1-1: Rubber Compounding

Rubber compounding is essentially the science (and art) of selecting and combining ingredients to produce a useful polymer which will have characteristics sufficient to perform satisfactorily under the conditions in which the end product is intended to be used. From the manufacturer's perspective, the major factors influencing compounding decisions are PRICE, PROCESSING, and PROPERTIES, not necessarily in that order. All three factors are important.

If the end product possesses all of the physical properties and satisfies all of the service requirements, but the price to produce the product is prohibitive to the average consumer, the product will languish on the shelf even though it has technical merit. Without sufficient demand at the price, the manufacturer has no incentive to continue manufacturing the product. Likewise, if processing costs drive the price of a particular compound to unaffordable proportions, the manufacturer may search for alternative ingredients which can be mixed or extruded with greater ease to make his product cost competitive. In any case, the compound must be safe - that is, it must possess the physical properties necessary to withstand the environment in which it is to be used.

1-1-2: RAW MATERIALS

There are many ingredients in any rubber compound; however, the ingredients can generally be classified into the following generic categories: **elastomers** (or polymers), **cure systems**, **fillers**, **processing aids**, **pigments**, **and miscellaneous** ingredients added to enhance particular properties.

The Polymer

The most important component of a rubber compound is the POLYMER (often referred to as the elastomer or the rubber). Each polymer has its advantages and disadvantages and its own inherent physical properties. For example, natural rubber is generally preferred in applications which require high tensile strength, high elongation, and fatigue resistance at comparatively high elongations. SBR (styrene-butadiene copolymers) is generally preferred in applications which require fatigue resistance at low elongations and in applications where the product will be flexed under compression. Neoprene is preferred in environments where flammability is a concern. Natural rubber is comparatively more abrasion resistant, whereas chlorobutyl (a synthetic rubber compound) is comparatively better able to withstand high temperatures. All rubbers have shortcomings in one or more properties, and oftentimes, one polymer is better able to satisfy one physical requirement of the end product's intended use, whereas a different polymer is better able to satisfy some other requirement. Therefore, blends of polymers are the rule rather than the exception in rubber compounds being manufactured today. The compounder's role is to select the best combination or blend of polymers to obtain the right compromise and to optimize the physical properties of the end product so that is can best withstand the environment into which it will most likely be placed.

Among the mechanical and physical properties to be considered in selecting a polymer are: **tensile strength, elongation, modulus (or stiffness), hardness, abrasion resistance, fatigue resistance (including cut growth), oil resistance, tack (or stickiness), water resistance, flammability, reaction to prolonged stress (including creep, drift, strain relaxation, permanent set, and stress relaxation), hysteresis (the irreversible loss of mechanical energy by internal friction), tear resistance, and aging characteristics.**

The Cure System

Selection of the CURE SYSTEM involves many of the same considerations involved in the selection of the elastomer. While cost is a consideration, it is usually secondary compared to the importance of obtaining the desired rate and state of cure, since "cure" is the process which gives the elastomer its desired physical properties. Cure is often called vulcanization or cross-linking. It is an intermolecular reaction caused by the introduction of chemicals (usually sulfur and zinc oxide or Morfax) which link or tie independent chain molecules together causing the polymer to form molecular networks. These chemical cross-links between polymer chains may be chains of sulfur atoms, single sulfur atoms, carbon to carbon bonds, polyvalent organic radicals, or polyvalent metal ions.

The critical parameters relating to the curing process are: (1) the time elapsed before the curing process starts, (2) the rate at which the process occurs, and (3) the extent to which the cross-linking occurs. There must be sufficient time before the process begins to allow the mixing of all of the ingredients of the rubber compound, the forming of the ultimate product and the molding. Thereafter, the process should be rapid, but controlled. Accelerators (such as zinc oxide) reduce the time required for cure while at the same time resisting premature vulcanization (called scorch).

Retarders, on the other hand, inhibit cross-linking or delay cure. It is desirable for a retarder to inhibit cross-linking at processing temperatures, but not at curing temperatures, thus providing more processing time without affecting the cure rate. It is the compounder's task to choose the proper cure system ingredients to accommodate the time required for mixing, forming, molding, and processing the selected polymer into the product or component being manufactured, while at the same time minimizing the time necessary to cure the material to its optimal physical properties. A strong background in chemistry (preferably rubber chemistry) is a highly desirable qualification for a compounder.

