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SOME BASIC FACTORS INVOLVED IN SETTING UP OF A DRY RUBBER BASED PRODUCTS MANUFACTURING INDUSTRY

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The technology of various kinds of rubber products manufacture could be based on a number of key processes and operations. For conventional vulcanized rubber products manufacture, the three fundamental stages involved are,

1. Mixing
2. Shaping
3. Vulcanization

The techniques used for each of these three stages will exert a substantial influence on productivity, performance and the quality of the final finished product.

The following basic fundamental steps are considered as essential in setting up of a rubber products manufacturing industry.

1. Planning the production system with respect to products, processes and facilities
2. Implementing the production system design
3. Monitoring and controlling operations at various levels of manufacturing processes

Once the market demand for a particular product has been identified, a detailed study of processing behavior of the materials used in the manufacturing process is essential for effective setting up of the manufacturing processes. These processes involve mixing, extrusion, calendering, moulding and vulcanization steps which require both organizational and technical skills. This study will also help to overcome some of the problems such as inappropriate mixing, aging, blooming *etc*. that may be experienced by the rubber products manufacturers during or after the products manufacturing process.

Having established the basic steps, the next approach useful for dealing with manufacturing industry should be the material testing, products performance and production organization for successful and efficient manufacture.

There are two distinct areas in which test results contribute to the objectives of optimization and control of process performance to produce good quality materials.

1. Process development and problem solving
2. Routine quality control testing

Each of these generates its own requirements with respect to testing procedures, conditions and the treatment of results; although it is often possible to use similar test equipment in each area.

For process development and to study the processability or the extent to which the performance of rubber processing operations may be fully controlled, the test results for each of the following three physical property groups are generally desirable.

1. Flow behaviour
2. Vulcanization characteristics
3. Heat transfer properties

Before dealing in detail with individual properties and their measurements, it is important to review their influence on property behaviour.

Rubber is a visco elastic material and even in the unvulcanized state is capable of displaying behaviour ranging from predominantly viscous to predominantly elastic, depending on temperature and rate of deformation. In processing, the main concern lies with flow and shaping operations and in conventional rubber mixes these operations prohibits with the introduction of cross-links.

The mixing operation of rubber is complex composite operation and it is very difficult to quantify. The complexity is a result of visco elastic behaviour of the rubber and of the nature of the materials with which it is required to be mixed. Particulate fillers are not masses of simple particles but consists of groups of particles called agglomerates, which must be broken down and uniformly distributed throughout the rubber during mixing.

Most mixing systems consist of an internal mixer and another machine, either a two-roll mill or an extruder/continuous mixer. The whole system must then be considered when setting the conditions necessary to produce an adequately mixed material.

General rubber goods manufacturers usually have mixers with chamber volumes in the range 40 - 250 l while tire manufacturers due to their large volume requirements, tend to use machines in the range 250 - 700 l.

Mixing of rubber involves a number of different mechanisms. These can be resolved into four basic processes.

1. Viscosity reduction
2. Incorporation
3. Distributive mixing
4. Disperse mixing

Each of these can occur simultaneously. Mixing time will depend on the type of compound being mixed and the mixing conditions.

When a charge of high elastic rubber is fed into a mixer it must be rapidly converted to a state in which it will accept particulate additives. This stage is called viscosity reduction and is achieved by three independent mechanisms.

1. Temperature rise
2. Chain extension
3. Mastication

Because of rubber's high viscosity and elastic stiffness, rubber in a mixer requires considerable mechanical energy, which is converted to heat causing a rapid temperature rise and viscosity reduction.

As the viscosity and elasticity of a rubber are reduced, the rubber can be caused to flow around the additives incorporating and enclosing them in a matrix of rubber.

Incorporation and distributive mixing generally proceed simultaneously, the latter commencing as soon as incorporated additives are available for distribution.

The mill operations have to be performed efficiently in order to achieve a mixed batch having the proportions required for downstream processing and product performance.

In an ideal mixing sequence for general rubber goods compounds, all the ingredients would be charged into an internal mixer together and mixed adequately, without danger of scorch, in a single cycle.

Rotor and chamber designs, discharge door configuration, temperature control facilities, drive systems are usually essential mixing-mixer variables whereas mixing time, batch temperature, mixing energy, rotor speed, fill factor and ram pressure are practical mixing variables which should be carefully looked into, for effective mixing.

