This type of mechanism can be made to move very fast, which will minimise the amount of time required to open and close the mould. The clamping force exerted comes from the elastic modulus of the steel tie bars that support and guide the moving platen and toggle mechanism, and join the fixed platen to the end frame of the machine. These bars are forced into tension as the toggle is straightened and locked into its fully extended position. The setting of these toggle mechanisms is critical if the correct clamping pressure is to be achieved. Over the years machine manufacturers have produced many variations in the toggle design to improve the ease of operation. Even allowing for such refinements, the purchaser of a toggle machine must examine the operation in detail and also consider the impact of wear on the closure mechanism.

In practice, many presses combine hydraulic and mechanical locking processes. High speed, low pressure, jack rams are used to effect a rapid movement to a point

just short of full closure. A mechanical lock is then swung into position between the moving platen and the main, high-pressure ram, which then applies the full clamping pressure. This system reduces the high pressure demands on the hydraulic system to a minimum [1].

4.4 Hydraulic Power

The modern press requires refined pressure control throughout the moulding cycle. The hydraulic system powers the jacking and clamping mechanisms and all the ancillary systems such as the screw and injector unit whilst, at the same time, powering the operation of the ejector bars. The design of the unit must be such that it can supply sufficient oil pressure to operate all the press functions that are likely to be required at the same time. Some systems are designed to deliver oil in a way that precludes concurrent operation. This results in significant waiting times in the moulding cycle whilst hydraulic pressure is built up.

4.4.1 Oil Cooling

The flow of oil through pumps, valves and pipes creates a great deal of heat. As the temperature of the oil rises there is a corresponding drop in viscosity. If the oil becomes too thin, damage can occur to the pumps and valves. As the viscosity decreases, the oil can escape past poorly made connections and will permeate rubber-bound sealing gaskets. It is therefore important that the cooling services to the press are properly maintained. Failure to look after this basic cooling need will lead to costly failure in the future. Cooling the oil will consume a great volume of mains water, and the cooling pipes become rapidly 'furred' or scaled if the water contains any calcium or magnesium salts. For presses in continuous operation it is necessary to provide a closed loop cooling system using a heat exchanger and de-ionised water. In winter the extracted heat can be used to help heat the factory.

4.4.2 Clean Oil

High-pressure hydraulic pumps contain components that are made to closely defined tolerances. For this reason it is very important that the oil that is used within the system is clean. Contamination of the oil, down to particles too small to be seen by the human eye, leads to erosive wear of the pump and a gradual loss of system pressure. It is well worth ensuring that oil maintenance is given a high priority and that sub-standard oils are not used.

4.5 Heating and Cooling

The temperature of the plasticising unit (comprising the screw, injection barrel and nozzle) is controlled by the use of jackets, through which a heating/cooling medium is circulated. The medium is either water or heat transfer oil. The choice between these two media is governed by the highest operating temperature of the unit. At temperatures below 95 °C water is satisfactory. Where operation is to be at or above 100 °C then oil is necessary. The purpose of the unit is to provide a consistently plasticised stock at uniform temperature, therefore, the temperature control unit must have the capacity to remove excess heat, and to provide a balance to heat lost after the plasticising action of the screw has stopped. The closer the temperature is kept to the set point, the better. An operating temperature fluctuation of greater than 3 °C should be regarded as less than satisfactory. On older presses the temperature control of the pre-plasticising unit is often separate from the main control unit. In such cases it may be prudent to apply regular, recorded checks to ensure that the temperature control is operating correctly.

The units are also designed to effect a rapid (or 'crash') cooling of the injection unit in the event of an un-programmed interruption in the operation of the cycle. The rapid cooling ensures that the rubber does not begin to cure in the injection unit before it can be safely removed or replaced with a purging compound.

Cold runner systems have a similar temperature control requirement to the plasticising and injection unit, since the cold runner acts as an extension to the nozzle, controlling the rubber temperature to preclude any build up of scorched material while it awaits injection into the mould.

4.5.1 Platen Heating

Press manufacturers have reacted to the need for improved temperature control of press platens. Electric heating elements are zoned with separate temperature controls applied to each zone. By this means it is possible to limit temperature gradients across the platen to ± 1 °C. The temperature gradients across the mould are less predictable and depend upon the mould geometry and construction, zone setting, and ambient conditions around the press. Temperature control of the platen depends on all of the elements within the platen being operational. If an element close to the controlling thermocouple becomes open circuit, the controlling sensor will call for additional power to the functioning heating elements to offset the temperature drop from the defunct element. This has the effect of creating hot spots, or temperature gradients in the platen and mould. Heating systems should therefore include self-diagnostic systems that will alert the user to any problems.

With the vertically mounted platens of horizontal presses there is an additional problem. Upon opening, strong thermal gradients are created vertically, producing a pronounced cooling effect at the lower part of the open mould faces. This can be counteracted by placing thermal barriers above the platens to prevent ingress of cold air, and by ensuring that the press is only open for a very short time. A sure sign that convectional cooling is occurring is the need to extend cure times to eliminate under-cure of components in the lower cavities of the mould.

4.5.2 Cavity Temperature

Close control of curing temperature can be accomplished by the use of individual heating and control units for each cavity. By this means it has been possible to obtain very consistent results from sample to sample and batch-to-batch. At the time of writing the author is not aware that this technique has been applied on a production basis.

Earlier it was stated that press manufacturers have made substantial improvements to the temperature control of platens. This work has to be extended to ensure that the moulds become integrated into the system. Some thermal control systems are available which allow such control, but cost is cited against their use to eliminate cavity-to-cavity variation. It is not logical to expect any system to maintain close temperature control over an area of half a square metre from one pair of thermocouples! Greater control will pay real dividends by allowing the technologist to optimise a cure time that is based on equal crosslink density rather than the cure time required for the coldest cavity.

4.6 Control Systems

Control systems have become an integral part of the injection moulding machine. The heart of the system is a processor unit (programmable logic controller) often called the PLC, which is pre-programmed with the basic operational commands that work the electro-mechanical part of the package. It is the PLC that provides the logic functions for auto- and semi-automatic operation, controlling the stop and start of pumps, adjusting pressures, reading micro-switch positions and all the other many functions of the machine. The user interface has a display screen and keypad to input the required operating parameters. Once satisfactory conditions are attained, the values of each setting can be stored as an integral computer file that can be recalled against a particular job number or description. It is essential that such stores are equipped with the means for data back-up, preferably automatically, for example through the company intranet.

As quality systems demand greater process integrity, press shop managers will take advantage of remotely programmed presses that are set up from a central server unit. This also monitors press operation, tracking operator efficiency and providing the operators with guidance to improve their performance. The effective press shop manager must be aware of the monitoring functions of the machines in his charge, and ensure that they are utilised fully to give viable operation in both quality and cost effectiveness.

Reference

1. J. Holzschuh, inventor; Battenfeld GmbH, assignee; US 5580585A, 1996.

5 Mould Design

The mould design is an essential part of product quality. With the correct mould design and an optimised rubber formulation, it is possible to produce products of world class quality. The choice of press makes that task either easier or more difficult, and has to be made on the individual requirements of the mould and the manufacturing environment.

5.1 Sizing of Moulds

The first stage in mould design is to determine the overall size; a task governed by the dimensions of the press platens to which it will be fitted. In an ideal world, the mould should be able to be sited on the platen within the effective heating area. This generally requires an outer margin of three to four centimetres. Modern press platens are usually equipped with a 'guard zone'. This allows the outermost parts of the mould to receive additional heat, which compensates for losses from the exposed outer surfaces.

The design of the moulding tool is determined from the shape of the components that will be produced. For this reason it is of prime importance that the designer of the components works closely with the tool designer and the moulding technologist. Co-operation at this level is vital to produce a tool design that will work well in production.

The number of cavities is determined by:

- The maximum shot volume of the injection press
- The component volume
- The maximum projected area of the component
- The clamping pressure
- The injection pressure
- The required production rate

Failure to recognise these constraints will result in collapse, or delay, of the project [1].

5.2 Runner System

Cavity layout will determine that of the runner system. For best operation, the cavities need to fill evenly and at the same time. Uneven filling often results in components that are 'light' and with runner systems that are heavily 'webbed' with thick flash, which is the result of high pressure build up before filling is complete. Each cavity must have a runner path length that is identical, or 'balanced'. Some cavity layouts have a runner system that will be inherently balanced, whilst others will need to be carefully designed to ensure balance. An example plan view of a balanced runner system is shown in Figure 5.1.

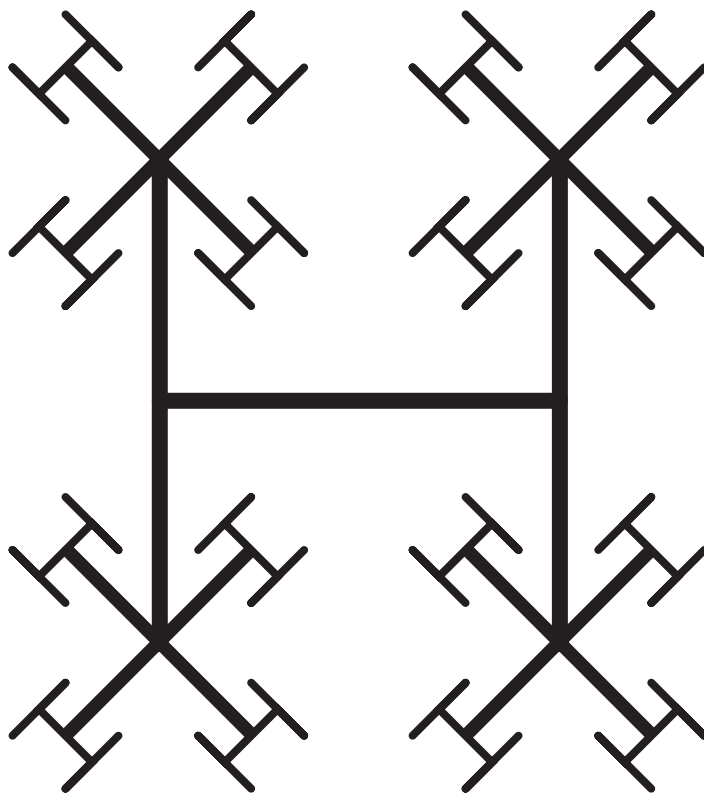


Figure 5.1 Example of a balanced runner system

A general, though not absolute, rule is: if the number of cavities (N) is such that

$$N=2^Y \quad (5.1)$$

where Y is an even number, then the runners to each cavity can be fully balanced without difficulty. Where Y is odd, then balancing becomes more difficult and the task is best achieved through the use of rubber flow modelling programs. A number of computer

packages have been designed for this purpose and their use is strongly recommended to ensure that a mould that will work first time in the press. The sizing of the runners can be rapidly achieved through the use of a factorial designed experiment that is run using the rubber flow modelling programme. The author has successfully used this method for many years using the Fillcalc IV programme [2] (see later), as do a number of mould makers. For this programme to run on modern computers it may be necessary to operate a dual boot system using an earlier version of the computer operating system.