Fillers

Apart from the polymer and the cure system, CARBON BLACK is the most important ingredient which can alter the properties of a rubber compound. Carbon black is a FILLER which can actually assist in the curing of the compound, reducing the need for curatives and cure time because of its activating effect. Carbon black also serves as reinforcement and imparts abrasion resistance to all rubbers.

The particle size of the carbon black determines its abrasion resistance. The smaller the particle, the greater the resistance of the polymer to tread wear during moderate service. However, carbon black with smaller particle size is more expensive, and the smaller-size blacks require more work on the rubber batch to achieve adequate dispersion of ingredients than coarser blacks. The smaller blacks also generate more heat during mixing which can lead to scorch (premature vulcanization). Though different elastomers have widely different molecular structures, the incorporation of fillers (specifically carbon black) in appropriate amounts greatly reduces such differences in both cured and uncured stock. This has generally been referred to as the leveling action of carbon black.

Pigments

Other fillers, generally referred to as non-black PIGMENTS, are divided into three groups: reinforcing, non-reinforcing, and clays. The introduction of reinforcing pigments such as Hi-Sil (hydrated silica) produces a dry, boardy stock. Non-reinforcing pigments such as titanium dioxide are used for extreme whiteness or to mask the inherent color of the rubber or other ingredients. Clays are generally regarded as slightly reinforcing pigments and are used to aid in extrusion and to improve abrasion resistance. They also reduce mold shrinkage more than any other known material and are effective in reducing air or gas permeability.

Processing Aids

PROCESSING AIDS generally consist of plasticizers, extenders, and other oils which aid the mixing, extruding, and calendering processes. They contribute flexibility at ambient temperatures, increasing the softness or reducing the stiffness of the raw stock with only modest changes in other physical properties. Processing aids may be either completely or partially soluble. Some are soluble when the stock is hot and bleed to the surface when the stock cools. Waxes used for ozone resistance fall into this category. As the wax migrates (or blooms) to the surface, it forms a protective coating which acts as a barrier against ozone attack (oxidation).

As stated previously, the most important compounding ingredient in a high quality rubber product is the polymer, followed closely by the curing system. The carbon black is the next most important ingredient. Selection of the remainder of the components is important, but generally not critical. Cost, in all cases, must be weighed against the intended function of the product, public safety issues, and the competitive environment in which the product is marketed.

Tire Manufacture

The Sumerians invented the wheel over 5000 years ago. R.W. Thomson invented the tire in 1846 - though he called it "an air tube device" in his patent, and his invention went unnoticed until 1888. We've come a long way in slightly more than 100 years, but there are still only three basic tire types:

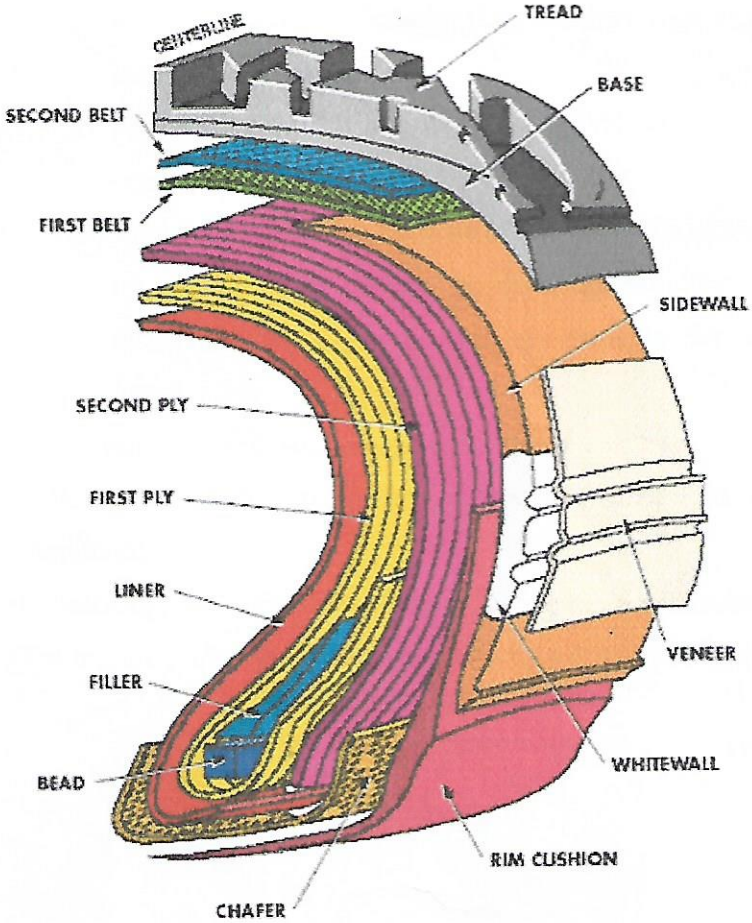
•**THE BIAS OR CROSS-PLY TIRE** which is constructed with reinforcing cords extending diagonally across the tire from bead to bead in successive layers called plies;