For compounds containing large quantity of reinforcing fillers and requiring substantial disperse mixing, three stage mixing sequences are commonly used with following sequence.

1. Master batch
2. Remill
3. Final Mix

Each of the three stages is carried out in an internal mixer and unless the output requirement is high, the same mixer is used for each stage. In the materbatch stage the rubber and the reinforcing filler are mixed at a high rotor speed (40-60 rpm depending on mixer size), together with any particulate additives which are not temperature sensitive. A substantial temperature rise occurs during this stage and the final batch temperature is often in the region of 140^0C - 160 ^{0}C. Following discharge from the internal mixer, the batch is either sheeted out on a two-roll mill, cooled and cut into slabs or is extruded and palletized. Disperse mixing can then be carried out again on the internal mixer at a low temperature. The addition of the curatives in the final stage can be carried out usually at 90-105°C. After this the compound is again sheeted out or palletized and cooled for downstream processing. For moderately reinforced samples, a two-roll mill can be used for remill stage effectively due to the absence of a problem with loose fillers. It is also a common practice to add curatives on a two-roll mill that are premixed with rubber to avoid powder loss.

For effective milling and homogenization in a rolling nip, a bank of materials must be formed above the nip. The reservoir of materials ensures that the nip is adequately fed and that effective flow work is being done on the material. The capacity of a two-roll mill is determined by the setting of the nip, which fixes the volume material banded round one roller, and by the need for the bank. If the bank of material is too large, stationary volume of material will form which take no part in the milling operation. Table 1 below gives typical mill sizes and capacities.

Table 1. *Typical mill sizes and capacities*

Roll length (m)	Roll diameter (m)	Mix Capacity (kg)	
		Minimum	Maximum
0.75	0.35	9.0	13.5
1.10	0.40	13.5	23.0
1.20	0.45	20.0	32.0
1.50	0.55	34.0	57.0
1.80	0.60	57.0	91.0
2.1	0.65	68.0	114.0
2.1	1.70	80.0	136.0

The next step which involves the selection of a suitable vulcanization process and optimization of the conditions first requires the measurement of the vulcanization characteristics and the heat transfer properties of the rubber mix. Prediction of cure time and uniformity of cure can then be made using these measurements.

The essential change in physical properties which occur when chemical cross-links are inserted between adjacent molecular chains change from viscous to elastic behaviour. Cross-links confer dimensional stability by forming a 3-D net work of rubber molecules and also result in the deformation properties, becoming temperature incentive over a broad and useful range. Since the requirement of scorch testing is the detection of the onset of cross-linking, when the material can no longer be subjected to flow, rheometers and viscometers are suitable test instruments. In the Mooney Viscometer and Monsanto Disk Curometer, the scorch time is defined as the time for 5 Mooney units or 2 lbs in^{-1} rise in torque above the minimum recorded value, respectively, at a given temperature. For quality control purposes a standard temperature (usually 180^{0}C) must be used.

Molding

In moulding, which involves an integral shaping operation prior to the onset of cross-links, the heat is transferred to the surface of the article through conducting. Here the mode of supply of heat to the surface of the article is through the mold metal and across the metal to the rubber, but cooling of the molded article is usually by free conversion, when it is demolded and air cooled.

In compression presses used for molding rubber articles the mold clamping force is invariably supplied by a hydraulic ram. For a single acting hydraulic ram the platens are closed by an upward motion of the ram and the opening by gravity is feasible. The clamping force is reacted against the tie bars or side frames of the press, which also serve to maintain the alignment of the platens. In modern presses the option of an automatic controlled curing cycles are available and when the cure time has elapsed, automatic control can include any "bumping" and "breathing" operations which are necessary to eliminate trapped air from a molding. Bumping consist of operating the hydraulic valve to open the press by a few millie-meters and then closing it again. Breathing only involves the release of the mold clamping pressure and its subsequent reapplication. The timing of these operations from the start of the cure cycle and their duration is important for their success. Automatic control ensures that the operations are carried out consistently.