An alternative solution may be to use a cold runner system that feeds each group of cavities directly. Such systems work well with components with cross sections of a few millimetres.

The way that the rubber flows through the runner system, into the cavity, has a profound influence on the properties of the moulded component. This subject will be discussed in greater depth when reviewing the moulding process. At this stage the reader should be aware that there are aspects of tool design that affect rubber flow, and that, once the mould has been produced, the effects will be costly to correct, both in terms of tooling changes and the loss of production and customer confidence.

Balancing of the runners is the easiest of the technological problems to solve. A designer also has to take into account the rate of flow of the rubber. The flow rate changes with every branch that occurs in each of the limbs of the runner system and this affects the pressure gradient that develops during the injection phase of the moulding cycle. The pressure gradient will also vary with the rate of injection. The faster that the rubber is injected, the greater will be the pressure gradient, and the less scorch as shown in **Figure 5.2**.

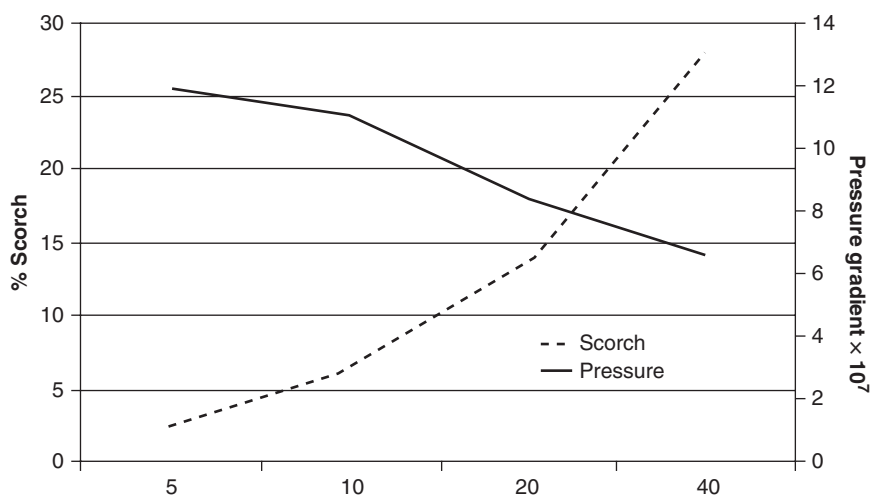


Figure 5.2 Effect of injection time on pressure gradient and scorch

The maximum pressure gradient that can be tolerated will depend on the maximum clamping force available to keep the mould in a fully closed position. The sizing of each of the limbs of the runner system is therefore critical to the operational running of the mould. Optimal sizes may need to exceed those normally used. The cross-sectional area of each part of the runner needs to be in proportion to the rubber volume that it needs to conduct and compensating for the additional resistance to flow imposed by longer paths. Use of undersized runners and gates leads to component faults such as 'light' parts and other problems ranging from minor 'weld' or flow fronts to faults that will seriously affect the component service life.

The cross-sectional shape of the runners is not critical provided that the cross-sectional area of the runner is not substantially greater than the equivalent round section. Trapezoidal or modified trapezoidal sections have a great deal to offer in terms of the control possible for the position of the runner when the mould opens, when they stay with the greatest surface area in contact with the mould. Flat section runners generate high-pressure differentials and engender the risk of scorch.

5.2.1 The Sprue Bush

The design of the sprue bush is important to the working of the mould. It is best made so that it can be readily changed or adjusted to suit different presses or in the case of damage. The sprue should be a smooth cone, increasing in diameter from the open until it meets with the runners. At this point it should blend into a round boss of sufficient diameter to readily accommodate each limb of the runner system. At the base of the boss it is useful to incorporate an undercut feature to ensure that the cured sprue will be withdrawn from the nozzle as the mould opens. Use of too small a nozzle is a common cause of 'light' components, due to pressure loss in the runners. In extreme cases high temperatures generated by small nozzles will result in scorch with attendant problems. A common complaint with this approach is that too much rubber is wasted in the runner system. It should be noted that rubber 'wasted' using these principles in the design of the runners will prevent costly rejects.

5.2.2 Injection Gates

The gates form the final restrictive pathway connecting the runners to the mould cavity. The gate design can be used to impart a heat increment to the rubber as it passes through, although this must be balanced by the need to allow the rubber to flow and fill the mould in a suitably short time. It should also be small enough and suitably placed, so that when the mould opens the rubber will break off neatly and easily. It should be sited so that it does not affect the function or appearance of the

component. The orientation of the cavities and the siting of the runners also affect the positioning, shape and size of the injection gates. The gate section is usually the same as that of the runner, but smaller. Flow modelling will determine whether the gate is too narrow, which causes scorch, or too wide which causes a low temperature of injection, and a longer cure time.

For components of irregular shape the flow path may have to divide and then re-join. It is at the meeting of two flow fronts that air traps and weld lines can be formed. If flow fronts are bound to meet, the gates should be positioned so that the fronts are pushed to the part of the component that is likely to be the least stressed in service. If possible a vacuum gate should be sited at the point where the fronts meet so that the initial weld front and associated gases can purge from the cavity into the vacuum runner (see **Section 5.4**).

For some moulds it is appropriate to site the gates at the cavity parting line. Two approaches may be used in these cases. The first is to employ wedge shaped ‘fan’ gates. These taper from the runner section to a slot shaped aperture that may be 0.2 to 0.5 mm in height and three to four times the runner diameter in length. The second way is to use a ‘subterranean’ gate that consists of a simple angled cylindrical hole that joins the runner to the cavity at a point several millimetres below the parting line. The junction between the gate and the runner needs to have a well-formed radius to ensure the rubber does not break at this point when the component is extracted from the cavity.

5.3 Air Removal

Moulders that experience air trapping problems will know how difficult it is to cure this problem when in production. It is a fault best avoided at the design stage.

The problem arises when the mould is filled so fast that the air within the mould does not have time to escape, or where converging rubber fronts meet. Trapped air causes light parts, and may cause localised oxidation of the rubber, seriously affecting component quality. Some component shapes will inherently produce air or gas traps. With a bonded system gases arise from the heated metals and the hot rubber produces vapours as it begins to crosslink. In such cases it is possible to reduce or eliminate the effect by using a vacuum system, with vacuum ports sited at, or as close as is possible to, the last point in the cavity to be filled, to remove air/gas from the mould before and during the injection phase. This method is a better solution than the traditional ‘bumping’ of the press, when the mould is opened minutely a number of times at, or shortly before, the end of injection. Bumping allows the relatively uncontrolled release of rubber from the cavity and can seriously reduce cavity pressure, leading to

components with significant micro-porosity. Computer modelling of the cavity can be used to predict where gas traps are likely to occur.

5.4 Modelling Software

Flow modelling software has been available for a number of years. With experience and knowledge of the technology of rubber processing, it is possible to study how rubber will flow and react in a two-dimensional representation of the mould. This allows the mould to be investigated, on the computer, for a range of conditions and with trial positions for gates. Used in conjunction with factorial experiments, it is thus possible to optimise the mould design and its operating conditions, before the mould is made! This approach really works and permits the manufacture of moulds that work the first time they are put in the press, saving wasted material, time and money. Several different flow modelling systems are currently available and should be used as a regular tool in the design and development stages of every new mould [2].

5.5 Ejector Systems

To ensure ease of operation, many moulds are designed with ejection systems that allow the components to be ejected automatically as the mould is opened. The precise design of the mechanism varies according to the shape of the cavities and the way they are arranged within the mould bolster. The ingenuity of the mould designer may have no bounds but it is worth noting that there may be a price to pay. The price relates to control over cavity temperature and cure. Internal ejector mechanisms require voids to be maintained in the body of mould in order to house the operating cams and levers. This interferes with the heat flow to the part of the cavity that is directly joined to the ejector. The temperature gradient between the heating platen and the cavity is usually of the order of 10 to 15 °C. Internal ejector mechanisms can cause the gradient to double that value, leading to high differential in the cure between different parts of the moulding. External ejectors should be designed to avoid the need for areas of the hot mould to be in contact with cold ejector bars since this causes heat loss problems in the mould. Insulation of the contact surfaces of the ejector bars with resin-based boards is often beneficial.

5.6 Flashless Mouldings

The moulder aims to achieve a moulding without flash. Flashless injection moulding has been made possible through the building of moulds with extremely close tolerances that are capable of resisting very high pressures at mould seam lines. Such accuracy

produces flashless parts. A new technology for flashless moulding of rubbers has been developed. It involves extremely precise dosing of the injection volume in relation to the mould, together with a very accurate alignment of the clamp platens and high precision mould manufacturing. The system eliminates post-moulding operations, whilst also avoiding possible damage or part quality problems associated with part demoulding and deflashing [3, 4].

5.7 Mould Monitoring Points

Wherever it is possible moulds should be provided with pockets for temperature measuring and recording instrumentation. This is essential if the moulding conditions are to be properly optimised and also provides a thermal ‘finger-print’ for audit of the process during the production cycle. Surface temperature probes are better than nothing, but give results which may well differ between operators and are affected by the condition of the mould surface [5].

5.8 Mould Materials

New moulds may produce parts that are essentially flash free but gradually deteriorate with use. A low rate of wear depends upon the right choice of tool steel. This should be a grade that can be hardened by heat treatment but without any attending distortion. The design specifications of the mould must include details of the materials from which the mould cavities and the mould bolster will be made. Failure to understand the reasons behind the choices may lead to substitutions of materials that are thought to be similar, but in reality have significantly different properties.

The mould bolster comprises the bulk of the moulding tool and forms the matrix that supports and locates the cavity inserts. The bolster block also encompasses the runner system. The metal of construction must reflect the working needs of the mould. These may be summarised as:

- Adequate compressive strength to withstand any tendency to deform under pressure.
- Good machinability, enabling the tool maker to shape it with minimum wear to the cutting edges of drills and milling cutters, and in the minimum time.
- Resistance to warping during machining and hardening operations.
- The ability to be hardened to a level that renders the finished tool insensitive to denting and the general hard wear of the production environment.

- Resistance to corrosion results in lower mould maintenance cost and a clean surface after the hardening process.
- For the bolster it is unnecessary to use steel capable of taking a high degree of polish.

The chemical composition of a steel that has properties compatible with the above is shown in **Table 5.1**.

Table 5.1 Steel composition appropriate for a mould bolster					
Typical analysis (%)	Carbon 0.33	Silicon 0.35	Manganese 1.35	Chromium 16.7	Sulfur 0.12
Standard	AISI 420F, DIN 1.2083 modified				
Condition	Hardened and conditioned				
Modulus of elasticity (N/mm ²)	200,000 at 20 °C, 190,000 at 200 °C				
Thermal conductivity (W/m/°C)	23 at 20 °C, 24 at 200 °C Carbon black				
Specific heat (J/kg/°C)	460				

The cavity inserts for general purpose rubbers require a metal of good edge retention properties and with a surface capable of allowing a clean release from the finished moulding. A suitable composition is shown in **Table 5.2**.