•**THE BIAS BELTED TIRE** which is constructed of a bias-angle carcass and a restricting belt around the circumference under the tread; and

•**THE RADIAL TIRE** which has plies of reinforcing cords extending across the tire from bead to bead, overlaid by a belt composed of several more layers of cord.

All tires consists of the following components:

Diagram



1. **The Tread**, which is the wear resistant component consisting of ribs designed for noise suppression and traction and grooves designed for traction, directional control, and cool running;
2. **The Sidewalls**, which are the portions of the tire between the beads and the tread compounded of rubber with high flex and weather resistance to control the ride and provide support;
3. **The Shoulder**, which is the upper portion of the sidewall just below the tread edge and affects tire heat behavior and cornering characteristics;
4. **The Bead**, which is a structure composed of high tensile strength steel wire formed into hoops which function as anchors for the plies and hold the tire assembly onto the rim of the wheel;
5. **The Plies**, which are layers of fabric cord extending from bead to bead to reinforce the tire;
6. **The Belts**, which are narrow layers of coated tire cord or rubber encased steel cords located directly under the tread in the crown of the tire to resist

deformation in the footprint (i.e., the tire's contact patch on the road) and to restrict the carcass plies;

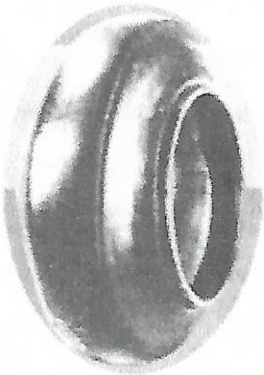
7. **The Liner**, which is a thin layer of rubber inside the tire which contains compressed air; and
8. **The Chafer**, which consists of narrow strips of material around the outside of the bead that protect the cord against wear and cutting by the rim, distributes flex above the rim, and prevents dirt and moisture from getting into the tire.

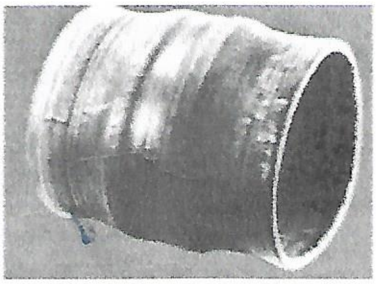
Tire manufacturing is still a very labor intensive process. It consists of:

• **Mixing** the elastomers, carbon blacks, and other chemicals to form the rubber compound;

•**Fabricating** the various fabrics and Coating them with rubber in a calender;

•**Tubing** the rubber treads and sidewalls by extruding the rubber from a tuber;





•**Assembling** all of those components (i.e., the calendered and cut carcasses and belts, and the extruded tread, sidewall, and beads) on a tire building machine;

•**Curing** the assembled tire under heat and pressure (called vulcanization);

•**Inflating** the tire; and

•**Finishing** it (which involves trimming, buffing, balancing, and inspecting).

Prior to vulcanization (cure), the rubber components are in their "green" (uncured) state. As stated above, the tire is built or assembled at the tire building machine in the green state. Basically tire building involves the application of plies and other components onto a cylindrical drum or barrel, commencing with the inner liner. Next, the beads are set in place, and the plies are turned up around the beads. In the case of a belted tire, the belts are applied next, followed by the tread and sidewall. Then, the