Raising the processing temperature generally results in the possibility of a higher output rate but brings with it the danger of the onset of cross-linking or scorch. However, increase in the temperature of a rubber mix decreases its viscosity which indicates that there will be a trend towards a temperature-viscosity equilibrium in a flow process. Conductive heating results in pronounced temperature gradient due to the slow rate of heat transfer through rubber. This is particularly important for vulcanization, where the main aim is to heat the rubber as quickly and uniformly as possible to minimize cure time.

Development of presses with vacuum chambers which are attached to the press platens to evacuate the mold cavities of air prior to the flow of rubber can practically eliminate trapped air and has led to substantial improvements in the final products.

Molding operations

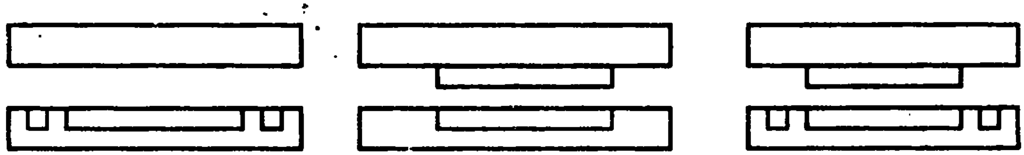
Molding operations are concerned with the sequential shaping and the cross-linking of a rubber mix. The interaction between the requirements for viscous flow and vulcanization and the dependence of both of these on temperature must be taken into consideration in molding.

High volume production will justify sophisticated techniques while small numbers indicate that expenditure on equipment dedicated to specific production should be minimal. To fulfill these requirements three main techniques have been developed, compression molding, transfer molding and injection molding with many variations on each to suit individual requirements of dimensional accuracy, complex shape, thick sections *etc.* In general the capital cost of machines and molds increases from a minimum for compression molding through transfer molding to a maximum for injection molding.

In compression molding a rubber charge or blank is made to flow to the shape of the mold cavity by the action of mold closer, the motion force for the closer being provided by a hydraulic press.

Three basic types of compression molds are

- open flash mold
- positive or plunger mold
- semi-positive mold (omitting guide pins and brushes)



open flash mold **positive or plunger mold** **semi-positive mold**

In open flash molding the shape, size and positioning of the charge is very important since it must flow fully to the form of the mold cavity in preference to flowing out through the gaps between the mold compounds during closer. Also, excessive outflow or flash can cause the mold components to be separated by a layer of rubber which varies in thickness between molding cycles, resulting in poor control of dimensions.

Positive or plunger type molds prevent escape of rubber due to the long and narrow flow path between the mold body and the plunger. For this reason, high pressure can be applied effectively to the rubber charge causing it to flow fully and constantly to the form of the mold cavity. Semi-positive molds are intended to embody the advantages of both open flash and positive molds.

The material selected for a compression mold will depend on the pressure to be applied to the clamping surfaces and the service life required of the mold. Hard steel give a good service life, provided that they are of a type which retain their hardness and dimensional stability at elevated temperatures but are difficult to the machine. In this category are Ni-Cr-Mo steels of hardness 37-64 Rockwell C.

Loose-tool molds are prone to damage since they are often opened manually using levers. One alternative is to avoid the use of metal tools for purpose and to avoid the use of metal tools for extracting the components from the mold, a compressed air line is usually suitable. Fixed-tool multi-cavity molds attached to the press platens are preferable, if justified by production volume. Cavity units are attached to backing plates or bolsters and the damaged or worn units can be replaced without removing the mold assembly from the press in many cases. The bottom bolster is usually mounted in slides, enabling it to be moved forward by a pneumatic actuator to a convenient position for stripping and loading.

In determining the dimensions of a mold cavity, an allowance must be made for thermal contraction of the molding due to cooling from the mold temperature.

Molding faults and their correction

Molding faults may arise during process development, as a result of the initial selection of inappropriate equipment or processing conditions, and during manufacture, as a result of deviations from the specified operating procedure, processing conditions etc. The following paragraphs describe the common molding faults and their causes and suggest remedies.

Distortion - This is elastic recovery of the molding, which takes place on release from the mold. It is caused by the flow in the mold occurring after the rubber compound has started to cross-link. The obvious remedy is to modify the processing conditions, the cure system of the compound, or the mold geometry. In production, a check of machine conditions and compound scorch characteristics should be sufficient to identify the source of problem. Particular attention should be paid to the press closing rate for compression and transfer molding and to the injection time for both screw and ram injection molding.