Table 5.2 Steel composition appropriate for cavity inserts		
Typical analysis (%)	C 0.33	Si 0.35
Standard	AISI 420, DIN 1.2083	
Condition	40-55 HRC according to tempering temperature	
HRC – Rockwell hardness scale C		
AISI 420 or DIN 1.2083 steel – stainless steel, Martensitic, chromium steel		

References

1. L. Sors, *Muanyag es Gumi*, 1995, **32**, 2, 35.
2. *Fillcalc*, Version 1.07, RAPRA Technology Ltd., Shawbury, Shrewsbury, UK, 1995.
3. *Rubber World*, 1987, **197**, 1, 85.
4. *MacPlas International*, 1999, **1**, 58.
5. *Plastics and Rubber Weekly*, 1984, **1040**, 12.

6 Moulding

When a mould first comes to production it should have gone through some initial processes. Of these, the first is that of checking that all the components are available, including all ancillary jigs and tools. The second is checking that it has been cleaned to remove any residual oils applied by the mould maker and that an initial coat of release aid has been applied. The moulding technologist and operator can then proceed with bringing the injection moulding machine to its predetermined operating conditions and cleaning or purging the injection moulding machine of any material from preceding jobs.

6.1 Purging

Purging is the process by which the injection unit is cleared of the rubber compound used for a previous job, or to clear scorched rubber stock from the system. For modern units this can be accomplished by completely withdrawing the plasticising screw from its barrel and physically removing any adhering material by hand. A small amount of compound will remain in the nozzle section; purging will require just sufficient rubber to clear this. For other machines one must use a sufficient number of full rubber shots to ensure that all the previous material has been cleared from the barrel.

The purging operation is accomplished by passing fresh rubber strip through the pre-plasticising unit. The fresh rubber should either be from the new compound to be moulded, or a non-curing stock specifically designed to clear the system. The use of the latter is advisable if the machine is to be shut down or stand idle for an extended period. The purging stock should contain sufficient filler to provide a scouring action within the plasticising unit. The amount of purge compound that needs to be used depends on several factors:

- The type and age of the machine.
- The type of polymer used for the preceding job. If the compounds are similar, then purging will require three to four shot weights of rubber. If there is a change of polymer, and the machine is not modern, then considerably more will be required. Work with coloured stock has shown that vestiges of the previous rubber are evident after as many as 40 shots! For this reason it is better to restrict machines to specific polymer types and colour.

Purge material should not be re-used. Re-used purge compound may work some of the time, but it will prove a false economy, through the re-introduction of cured rubber into the system. Examples of purge compound formulations are to be found in **Appendix 7**.

6.2 Single Cavity Tools

The initial stages of a new project will include the design and manufacture of a single cavity tool that will allow the production of sample parts. This should fulfil two objectives:

- Establish that the component design will meet the customer's expectations, and
- Provide a positive guide to the multi-cavity mould design.

When the time comes to work with the multi-cavity tool for production, the settings developed for the single cavity tool are the best guide for set up. A common cause for complaint is that the properties of the components from the multi-cavity mould do not match those of the prototype single cavity. The problem usually arises from inequalities in cavity temperatures and the heat history of the rubber. Thermal gradients differ substantially between single and multi-cavity moulds. To minimise the thermal changes, the mould should be equipped with monitors to ensure that the cavity temperatures of the production tool are as close as possible to that of the single cavity. Additionally, the temperature of the rubber stock and the time to injection must match those used for the single cavity trials. In addition the initial siting of the gates and their size should also be studied using mould flow software (see **Chapter 5**). Using these measures it is possible to obtain duplication of results. This may necessitate significantly different settings of the platen temperature controls in order to obtain similar cavity temperatures.

6.3 Initial Process Set-up

The task of initial set-up really starts at the single cavity trial stage. If the reader has arrived at this point with a production tool and without experience of a prototype single cavity tool then a difficult time may be forecast! Whether the task involves single or multi-cavity tooling, setting up should follow the same broad principles. The steps are:

- Ensure that the mould has been cleaned and treated sparingly with mould release agent.
- Establish the nature of the polymer and curing system and discover if an optimum cure temperature is recommended for the rubber stock.

- Plan for the material to be prepared to the correct strip profile for the injection machine.
- Establish an action plan for the trial. This should take the form of a simple factorial experiment varying stock temperature, cavity temperature and cure time, similar to that shown in **Table 6.1**.

Table 6.1 Multifactorial experimental design for three variables			
Experiment number	Cavity temperature (°C)	Cure time (s)	Stock temperature (°C)
1	160	Minimum	80
2	170	Minimum	80
3	160	Minimum + 30	80
4	170	Minimum + 30	80
5	160	Minimum	100
6	170	Minimum	100
7	160	Minimum + 30	100
8	170	Minimum + 30	100
Experimental design for three variables (example) Note: The cure times are defined in terms of the minimum time to produce a component that is free from porosity.			

- Preheat the mould and platens to about 15 °C higher than that expected for the cavity operating temperature. Start to monitor the cavity temperature.
- A nozzle insert of internal diameter equal to that of the sprue bush is fitted. Use of too small a nozzle is a common cause of ‘light’ components due to a decrease in pressure in the runner, or in extreme cases scorch with attendant problems.
- The screw and barrel temperature should be set to a value of 70 °C to 80 °C for initial trials. The actual temperature of the rubber will depend on the frictional energy generated by the screw and can be controlled by adjusting the back pressure or screw speed. It is always advisable to run a small trial at this stage, to establish the relationship between these parameters and the final rubber temperature.
- The time delay, between the end of the injection phase and the automatic refilling of the screw and barrel with rubber should be set to minimise the time that plasticised rubber is held in the barrel before injection. If there is any undue delay before the start of the next cycle, this rubber should be purged from the barrel and the process restarted.

- When the cavity temperature is stable at the desired value, start to ‘dry cycle’ the tool, mimicking the expected cycle. After several such operations, and whilst the tool is open, feed the rubber strip into the injection machine pre-plasticiser. This rubber will be used initially to purge the system of the previous rubber used (see **Section 6.3** on purging).
- Pressure and speed settings should be adjusted so that the mould is filled as quickly as possible, without flash over of rubber from the runners. Aim for compaction of the rubber in the cavity with a minimum pressure of 15 MPa. This will reduce the possibility of micro-porosity in the finished component. If the rubber flow has been modelled previously, then the guide time for injection speed should be achieved (for example, see **Figure 5.2**).
- The cure time will vary according to the compound in use, the rubber sectional thickness, and the moulding conditions. The optimum value should be determined by the trials planned in **step 6.3.4**. For guidance see **Table 6.2**. The overall cure time will depend on the temperature of the injected rubber. The hotter that this can be sustained without incurring scorch penalties, the more even will be the crosslink density across the rubber section. The optimum value that is often quoted for crosslink density is 90%. This value was determined from a 2 mm thick sheet tested for tensile and related properties.

Table 6.2 Target cure times	
Rubber section (mm)	Cure time (s)
<1	30
2	60
4	120
8	180
16	240
30	360

- The components from the various trials need to be assiduously tested against the customer’s specifications. Some components may have different measured properties. This will only be resolved through regression analysis of the results from the factorial experiments. Happily, there are a number of commercially available compute-based packages that will assist the technologist in this task.
- Finally check all critical dimensions and geometrical tolerances to ensure that the mould is producing products as specified. These initial measurements will be needed for regular checks of the product during manufacture.

6.4 Problem Solving

In the ideal world moulding faults do not exist. Unhappily companies continue to live with problems, either because the problem is thought to be impossible to solve or it has not been recognised as a production cost that can be saved. If company rejects are zero, then skip this section!

6.4.1 Recognition

The first step in improving any process is to ensure that all product failures are counted and classified according to the reason for rejection. This process needs to be done on a regular shift-by-shift basis.

6.4.2 Classifying the Fault

Short but regular meetings should be held involving the production, design, and technical team members. The faulty products should be examined minutely to establish that the fault has been classified correctly. This is an important step since a great deal of time can be wasted through discussion of the wrong problem.

6.4.3 Identifying Causes

All of the team must be encouraged to put forward their ideas on the possible causes of the problem. No idea should be discarded at this stage. The result may be a list of 30 to 50 possible causes. Joint discussion and examination of the list should discover common themes. Commonality of causes should then resolve the problem into perhaps six or seven possible variables. Resolution of the fault can then commence through factorial experiments. Very few problems exist that cannot be solved in this way. The method of changing one variable at a time often fails because it cannot show possible interaction between variables. Interactive variables can, and do exist.

Common component faults and their possible causes are listed in **Table 6.3**.

Table 6.3 Faults, causes and solutions		
Fault	Possible cause	Action
Light	Shot weight too low	Increase setting
	Blocked injection gate	Check rubber for contamination Check rubber at nozzle for nibs
	Scorch	Check for 'banana' shaped injection sprues. Check compound and settings
	Unbalanced runners	Use a short shot and weigh the amount in each cavity Examine the runners for excessive flash
	Poor gating	As for unbalanced runner
	Gas trapping	As for unbalanced runner + bumping
	Pressure too low	Increase setting
	Injection too fast	Reduce speed
Under-cured	Cure timer setting	Check
	Rubber compound	Test cure rate, check grade, test with rheometry
	Faulty platen element(s)	Some cavities OK Measure current drawn
	Faulty platen controller/ thermocouple	Check for mechanical damage and electrical malfunction
	Back pressure low	Check stock temperature at the nozzle
	Screw/barrel heating	Check
Distorted	As under-cured	
	Ejectors too fast	Slow down
	Scorched rubber	Check for 'banana' shaped injection sprues, check rubber with rheometer.
	Cavity too hot	Try lower temperature
	Injection too slow	Check time to inject. Check for correct nozzle
Blisters	Vacuum not working	Check
	Insufficient back pressure	Check
	Rubber contaminated	Microscopic examination of blisters

Blisters (continued)	High moisture content of rubber	Check less than 0.5%
	Bumps not activated	Check
	Incorrectly gated	Design!
Splits	Scorch	Check for 'banana' shaped injection sprues
	Injection too slow	Check time
	Too much mould release	Evaluate Retrain operator
	Wrong mould release	Change
	Gating wrong	Design!
'Lakey' (irregular surface depression)	Final pressure too low	Evaluate
	Nozzle too small	Design!
	Excessive gas trapping	Check vacuum and moisture
Sunken injection pips	Scorch	Check for 'banana' shaped injection sprues
	Shot weight too high	Adjust
'Back-rinding'	Cavity temperature too high	Evaluate
	Rubber too fast	Try slower compound
	Nozzle and sprue bush too small	Change design
Micro-porosity	Moisture in compound	Check
	Cavity pressure too low	Examine
Dimensions incorrect	Cavity wrong	Measure
	Wrong shrinkage applied	Check design calculations
	Moulding temperature too high or low (large sections)	Refer to design reference temperature

7 Mould Fouling, Cleaning and Management

During the moulding cycle rubber compounds produce by-products that are given off as rubber fume or left as residues on the mould surfaces. If the residues are allowed to remain on the mould they gradually build in thickness and cause moulding defects. The other cause of mould fouling is the oxidation of portions of rubber, either from contact with trapped air pockets, or from the incomplete stripping of the mould at the end of the cycle. Component faults then arise either through physical dimensional changes to the mould with an accompanying marring of the component surface, or through adhesion between the deposits and the cured rubber causing lumps to be torn from the surface of the component.

The well-run factory should plan to minimise the problem of mould fouling in the following ways:

- First, ensure that the mould is cleaned on a regular basis. After use, never replace the mould in its position in the store without cleaning it and inspecting it for damage.
- Second, apply a coating of semi-permanent mould release agent to the mould immediately after cleaning. With the right choice of release agent, this will bestow two advantages. Of these, the first is that the mould will be protected from any rusting whilst it remains out of use, and the second is that it will enable the product to be de-moulded more easily and help reduce cycle times.
- The third stratagem is to formulate rubber compounds to minimise residues. This is more easily said than done. The rules are:
 - Use clean polymers, free from excessive levels of non-rubber materials.
 - Avoid the use of oils, especially of a tarry, fume-producing nature.
 - Minimise the amount of wax used to a level compatible with the protection required.
 - Use a good antioxidant system.

- Avoid cheap filler loading, because this reduces tear strength, leaving a rubber film on the mould surface and rubber fragments in awkward corners of the mould.
- Fourthly, avoid the use of very high cavity temperatures. These are not generally necessary to obtain short cure times, and certainly speed the rates at which residues are deposited. For natural rubber aim at a cavity temperature of 165 °C. For synthetic rubbers with low levels of unsaturation such as ethylene-propylene diene terpolymer this will need to be increased to 180 °C. The cavity temperature is usually 10 °C to 15 °C below the set point of the platens.

There are a number of methods available to clean rubber moulds. These may be classified into wet or dry processes. Wet processes require the mould pieces to be soaked in a cleaning medium. The choice of these is wide and ranges from simple alkali solutions to complex organic mixtures. Each solution has its advocate and it is probably best if the choice is made through careful trials, and with due regard for environmental constraints! These solutions have associated health risks, and give rise to disposal problems of the spent liquors. Since there are strict regulations on the discharge of solvents it may be best to avoid their use for cleaning.

No matter how good the washing solution may be, some residual matter usually remains on the surface and will require mechanical removal. For this reason it is always wise to provide a final cleaning stage that uses a high-pressure water jet with an entrained plastic or glass bead medium. Wet processes can be combined with ultrasonic methods to dislodge the adherent rubber. The ultrasound agitates the liquid, generating bubbles, which effectively scour the mould, without causing abrasion. The success of ultrasonic cleaning depends upon the shapes to be cleaned and are good for cleaning delicate parts of the mould, especially if the latter are readily removed from the parent tool.

Trials are therefore an essential precursor to selection of the cleaning method. Dry blasting with fine glass beads produces a polished surface with minimal environmental impact. However, care needs to be taken with injection gates, vacuum ports and sprues, since they can become easily blocked or not be cleaned at all!

All abrasive cleaning processes may significantly change mould dimensions over a period of repeated cleaning cycles. For this reason it is imperative that regular dimensional checks are made and recorded for each mould.

A relatively recent method is the use of solid carbon dioxide (dry ice). This is used in 'rice grain' form or as granules shaved from solid blocks. These particles are applied

in a powerful stream of compressed air, which is directed at the surface to be cleaned. The process can be applied effectively to hot moulds that are *in situ* in the press. It is very noisy and consumes a great deal of compressed air. However it reduces mould wear and machine down time. For applications where other methods are too difficult to apply or where the production runs are of a length that does not permit more regular cleaning, this might be worth a trial.

Once the mould has been cleaned it becomes very susceptible to corrosion. Some factories overcome this problem by oiling the mould surfaces. This in itself gives rise to problems when the mould is needed for production. The best solution is to immediately apply a coating of a semi-permanent silicone resin release agent followed by a short bake cycle. This gives a mould that is immediately ready to produce first class mouldings.

7.1 Mould Management

Moulds, by virtue of their mass and materials of construction, take a significant time to reach their operating temperature. An efficient business cannot afford to have expensive injection moulding machines unproductive whilst a mould attains the correct temperature. Preheating of the mould can be achieved using thermostatically controlled platen tables fitted with an insulated cover and monitoring equipment to establish when thermal equilibrium is established. If a faster method is required to meet production schedules it is possible to use an electric induction heating oven. These devices, depending on the power rating, can really speed the heating process.

7.2 Platen Condition

An important aspect of the maintenance of an injection moulding machine is a regular check on the condition of the platen surfaces. Platens can become distorted due to mistakes made whilst moulds are being fitted or through excess pressure being applied to a mould that has a smaller surface area than usual. A platen that is not perfectly flat must be removed and reground or replaced since it will distort the mould and endanger future production.

The presence of scale or other deposits on the surface has a measurable effect on the rate of heat transfer from the platen to the mould. A layer that is as little as 0.01 mm deep can cause a significant increase in cure time, a result that has in past times been ascribed to the fault of the rubber compound!

8 Mould Release Agents

Choosing a release agent that suits the process is an exercise that needs to be undertaken with care. Six factors should be considered:

- Ease of release,
- Durability,
- Cost efficiency,
- Inertness,
- Environmental safety, and
- Effects on the component.

The selected agent needs to confer the necessary release properties without incurring any penalty, such as surface weld lines and splits. The untrained operator often views the release agent as a means of removing parts from a mould with the least effort and will apply the release agent in a fashion more suitable for spraying the garden. The release agent to be used will vary according to the type of polymer and the component, and its rate of application can only be determined by trial. The manufacturers of the material should provide full assistance during trials and offer advice with respect to the best means of application.

8.1 Sacrificial Mould Release Agents

The sacrificial mould release agent works by not adhering fully to the mould, so that when the component is removed, the release agent is removed with it as a thin surface film. The most common agents of this type are silicone-based, for example the polydimethylsiloxanes. These can cause problems in two ways. First, when the rubber fills the mould some of the release agent will move with the rubber and prevent rubber-to-rubber bonding during curing. The end result is a defective part with 'knitline' failure. This occurs most often just after the mould release agent has

been applied, but due to the nature of these agents they have to be applied quite frequently. Secondly, if the moulding involves rubber to metal in-mould bonding, this type of agent will cause failure of that bonding.

8.2 Internal Mould Release Agents

Some rubber additives act as mould release agents becoming surface active as the rubber cures. The most commonly used chemical is zinc stearate, which also functions as an accelerator. However, zinc stearate is relatively ineffective and often needs to be used with an external release agent. Developments in this field include silicone elastomer formulations containing propanediamine dioleate and propanediamine distearate cationic surfactants. During the curing process in the mould these additives break down into a primary amine which functions as an accelerator, and a fatty acid, which acts as a mould release agent. Problems arise when the internal mould release agent not only acts on the surface of the rubber, but also within it, causing cohesive failure when the component is stressed.

8.3 Semi-permanent Mould Release Agents

A semi-permanent release agent that is baked on to the clean mould has been found to give optimum results. Semi-permanent release agents are usually polymers applied in solution to the mould surface. The carrier is then evaporated and the polymer cured *in situ*. These agents permit only minimal transfer of release agent to the component surface and only need to be topped up after about every 10 cure cycles. More force is required to release the component than when using a sacrificial release agent, but these agents do not interfere with rubber-metal in-mould bonding.

When first introduced, semi-permanent release agents were formulated in hydrocarbon solvents or chlorofluorocarbon (CFC) aerosol propellants for application. However, with the environmental concerns about the use of solvents, and the Montreal Protocol banning the use of CFC, semi-permanent release agents are produced with a water base, that are equal in their properties to the solvent borne materials.

8.4 Method of Application

The method of application of a mould release agent is often a neglected process in a moulding company. An often used method is to give the release agent to the machine operator together with a paint bush and allow the operator to struggle. The operator will, however, win by overdosing the mould. This has three effects. First, the excess

release agent causes moulding defects. Second, the cooling effect of the solution causes the average mould temperature to drop and require further adjustment to mould cycle conditions and third is the cost of over use of the release agent. The best of these are expensive to buy and it is worthwhile making an effort to control the process properly. The material needs to be applied as a very light coating in as little time as possible. It should only need to be applied once every 15 to 20 mould openings and this is best done by the use of a spray lance supplied from a central source. Presses that are robotically serviced can be easily adapted to include this operation. For manually operated presses it is advisable to require the operator to record the operation with a tick to the production sheet.

9 Maintenance

9.1 Routine Matters

As with moulds, machines that are in continual use need to be checked regularly to ensure that they are maintained in peak operating condition. The maintenance function within the factory is of great importance in the battle to maintain the highest quality standards. Technological advances in processing, compounding and moulding must be matched by improvements in basic maintenance. The mentality must change from reacting to problems to being proactive. This will result in reduced machine downtime and greater productivity. In one survey of 100 injection moulding plants, it was found that around 11% of production was lost due to defects in machinery and moulds. Maintenance and servicing of machinery and moulds should be scheduled, and the downtime incorporated in costing.

Maintenance factors that will lead to failure are generally related to heat and pressure. Oil leaks are not only unsightly and dangerous but are signals that the system is losing pressure and therefore hydraulic efficiency. They can, and should be controlled. Heating elements have a failure rate that depends on a number of factors apart from the number of hours that they are in use. This applies to all heating systems, not just those in the platens. Systems need to be in place to ensure that they are regularly monitored. Operators can be trained to report variations and supervision to take notice of their observations.

Maintenance can be scheduled on a time basis or, more accurately, on the basis of the number of mouldings produced. The latter more accurately reflects the wear on the machine. Injection moulding machines can be equipped with shot meters to facilitate this type of maintenance cycle. Software is available to support and monitor routine maintenance in the injection moulding industry.

Mould designers should be encouraged to bear maintenance in mind, for example, using standardised parts from catalogues, which can be easily replaced. Ejector pins for large parts are often hard to get hold of, whereas standard pin extensions can be easily purchased. Designing hot runners as part of the mould permits any repairs to the platen to be carried out without dismantling the system. Heating and cooling fluids are used to control temperature by circulation through some moulds. Connection to

these should be clearly labelled and provided with quick release couplings. If standard parts are used, and wear is anticipated, a stock of parts can be kept to speed up repairs.

9.2 Routine Maintenance

Simple maintenance operations should include:

- Servicing moulds in the press, removing stuck parts and runners, checking for drying out and premature wear.
- Greasing pins and bushings, gears racks, wear pads, interlocks, and so on.
- Replacing or re-working worn tooling before it causes moulding defects.
- Taking measures to prevent and treat internal corrosion and contamination.
- O-rings which connect the cooling channels of the mould are easily damaged by excessive compression and need to be checked for proper fitting, fatigue and premature wear.
- Checking for contaminated O-ring counter bores, pitting and damaged plates, dirty tooling and vent channels, sloppy pin or bushing holes in moulds.
- Checking for oil and water leaks.
- Checking for corroded or plugged water lines and fountains.
- Checking the mould, documenting measurements and history (in-press servicing, production runs, process or press changes, pulling and setting, part defects and inserts).