Delamination - This fault is due to material continuing to enter and fill the mold after the initial layer of rubber laid down by the mold surface have vulcanized. In addition to having the causes described for the previous molding fault , delamination is exacerbated by long flow paths, thin sections, and high mold temperatures. Since high temperatures are desirable with thin sections, to give short cure times, the main remedy for this problem is to lengthen the scorch time of the compound, provided that the procedures described for the previous fault do not reveal another remedy.

Backrinding - This is a severe local deformation at the split lines of compression molds and at the gates of transfer and injection molds. It is caused by thermal expansion of the rubber during vulcanization and can result, on demolding, in local failure of the rubber. In all cases, raising the temperature of the rubber entering the mold will reduce or eliminate the problem. Compression mold design can influence the tendency to backrinding and care should be taken to choose a split line which does not concentrate the thermal expansion of the rubber into a small region of the mold, otherwise large local deformation will occur.

Porosity - This is the expansion of the molding, on removal from the mold, to give a cellular or spongy structure. It is caused by undercure and by the presence of volatile materials, mainly water, in the rubber compound. While it is necessary to maintain the volatile materials in a compound below limits dictated by their influence on vulcanizate properties, porosity is invariably a sign of undercure. For bulky moldings it may be possible to raise the preheat temperature and thus avoid extending the cure time. For thin-section moldings, raising the cure temperature is desirable.

Blisters - These are mainly due to air-trapped or entrailed in the rubber. This can occur either in preparation or, in the case of screw injection machines, in the preplasticization unit. In the latter case it is possible to reduce or eliminate the problem by adopting one or more of the following - increasing the screw back pressure, injecting at a slower rate, and venting the mold adequately (vacuum may be desirable).

Air traps - These are faults due to air being trapped between the rubber and the surface of the mold. In all methods of moldings, air traps are due to the mold filling pattern, and molds should be designed to that air is swept from the cavity by the advancing rubber. This is a result of the correct choice of split line and, for compression molding, blank shape and placement and, for transfer and injection molding, choice of the gating position(s). For complex moldings these objectives cannot be achieved and vacuum should be used.

Process control and quality control

Quality control has traditionally been concerned with the setting of standards which must be maintained at each stage of manufacture, followed by the manual monitoring of supplies, operations, and products to check if the specified standards are maintained. In contrast, process control has been almost entirely concerned with the design and performance of systems for maintaining machine conditions and controlling machine operations. However, both quality control and process control have the common objective of enabling products which are acceptable to the customer to be produced at a cost which ensures both a competitive price and a viable profit margin.

Specifications of materials are required at three stages:

1. Raw materials
2. Mixed unvulcanized compound
3. Vulcanized compound

The manufacturing specifications for materials are generally very simple, initially serving to identify the type and quantity of each constituent of a rubber mix and then providing an identifier, usually a code number, for the mix during its progress through the manufacturing procedures. The problem of selecting measurements by which raw materials can be characterized is particularly acute, due to the wide range of materials used in rubber compounds and their often complex interactions with other ingredients. The guidance provided by the standards organizations is not very helpful in this area, and the response of many rubber companies has been to rely on raw-material manufacturers to supply consistent materials. The lack of safeguards resulting from this policy can lead to serious problems. It also implies that the product manufacturer does not know what makes a particular polymer suitable for processing operations. This lack of knowledge can make a change over to an alternative supplier's material very problematic. Hence the problems of specifying raw-material tests need to be tackled.

A typical rubber mix consists of bulk particulate fillers, a cross-linking system, oils or plasticizers, and anti-degradents, as well as one or more types of rubber. Each of these groups of materials have their own testing requirements for characterization of their influence on manufacturing operations and product performance. They will also depend on the product.

Specifications for machine settings. such as times, temperatures, positions and pressures are fairly straight forward to deal with provided certain basic rules are observed. The format for machine setting operations is required to be easily understood by those who are using them in the manufacturing process. A product specification will depend on dimensions, appearance and its function.

For a manufacturing operation to be controllable, in process control terms, systems set up for quality control methods should ensure that defective work such as waste material *e.g.* losses prior to or during mixing, incorrect weighing of ingredients and incorrect mixing, rework material, scrapped semi-finished and finished products and repairs are minimum.