9.3 New Job Start-up Procedures

Probably the most critical time in the life-cycle of a production component is when the part is first introduced to manufacture. Until that time the volume produced has of necessity been kept to a relatively low volume. Components already in production have a proven track record and the need for high levels of test has been relaxed to a low level routine test by the production staff. The question as to how that final state is achieved needs to be answered by a clearly defined and documented route. For rubber injection moulding the route can be split into two: rubber compound quality and component performance.

The rubber has to satisfy a number of criteria. First it should meet the general standard of physical properties laid down by the customer. To demonstrate compliance the first five batches of compound are subjected to the full specification tests to which are added rheometer and thermogravimetric analysis (TGA). These last two provide a production marker that will show conformity for the cure rate and to composition. They are rapid tests and allow bought in compounds to be used with a high level of confidence provided that the supplier of the compound has been audited and found to conform to the required standard.

Components produced from the first five batches are subject to performance related tests to include load deflection, creep and fatigue. If a satisfactory result is obtained, production can proceed with tests on each batch of the rubber for rheometry and TGA. After 50 batches the standard deviation for all results is reviewed and the frequency of test for the compound can be reduced to a frequency set by the company and agreed with the customer. A similar test frequency can be set for the component.

9.4 Reworking

Many companies have adopted a practice known as reworking. This is the application of a further process to a compound or component that fails to meet the pass criteria, in an effort to 'rectify' it. For rubber compounds this usually means a further mixing cycle with or without the addition of additional ingredients. The desired outcome is often to get the compound to meet hardness, deflection or cure rate standards. The ingenuity of the rubber chemist is to be admired but the practice of reworking is not. A reworked batch will always be a risk to the quality of components made from it and it denotes a total failure to the concept of 'right first time'. If reworking, on any process, is a practice used in the factory, then management must ask themselves the question 'what is wrong with the system in this factory?'

10 Bonding of Rubber to Substrates

10.1 Introduction

Bonding rubber to a solid insert as part of the injection moulding was a process first begun in the 1960s. Since that era the process has become, like rubber processes in general, a science rather than the 'black art' as it was once regarded. The process does need to be closely controlled to ensure 100% compliance with automotive requirements. This chapter will help the reader understand the processes and how components can be produced that will 'surpass the customers' expectations' [1, 2].

The design parameters of the product control the selection of the rubber compound and the insert (substrate) material. These, in turn, determine the means of surface preparation for the insert and the bonding agent to be used.

10.2 Compound

It is possible to bond most compounds to a metal or plastic substrate. The ease with which they may be bonded depends principally on two factors: the polymer type and the curing system.

10.2.1 Polymer

General purpose polymers (natural rubber and SBR) pose no difficulty unless they are of high viscosity or conversely are of very low hardness, i.e., ≤ 40 IRHD (NR) and styrene-butadiene rubber (SBR).

Saturated polymers such as butyl and ethylene-propylene-diene terpolymer are more difficult to bond and generally exhibit lower bond strengths compared to those found with the general purpose polymers. Once a degree of functionality is introduced into the polymer such as with chloro or preferably bromobutyl rubber and chlorosulfonated polyethylene (Hypalon®) then the ability to bond is enhanced.

10.2.2 Curing System

To achieve a sustainable high quality bond there are two factors of importance. Of these the first is the scorch level at the point of final fill to the cavity. This needs to be regulated so that no more than 5% of crosslinking has occurred when the plasticised compound meets the surfaces to be bonded (See **Figure 3.1**).

The highest bond strengths are those obtained with NR and SBR when a relatively high level of sulfur is used (2 to 3 pphr). At these levels, reversion in the rubber can be countered by increasing the sulfenamide dosage (for compounding examples see **the Appendices**).

Where it is necessary to use low sulfur levels, good bonds can be obtained by use of bonding agents with a higher activity (see **Section 10.6** on bonding agents).

10.2.3 Rubber Presentation at the Press

Preparation of the compound for the moulding process, as for all injection processes, needs to be carefully controlled. The stock needs to be presented to the mould in a clean, fresh state. The strip must be free from excessive amounts of anti-tack agents and should be of a continuous and uniform section that will feed without hindrance into the injection moulding machine screw. If the compound is based on butadiene-acrylonitrile copolymer, or similar polar materials, then it is necessary to ensure that the anti-tack agent used is based on zinc stearate.

10.3 Inserts

10.3.1 Condition

It is expected that the delivered insert will conform to the design drawing in every respect. This is necessary to be within the strictures of 'just in time' manufacturing and ISO TS16949 [3]. However, it is useful to remind ourselves of the basic requirements apart from those of shape and dimension. Conformity to shape and size is vital if damage to the mould is to be avoided.

10.3.2 Metal Inserts

Metal inserts should be free from scale, rust, pitting and cracks. The surface should be bright and not heavily contaminated with oil or grease. This reduces cleaning costs

and also the amount of waste for disposal. Inserts of cast iron will absorb oils and grease that cannot be easily removed by degreasing. If machining is required it should be done without the use of lubricant. Aluminium inserts can be delivered in a clean condition, ready for use. Welded metals should be clean and an adequate depth of penetration should be demonstrated. The analysis of the metal should be disclosed and batch integrity must be maintained.

10.3.3 Plastic Inserts

Many of the plastics available today may be bonded to rubber provided that the thermal and mechanical properties of the plastic are compatible with the process conditions required for the bonding process. Fully saturated polymers such as polyethylene and polypropylene are not generally considered to be suitable for the process but can be successfully moulded to cured rubber. Examples of this can be seen on military vehicles where such mouldings work as aerial bases.

The use of plastic substrates is increasingly common, especially in suspension system bushes, where its use reduces weight and eliminates the need to swage or calibrate the outer insert. An interesting development is the use of plastic interleaving, eliminating the need to expand the inner tube. It should be noted that this was the subject of a BTR AVS patent.

The most commonly used plastic for inserts is polyamide 6,6. This is used in both natural and glass-filled forms. A wide variety of grades are available but care must be exercised in their selection. Properties of modulus, impact strength and heat resistance should be optimised in the selection process. In production it is useful to monitor the filler content and type together with the glass transition temperature.

The market has also seen the introduction of a new material that bonds directly to rubber. This appears to very attractive unless you sell bonding agent! There are some snags. The price is quite high and its use in the UK is not viable except for very low weight items. For successful bonding the rubber must contain some SBR.

Plastic inserts can, and should, be delivered in clean containers and manufactured from grades that contain little or no internal release agents or process aids. This will allow the inserts to be coated with bonding agents without further treatment (see later). Polyamide grades should be selected for their mechanical properties and especially with regard to the temperature at which distortion can occur.

Polytetrafluoroethylene can be successfully bonded by surface etching treatment with sodium ions in a solvent shielded with an inert gas. This is a highly specialised process and should only be attempted by fully qualified and equipped staff. There

are a number of companies who offer a treatment service. It is important that the treated components are delivered free from any contamination.

10.4 Insert Preparation

The most common substrate is steel, for which a number of preparative routes are in common use. Each route has its merits. A degreaser stage is a common precursor to all the methods, followed by either grit blasting or a chemical conversion coating. The degreaser used prior to grit blast may use either solvent or aqueous systems.

10.4.1 Solvent Degreasing

Despite environmental pressures to move away from solvent degreasing systems many plants find solvents to be the easiest to use.

Of the solvent systems, trichloroethylene is the most efficient. The inserts are first tumbled in the solvent to remove the majority of the organic contaminants. To obtain a surface that is free from oils and grease, a vapour phase degrease is then used. When the inserts are flooded with vapour, the solvent immediately begins to condense on the insert surface and then run off, carrying with it in solution the last traces of organic contaminants. The volume of condensate, per insert, depends on:

- The mass of the insert
- The specific heat of the insert
- The temperature of the insert, i.e., the temperature of the solvent at the end of the rinse cycle
- The latent heat of vaporisation of the solvent

The process is complete once the insert temperature reaches that of the vapour when there is no further condensation.

It should be noted that finely divided aluminium and magnesium alloy dust, produced when tumbling castings and machined components of the metals, can react with halogenated solvents with considerable violence. Grades of trichloroethylene are available that are stabilised for use with aluminium.

When aluminium is delivered to the plant in a clean state there is no need for a degreasing step.

Cast iron is micro porous and can sometime 'sweat' grease and solvents after degreasing. For this reason cast iron components should never be in contact with oils and greases before the bonding processes.

10.4.2 Aqueous Degreasing

The bonding industry, when presented with the difficulties of reducing solvent emissions to meet the Environmental Protection Act (1990), faced problems in believing that water could solve some of the problem. When clean steel is in contact with water and oxygen, it rapidly oxidises to form ferrous hydroxide, which further oxidises to ferrosoferric oxide hydrate.

The process is initially electrolytic. Iron in the steel forms an anode and the iron passes into solution as ferrous ions (Fe^{2+}) shedding two electrons in the process. Other elements in the steel form a cathode where hydrogen ions from the water take up electrons and are discharged. The process is therefore accelerated by aqueous systems that increase the concentration of hydrogen ions. Some electrolytes such as caustic soda lower the concentration of hydrogen ions and, therefore, retard the rusting action. This fortunately allows ferrous metals to be degreased adequately in alkaline solutions. The equipment used for aqueous degreasing varies widely in construction but all machines have common factors. For bonding preparation, the inserts must be contained in baskets that can be rotated and the cleaning liquor is heated and pumped under high pressure to form a spray wash. This liquor is continually filtered, to remove solids, and excess oil is skimmed from the fluid. At the end of the wash cycle a second cleaning spray containing a measure of rust inhibitor is used to remove the last vestige of oil, to be followed by a rapid drying cycle with hot air. This process can be conveniently combined with blasting where the grit is entrained into the high pressure liquor feed to give a degrease and grit blast in a single stage.

Whether degreasing is by solvent or is aqueous, to ensure that the process is in control, it is necessary to monitor the media and the machine. Trichloroethylene should be tested to ensure there is no build up of acidity and that the oil content of the wash liquor is low. The machine should monitor and reflect the operating temperature during each part of the cycle and a constant watch is necessary to ensure that emission levels are within control. Similar controls are important adjuncts of the aqueous systems.

10.5 Surface Preparation

After cleaning, the next step in the process is designed to establish a sound surface on which to bond. For steel there exists a number of processes, which may be used

alone or in combination to remove scale and oxidation and give a highly active surface.

10.5.1 Grit Blasting

A grit blasting often forms the basis for surface preparation. The equipment, which may be used needs to offer a number of features. Of these the first is that the inserts should be presented to the grit stream in a uniform and continuous pattern so that the blasting medium is distributed evenly over the work area. The second requirement is that of dust removal. The process continuously removes material from the inserts and at the same time the grit itself is reduced in size. This debris must be removed so that the size distribution of the grit remains constant to ensure that a clean, uniform surface is maintained.

The selection of the correct size and type of grit has a major effect upon the success of the process. Surface scale on steel is best removed by blasting with chilled iron grit. The plant maintenance engineer favours use of steel grits because of the lower wear rate experienced by the machines. Iron grit produces a cleaner surface whilst steel grit has a tendency to embed itself in the surface being cleaned. Under stress the embedded grit provides a failure path. It will also accelerate underbond corrosion processes by providing micro cells for electrolytic action.

Control of the process is required to ensure a satisfactory and enduring bond. To ensure that the size range of the grit in use does not change through attrition and dust build up, it is advisable to run regular checks using graded mesh sieves. If the supplied grit is 40-mesh then the in-process grit should show a size profile that peaks at about 60-mesh and then tails rapidly to zero. To maintain the system new grit needs to be added on a regular basis that is consistent with the volume of work that is processed together with daily maintenance of the dust extractor.

Surface hardened steels show a different reaction to the standard treatment of mild steel. Normal grit blasting with chilled iron will only polish the surface and not remove the scale adequately. Aluminium oxide, or corundum, is the best choice for cleaning these materials.

Aluminium is used increasingly to reduce the weight of bonded components. This metal should never be cleaned with ferrous grit, which will impact into the surface and can give rise to a significant rust effect. It is also worth noting that spontaneous combustion can occur in the dust exhaust system where aluminium dust is mixed with that of iron oxide. The use of aluminium oxide should be used although a caustic etch can also be effective (See **Section 10.4.1**).

Grit blasting processes are unnecessary with plastic inserts (See **Section 10.3.3**).

10.5.2 Wet Processes

Although by tradition grit blasting has been a dry process it is possible to use a wet technique that combines both degreasing and blasting into one operation. For this process the inserts are grit blasted with an alkaline degreaser in which is entrained an aluminium oxide grit. The process works well for tubes but difficulty has been experienced with processing flat plates due to the plates failing to separate.

Wet blasting processes can incorporate a phosphate conversion coating. Such systems are ideally suited to be used in conjunction with aqueous degreasing and wet blasting processes and produce a surface to which rubber can be securely bonded. The resistance to under-bond corrosion is one measure of how well the surface has been prepared. A phosphated metal can show superior performance in this respect over one prepared by poorly controlled dry grit blasting.

For bonding there are two principle phosphates available. These are calcium modified and tri-cation modified zinc processes. Both are designed to yield low coating weights and fine crystal structures. Each system has its merits and is critical for the control of the baths.

The word steel covers a wide variation in the carbon, silicon, manganese and phosphorus contents of the materials selected for insert manufacture. The proportion of these and various other elements, which may be present could affect the rate of build of the phosphate coating and also affects the crystal structure.

10.6 Bonding Systems

Prior to the 1960s bonding to metal relied heavily upon brass plating. The insert was plated with a 70/30 ratio of copper and zinc. Maintenance of the cyanide process was critical and small variation lead to poor bonds. The composition of the rubber required sulfur levels of at least 2.8 parts per hundred of rubber. In the 1960s the Lord Corporation issued a patent that changed the ability of the industry to produce high quality bonds. The bond systems that were subsequently marketed had their basis in the technology that stemmed from this patent. The bond system was in two parts, a primer and a bonding coat. The primer is essentially a solution of a phenolic resin dispersed in a ketone together with zinc oxide and a little carbon. The top coat contains a halogenated polymer dispersed in a xylene base together with carbon black, inorganic stabilisers and an organic compound named *p*-dinitrosobenzene (DNB). This material can be varied in content to adjust the reactivity of the bonding agent. In practice it appears to be present at 0.5% to ~3% depending on the grade. The effect of increasing the level of the DNB is to increase the ‘bondability’ of rubber

compounds containing lower levels of sulfur. Increased levels of DNB also come at a cost. It is more expensive and it also greatly increases mould fouling although this latter effect can be mitigated. Bonding agents are also available in aqueous systems.

The perfect bond starts with the selection of the bond system. Five principle factors must be considered:

- The polymer to be bonded, especially the level of sulfur,
- The substrate material,
- The modulus of the rubber - rubbers below 50 IRHD become progressively more difficult to bond,
- The shape factor: this affects the stress at the bond edge, and
- Environmental concerns affecting pollution and health and safety issues.

The correct selection requires that one must have knowledge of process parameters, which can only be assessed through experimentation or extensive experience.

Once the correct selection has been made, it is necessary to follow all the rules laid down by the manufacturer for the application of the bonding agent. Bonding agent solutions, as supplied, have a wide viscosity specification. Spraying equipment will work much better if the solution is controlled to a minimal level of viscosity variation through control of the dilution. Through negotiation with the supplier it may be possible to obtain deliveries to a tighter specification than is published.

Quality assurance procedures by the manufacturers of the bonding agents should be at a level that reliance can be placed on their test certification. This can only be ascertained by inspection of certification and comparison with in-house testing.

The evaluation of bond strength has, for many years, depended upon the ASTM D429 methods A to C [4] and their BS equivalents such as BS 5350-C1 [5]. The 30° peel test is often used for evaluation but is subject to experimental errors and is more a test of the rubber tear strength. The parallel plate test is more favoured by engineers but gives little evidence of the peel resistance of the bonds. Method C defines the cone test which gives much more useful information but suffers from a high dependency on maintaining cone point geometry.

A SERC project (1982-1983) [1, 2] produced a new arrow-head test piece that allows the benefits of the cone test piece with no tip sensitivity and the added benefit of the ability to calculate the fracture energy of the bond. The failure generated with this

test piece will always occur in the plane of the bonded surface and provides a true ranking of compound bondability *versus* bonding agent and cure condition. The test piece is also readily fabricated from any material.

10.6.1 Control of the Bonding Agent

Bonding agent, both primer and top coat, must be applied to give an even and controlled dried coating weight. This needs to be ascertained using the test methods available in the plant, since results will vary according to the type of metal preparation and the measuring instruments used. In practice a result of approximately 20 to 25 μm will be satisfactory for the top coat. The result for the primer, on steel, can be as little as 10 μm but this should be kept to 25 μm on polyamide surfaces where the bond depends on the phenolic resin partially dissolving the polyamide surface during the moulding process. When bonding to medium and high nitrile compounds the primer coat is all that is required.

Consistency can only be attained by control of the bonding agent dilution and temperature. The viscosity of these materials varies with the ambient temperature and may be very cold and viscous when first delivered. Similarly in hotter countries it could be very hot and have low viscosity. In either case dilution in an uncontrolled way will result in inevitable errors. Dilution and storage prior to use should therefore be made in covered vats that are jacketed and temperature controlled to the average ambient condition. The interior surfaces of the vats should be constructed entirely of stainless steel, including the stirrers. Measurement of the viscosity can be checked with a rotational viscometer from a suitable sample mounted in a water bath.

Comparative standards of the bonding agents used can be obtained from small samples dried at ambient temperature to a constant weight and then subjected to thermogravimetric analysis over a range of 20 °C to 600 °C. This, for the top coat, will typically show several characteristic weight loss steps that are related to the composition of the bonding agent.

10.6.2 Application Methods

It is possible to apply bonding agents by brush, roller, dipping, transfer pad printing and spraying. All of these methods have been trialled or used in industry with varying degrees of success depending on how they were applied. The most popular method is by spray, and of the spray systems available the most satisfactory and cost effective is the low pressure, high volume spray system. This uses air at about 0.1 to 0.12 MPa and a high air flow. It results in a narrow spray pattern that

significantly reduces the volume of bonding agent used (overspray) and gives an even coating, especially inside tubes where the much reduced 'bounce back' ensures run-free coatings. The method can be combined with hot spray techniques but this offers little advantage in drying time unless the spray machine is not equipped with a drying tunnel. Hot spray equipment will require frequent attention to nozzle cleaning of the spray guns.

Whichever the method used, it is vital that any handling of the inserts, before or after the process should be either mechanical (robotic) or with cotton gloved hands.

10.6.3 Storage and Handling of Prepared Inserts

Ideally the time between spraying and the moulding process should be as little as possible. The tote bins must be regularly cleaned and once filled with the requisite number of inserts, should be covered. Overfilling of the bin leads to damage of the coated surface and generation of dust. Inserts not used after a maximum time of three weeks should be reprocessed.

10.7 Moulding

The secret of success for bonding starts, as it does for all moulding, with the design of the mould. Bonding does, however, bring its own special problems. These can be always overcome by paying special attention to the design of the runners and sprues and to the positioning of the gates and vacuum ports. The latter are a necessity in ensuring that components are free from bond problems. It is especially important that the cavities fill together (see **Chapter 5**).

10.7.1 Preheating the Inserts

The second factor is the temperature of the inserts at the start of the moulding cycle and the time taken to load the inserts. For large multi-cavity moulds, two methods are used, sometimes in conjunction with one another, to shorten the time that the tool is open. Inserts can be loaded by a robot or the inserts can be placed by the operator into a loading jig whilst the components are curing. In order to keep the curing cycle to a minimum, inserts that would take a significant proportion of the cure time to heat to the mould temperature can be heated in an oven or on a preheating table as appropriate to their size. Large, or heavy, inserts can be effectively preheated by induction. The amount of preheating can be determined experimentally using inserts fitted with thermocouples and heated within a temperature controlled block or oil

bath. Inserts that are preheated for too long can ‘prebake’, losing much of their ability to bond to the rubber and producing components that have low bond strength.

10.7.2 The injection Cycle

The pre-plasticising and injection process needs to be arranged so that the scorch in the rubber compound at the end of the injection cycle is less than 5%. This is because at about 5% the viscosity of the rubber has already increased to a level at which the union between the rubber and the bonding agent cannot be completely assured. Whilst the rubber is filling the mould the bonding agent is heating to the mould temperature and the DNB causes the development of a high modulus layer in the rubber with the insert. If this is formed, or partially formed before filling is complete the bond will fail (sooner or later). A good, simple test as to the state of the rubber at the injection stage can be made by lifting the nozzle away from the mould and injecting a shot into the space between the nozzle and the mould (air shot). This can then be squashed between two cold metal surfaces and sampled at several places for a rheometer test. If the mould takes longer than about 20 seconds to fill then something is wrong with the process (mould design, nozzle too small, compound viscosity too high, rubber scorched).

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Appendix 1

Table 1 Natural rubber compounds using low levels of sulfur, 40 to 46 International rubber hardness degrees (IRHD)													
Target IRHD	40	40	40	40	40	41	42	45	45	45	45	46	46
Material													
Flexon 845 paraffinic oil		11.000	10.000	5.000				2.000	4.000				
Sunpar 2280													
CaO 80%		2.700	2.400	2.500									
Renacit 7								0.500					
53362 M/B	55.718	61.024	37.145	29.185	23.879	26.532	37.145	39.798	47.758	50.411			
SMR5 CV60	66.129	64.476	79.355	84.315	87.621	85.968	79.355	77.702	72.742	71.089			
SBR S1606													
SBR S1808													
Zinc oxide activ	1.323	1.000	1.300	1.500	1.600	1.700	4.500	1.300	1.500	3.700			
Flectol		1.000				2.000	2.000			2.000			
ZEH 75%	2.000		2.000	2.000	2.000	2.000	3.000	2.000	2.000	3.000			
Akriplast T		2.000											
Dispergum 24	3.000	3.000		3.000	3.000	3.000	3.000	3.000	3.000	5.000			
Stearic acid													
Wingstay 100													
IPPD 80%													
6PPD	2.000	1.000	2.000	2.000	2.000	3.000	3.000	2.000	3.000	3.000			
Okerin 1995	2.000	2.000	2.000	2.000	2.000	2.000							
Rhenogran S	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000			
TMTD 80%							1.000	0.700		0.500			

[illegible]

Table 2 Natural rubber compounds using low levels of sulfur, 46 to 54 IRHD													
Target IRHD	46	47	48	48	48	49	50	50	51	51	52	54	
Material													
Flexon 845 paraffinic oil									5.000				
Sunpar 2280						10.000							
CaO 80%													
Renacit 7													
53362 M/B	68.984	74.290	66.331	82.250	82.250	82.250	63.677	90.210	63.677	37.681	82.250	106.129	
SMR5 CV60	58.065	56.210	61.169	51.250	51.250	51.250	62.823	46.290	62.823	42.984	51.250	36.371	
SBR S1606													
SBR S1808													
Zinc oxide activ	4.161	1.500	4.000	1.500	1.500	3.700	4.000	1.500	1.000	1.500	3.800	0.700	
Flectol	2.000	2.000	2.000	1.500	1.500	2.000	2.000	2.000	2.000	2.000	2.000	2.000	
ZEH 75%	3.000	2.000		2.000	2.000	3.000		2.000	3.000	2.000	3.000	2.000	
Aktioplast T							3.000						
Dispergum 24	5.000	3.000	3.000	3.000	3.000	3.100	3.000	3.000	3.000	3.000	3.000	3.000	
Stearic acid													
Wingstay 100													
IPPD 80%													

6PPD	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Okerin 1995	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Rhenogran S	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
TMTD 80%	0.400			1.000	1.000	0.700				0.400		
TMTM 80%												
TBBS	1.600		1.600	1.300	1.600		1.500		2.100			
CBS		2.000		2.000		2.000		2.000			2.000	
Perkacit MBTS 80												
MBT 80%	0.700	0.550		0.550	0.750			0.550			0.550	
DPG 75%												

Table 3 Natural rubber compounds using low levels of sulfur, 55 to 64 IRHD														
Target IRHD	55	55	55	54	56	57	60	61	61	63	63	65	64	
Material														
Flexon 845 paraffinic oil		4.500												
Sunpar 2280														
CaO 80%														
Renacit 7														
53362 M/B	82.250	125.702	87.556	111.435	106.129	127.355	137.968	119.395	153.887	135.315	160.520	140.621	164.500	
SMR5 CV60	51.250	24.798	47.944	33.065	36.371	22.581	16.532	28.105	6.613	18.185	2.480	14.879		
SBR S1606														
SBR S1808														
Zinc oxide activ	0.700	3.300	3.700	0.700	3.700	0.452	0.300	3.400		3.300	0.300	3.000		
Flectol		2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000		2.000	2.000	2.000	
ZEH 75%	2.000	3.000	3.700	2.000	3.000	2.000	2.000	3.000	3.000	3.000	2.000	3.000	2.000	
Aktioplast T														
Dispergum 24	3.000	3.000	3.000	3.000	5.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	
Stearic acid														
Wingstay 100														
IPPD 80%														

[illegible]

Appendix 2

Table 1 Natural rubber compounds with intermediate sulfur levels -42 to 66 IRHD													
Target IRHD	42	45	50	51	52	60	60	61	61	63	66		
Material													
Flexon 845 paraffinic oil	3.000		4.750						7.000				
Sunpar 2280													
CaO 80%													
Renacit 7													
53362 M/B	18.573	18.573	82.250	55.718	61.024	95.516	106.129	108.782	135.315	119.395	132.661		
SMR5 CV60	90.927	90.927	51.250	67.782	64.476	42.984	36.371	34.718	18.185	27.419	19.839		
SBR S1606													
SBR S1808													
Zinc oxide activ	1.500	1.500	0.700	1.200	1.200	3.000	0.400	0.700	0.300	0.548			
Flectrol	1.500	1.500		1.500	1.500	2.000	1.500				1.500		
ZEH 75%	2.000	2.000	3.000	2.000	2.000	3.000	2.000			2.000	2.000		
Akriplast T								2.000	3.000				
Dispergum 24	3.000	2.000	3.000	3.000	3.000	3.000	3.000	3.000	5.000	3.000	3.000		
Stearic acid													
Wingstay 100													
IPPD 80%													

[illegible]

Table 2 Natural rubber compounds with intermediate sulfur levels -67 to 72 IRHD												
Target IRHD	67	68	69	69	70	71	71	71	72	72	72	72
Material												
Flexon 845 paraffinic oil												
Sunpar 2280												
CaO 80%										3.000		
Renacit 7												
53362 M/B	145.927	143.274	164.500	159.194	156.540	164.500	164.500	164.500	164.500	164.500	164.500	164.500
SMR5 CV60	11.290	13.226		3.306	4.960							
SBR S1606												
SBR S1808												
Zinc oxide activ	0.226											
Flectol	1.500	1.500	1.500	1.500	1.500	2.000	2.000		1.500			
ZEH 75%	2.000	2.000	2.000	2.000	2.000	3.000	3.000	2.000	2.000			
Akriplast T										2.000	2.000	
Dispergum 24	3.000	3.000	2.000	3.000	3.000	5.000	3.000	3.000	3.000	3.000	3.000	
Stearic acid												
Wingstay 100										1.000	1.000	
IPPD 80%												

[illegible]

Appendix 3

Table 1 Natural rubber compounds using high levels of sulfur, 40 to 57 IRHD													
Target IRHD	40	42	42	44	47	47	48	50	51	52	54	56	57
Material													
Flexon 845	11.000				5.000						7.000		1.000
Sunpar 2280													
CaO 80%	2.700								2.400				
Renacit 7		0.350											
53362 M/B	61.024	22.552	5.306	10.613	87.556	76.944	58.371	68.984	26.532	79.597	124.702	74.290	122.048
SMR5 CV60	64.476	88.448	99.194	95.887	47.944	54.556	66.129	59.516	83.871	52.903	24.798	56.210	26.452
SBR S1606													
SBR S1808													
Zinc oxide activ	1.000	4.220	1.700	1.700	0.800	0.800	1.300	1.000	1.677	0.800	3.000	0.800	0.800
Flectol	1.000	1.500	2.000		1.500	1.500	2.000	2.000		2.000	1.000		1.500
ZEH 75%			2.000	2.000			2.000	2.000	3.000	2.000	2.000	3.000	
Aktioplast T	2.000												
Dispergum 24	3.000		2.000	3.000	1.500	1.500	3.000	3.000	3.000	3.000	3.000	3.000	1.500
Stearic acid		2.000			1.000	1.000							1.000
Wingstay 100		1.000			1.000	1.000							1.000
IPPD 80%		3.000			3.000	3.000					3.000		3.000
6PPD	1.000		3.000	3.000	2.000	2.000	3.000	3.000	2.000	3.000	2.000	2.000	2.000

Okerin 1995	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Rhenogran S	2.000	3.000	3.000	3.000	2.500	2.500	2.500	2.500	2.500	2.500	3.600	2.500
TMTD 80%		0.200			0.200	0.200					0.200	0.200
TMTM 80%												
TBBS										0.900	1.100	
CBS	1.300	0.600	0.600	0.600			0.600	0.600	0.600			
Perkacit MBTS 80						0.375						0.500
MBT 80%	0.900		0.400	0.400	0.500	0.250	0.400	0.400	0.400			

Table 2 Natural rubber compounds using high levels of sulfur, 58 to 76 IRHD												
Target IRHD	58	58	60	62	66	67	69	69	71	72	73	76
Material												
Flexon 845												
Sunpar 2280												
CaO 80%					2.770			2.770				
Renacit 7												
53362 M/B	122.048	71.637	127.355	137.968	153.887	143.274	156.540	140.621	164.500	145.927	156.540	164.500
SMR5 CV60	26.452	57.863	23.145	16.532	6.613	13.226	4.960	14.879		11.573	4.960	
SBR S1606												
SBR S1808												
Zinc oxide activ	0.800	0.700	0.800	3.000		0.300			0.300			
Flectol	1.500		2.000	2.000		1.500			1.500	1.500		
ZEH 75%		3.000	2.000	3.000								
Aktioplast T					2.000		2.000	2.000		2.000	2.000	2.000
Dispergum 24	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000		3.000	3.000	3.000
Stearic acid	1.000					1.000			1.000			
Wingstay 100	1.000					1.000	1.000	1.000	1.000	1.000	1.000	1.000
IPPD 80%	3.000					3.000			3.000	3.000		

6PPD		2.000	2.000	3.000	3.000	1.000	2.000	1.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Okerin 1995		2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Rhenogran S		2.500	3.600	2.500		2.100	2.800	3.000	2.700	2.800	3.000	2.800	2.800	2.800	3.300
TMTD 80%		0.200													
TMTM 80%															
TBBS			1.100												
CBS				0.600	1.200	1.700	1.600	1.700	1.600	1.600	1.600	1.600	1.600	1.600	1.600
MBTS 80	0.500														
MBT 80%			0.100	0.400	0.300										
DPG 75%															

A ppendix 4

Table 1 Medium damping natural rubber blends								
Target IRHD	46	54	55	56	60	61	62	70
Materials								
Flexon 845		7.000	6.000					
53362 M/B	81.719	106.023	120.987	96.976	100.822	111.515	90.210	57.600
SMR5 CV60	20.831	26.187	6.613	26.699	19.178	22.765	30.915	
SBR S1606	48.600	22.500			45.000		24.300	105.300
SBR S1808			45.000	33.750		22.500		
Zinc oxide activ	2.000	1.000	0.700	1.000	0.800	1.000	1.000	2.000
Flectol								
ZEH 75%	3.000	3.000		3.000		3.000		
Aktioplast T			3.000					
Dispergum 24	3.000	3.000	3.000	3.000	2.000	3.000	3.000	3.000
Stearic acid					1.500		1.500	2.000
6PPD	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Okerin 1995	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Rhenogran S	1.100	1.300	1.000	1.300	1.250	1.300	1.600	2.000
TMTD 80%			1.000		0.300		0.400	0.500
TBBS	1.000	1.200	1.400	1.200		1.200		
CBS					1.100		1.200	0.700
MBTS 80					0.625		0.625	
MBT 80%	0.375	0.200		0.200	1.000	0.200	0.750	
DPG 75%	2.670	2.670	0.930	2.670		2.670		

Appendix 5

Table 1 Natural rubber compounds with a range of carbon black grades													
Compound IRHD	30	30	40	40	45	45	60	60	60	60	60	60	70
Compound reference			A	B	C	D	E	F	G	H			G
Ingredients													
SMR CV60	92.581	100.000	100.000		100.000	79.355	100.000	51.250	100.000	6.613			
SMR 20 CV				100.000									
56693 M/B	18.919												
53362 M/B						37.145		82.250		153.887	162.500		
Renacit 7		0.400			1.000	0.500	0.700		0.450				
N900				76.000									
N762							38.000						
N765									48.000				
N330			36.000		13.000								
N660		7.000											
Sunpar 2280			36.000		3.000	2.000							
Flexon 845	21.000	16.000		23.000			4.000	4.750	4.000				
ZEH 75%			3.000		3.000	3.000		3.000	3.000	3.000	2.000		
Dispersum 24			4.000	4.000		3.000	3.300	2.000	3.000	3.000	3.000		
Zinc oxide activ	1.800	2.000	5.000	2.000	5.000	4.500	2.000	0.700	1.750				
Stearic acid	1.000	1.000											
Wingstay 100											1.000		
Flectol					2.000	2.000				2.000			
6PPD	1.000	1.000	3.000	2.000	3.000	3.000	3.000	3.000	2.000	3.000			

Okerin 1995	3.000	3.000	3.000	2.000	2.000	2.000		2.000	2.000	2.000	2.000	2.000	2.000	
Rhenogran S	3.000	3.000	3.000	1.000	1.000	0.900	1.000	1.000	1.300	1.700	1.000	1.800		
TMTD 80%				0.700	0.625	1.000	1.000	1.200	0.800			0.200		
TBBS				1.500		1.200	1.300		1.200					
CBS										2.000	2.000	2.000		
Perkacit MBTS 80	0.350	0.350	0.350		1.250									
MBT 80%				0.625	0.625					0.200	0.550			
PVI				0.300			3.000							
DPG 75%	0.350	0.350	0.350	1.330				0.330						
PVI – N-(cyclohexylthio) phthalimide														

Table 2 Natural rubber master batches and suggested use of compounds in Appendix 1													
Masterbatches	56693 M/B	53362.00	Uses:										
SSMR CV60	100.00	100.00	A: Engine mounts to 100 °C										
Renacit 11G	0.50	0.50	B: Bump stops										
N330	0.00	60.00	C, D: Mounts upto 140 °C										
N660	93.00	0.00	E, F: Spring-leaf pads										
Zinc oxide activ	2.00	2.00	G: Suspension bush										
TOTAL	195.50	162.50	H: Bush with high fatigue resistance										

Masterbatch equivalent	
N660	9.00
Natural rubber	9.68
Zinc oxide activ	0.19

Appendix 6 High damping compounds - Examples of halo-polymer formulations

Table 1 Bromo butyl example	
Target IRHD	60
Ingredients (pphr)	
Bromo butyl rubber 2225	100
Flexon 845	4
N330 carbon black	60
Stearic acid	2
Paraffin wax	4
Rhenogran S	1.25
Zinc oxide 80%	2.5

Table 2 Polychloroprene examples			
Target IRHD	50	60	75
Ingredients (pphr)			
Neoprene TRT	100.00	100.00	100.00
Bisoflex 111	5.00	6.00	5.00
Deoflow A	4.00		5.00
Polyethylene AC617A	2.00		
Okerin 1995		2.00	
N330 carbon black	30.00	30.00	51.00
Ethylene thiourea 80%	0.50	0.30	0.63
TMTD 80%	1.25		
TMTM 80%		0.60	
Di- <i>ortho</i> -tolylguanidine (DOTG) 80%		0.50	
MBTS 80%			1.56
Rhenogran S		1.25	
Rapiblend 1793	11.00	11.00	11.00

Table 3 Butadiene acrylonitrile compounds						
Target IRHD	55	60	65	65	70	70
Ingredients						
NBR 28-30% acrylonitrile	100.00	100.00				
NBR 33-35% acrylonitrile			100.00	100.00	100.00	
NBR 40-42% acrylonitrile						100.00
Bisoflex 111	10.00	15.00	15.00	12.00	14.00	10.00
Carbon black N330	28.00	40.00	66.00	54.00	75.00	
Sulfur 80%(Rhenogran S)	1.25	0.60	0.60	1.25	1.63	0.35
6PPD	2.00	2.00	2.00	2.00	1.00	2.00
Okerin 1995					2.00	
Flectol				2.00		
Zinc oxide active	2.00	2.50	2.00	2.00	2.00	2.00
Dispergum 24		2.00	1.00			3.00
Stearic acid	1.00					
TMTD 80%			2.90			2.00
TMTM 80%	2.00			1.40	2.50	
CBS		2.50	2.50			2.00
PVI 80PM		0.20				
Tip: Always add the sulfur with the carbon black NBR – Nitrile-butadiene rubber						

A ppendix 7

Table 1 Purge compounds		
	General purpose	EPDM
Ingredients		
SIR 20	50.00	
SBR 1712	50.00	
EPDM		100.00
N660 black	25.00	200.00
2280 oil	20.00	100.00
Calcium carbonate	50.00	
Deoflow A	4.00	
The general purpose compound can be used for purging machines using all natural rubber and natural rubber blends and also bromobutyl, polychloroprene and nitrile compounds. The EPDM purge is intended for use with EPM and EPDM compounds.		

A ppendix 8

Table 1 Glossary of materials	
Ingredient	Description
6PPD	<i>N</i> -(1,3-dimethylbutyl)- <i>N'</i> -phenyl-1,4-benzenediamine, antiozonant
Aktiplast T	Combination of zinc salts of unsaturated fatty acids, activator and process aid
Bisoflex 111	Bis[2-(2-butoxyethoxy)ethyl] adipate, plasticiser
Bromo butyl rubber 2225	Brominated butyl bromine content 1.3%, polymer
CaO 80%	Oil paste containing 80% anhydrous calcium oxide, dessicant
CBS	<i>N</i> -Cyclohexyl-2-benzothiazole sulfonamide, accelerator
Deoflow A	Blend of fatty alcohols and fatty acid esters, process aid
Dispergum 24	Proprietary oxidation catalyst combined with zinc salt of defined fatty acids, activator and process aid
DOTG 80%	Di- <i>ortho</i> -tolylguanidine dispersion
DPG 75%	Diphenylguanidine, accelerator
Ethylene thiourea 80%	<i>N,N'</i> -ethylene thiourea, polychloroprene accelerator
Flectol	2,2,4-Trimethyl-1,2-dihydroquinoline, antioxidant
Flexon 845	Paraffinic oil, 0.86 g/ml, process oil
IPPD 80%	<i>N</i> -isopropyl- <i>N'</i> -phenyl- <i>p</i> -phenylenediamine, antiozonant
MBT 80%	2-Mercaptobenzothiazole, accelerator
MBTS 80%	Dibenzothiazyl disulfide, accelerator
N330	High abrasion furnace carbon black, reinforcing filler
N660	General purpose furnace carbon black, reinforcing filler
N762	Low structure soft furnace carbon black, reinforcing filler
N765	Soft furnace carbon black
N900	Medium thermal black
Neoprene TRT	Polychloroprene grade
Okerin 1995	Microcrystalline wax, mp ~53 °C, static antiozanant

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Paraffin wax	Process aid, release aid
Polyethylene AC617A	Process and release aid
PVI	<i>N</i> -(cyclohexylthio) phthalimide, retarder, prevulcanisation inhibitor
Rapiblend 1793	Blend of zinc oxide and magnesium oxide in polymer/oil, curative for polychloroprene
Renacit 7	Pentachlorothiophenol , peptising agent
Rhenogran S	Sulfur dispersed in EPDM/EVA, fast dispersing sulfur
SBR S1606	Styrene-butadiene rubber black masterbatch, 52 pphr N330, 10 pphr oil
SBR S1808	styrene butadiene rubber, black masterbatch, 75 pphr N330, 50 pphr oil
SMR 20 CV	Standard Malaysian rubber, 0.16 % dirt
SMR CV60	Standard Malaysian rubber, 0.02% dirt, controlled viscosity
SMR5 CV60	As above
Stearic acid	Low iodine value grade, activator
Sunpar 2280	Paraffinic oil 28 to 32 cps
TBBS	<i>N-Tert</i> -butyl-2-benzothiazole sulfenamide, accelerator
TMTD 80%	Tetramethyl thiuram disulfide, 80% dispersion in EPDM/EVA base
TMTM 80%	Tetramethyl thiuram monosulfide, 80% dispersion in EPDM/EVA base
Wingstay 100	1,4-Benzenediamine <i>N,N'</i> -mixed phenyl and tolyl derivatives, antioxidant
ZEH 75%	Zinc 2-ethyl hexanoate on silica base
Zinc oxide 80%	Zinc oxide 9 m ² /g, dispersed in EPDM/EVA base, activator
Zinc oxide activ	Zinc oxide 9 m ² /g, activator
EPDM – Ethylene-propylene-diene terpolymer EVA – Ethylene vinyl acetate copolymer Cps – Centipoise	

Abbreviations

6PPD	<i>N</i> -(1,3-dimethylbutyl)- <i>N'</i> -phenyl-1,4-benzenediamine
CaO	Calcium oxide
CBS	<i>N</i> -Cyclohexyl-2-benzothiazole sulfonamide
CEO	Chief Executive Officer
CFC	Chlorofluorocarbon(s)
Cps	Centipoise
CV	Control viscosity
DOTG	Di- <i>ortho</i> -tolylguanidine
DPG	Diphenylguanidine, accelerator
EVA	Ethylene vinyl acetate copolymer
FED	Factorial experiment design
FIFO	First in, first out
FMEA	Failure mode effect and analysis
HRC	Rockwell hardness scale C
IPPD	<i>N</i> -isopropyl- <i>N'</i> -phenyl- <i>p</i> -phenylenediamine
IRHD	International Rubber Hardness Degrees
MBT	2-Mercaptobenzothiazole
MBTS	Dibenzothiazyl disulfide
MH	Minimum torque
ML	Maximum torque
MRPRA	Malaysian Rubber Producers' Research Association
NBR	Nitrile-butadiene rubber
NR	Natural rubber
PC	Polychloroprene
PLC	Programmable logic controller
pphr	Parts per hundred rubber
SBR	Styrene-butadiene rubber

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SMR	Standard Malaysian rubber
TARRC	Tun Abdel Razak Research Centre
TBBS	<i>N-Tert</i> -butyl-2-benzothiazole sulfenamide
TGA	Thermogravimetric analysis
TMTD	Tetramethyl thiuram disulfide
TMTM	Tetramethyl thiuram monosulfide
ZEH	Zinc 2-ethyl hexanoate

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Published by Smithers Rapra Technology Ltd, 2012

Many injection moulding processes produce rejects or scrap, because they depend on a number of variables. To eliminate waste it is necessary to learn how to recognise the variables that cause problems, and then experiment to understand their interdependence. This can be developed to a fine art and lead towards 'right first time' processing, the commercial ideal. There are many factors that contribute to success or failure in rubber injection moulding from the design stage of a product, through choosing and setting up machinery, to experimenting to find the best operating conditions. Varying any one factor, such as the polymer additives, can affect the ability of the equipment to adequately process the rubber.

The book is aimed at potential customers and personnel in the injection moulding industry, and emphasises quality control, including working to the ISO 9001 Standard. It also highlights the need to consider the economics of operation prior to taking on new projects. Above all, the customer-manufacturer relationship is emphasised at all stages. The customer is encouraged to examine the capabilities of the manufacturer, and the manufacturer is encouraged to develop a good understanding of the exact requirements of the customer. This book is of value to all areas of a company, from those who purchase raw materials to those working in design, technology and production. It will provide a guide for automotive component buyers and should also be useful to a CEO or board member who is new to the industry.



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