

CHAPTER II

THEORY AND LITERATURE REVIEWS

2.1 Rubber blends

In rubber industry, the usage of rubber blends was developing for several years. General desire is to combine the best features, technical or economic, of two rubbers to achieve durability at a minimum cost in blends. Such as new requirements for tyres by improved rolling resistance without the loss of traction and good ozone resistance. The development of NR and EPDM blends with the aim of combining the excellent physical properties of NR with the ozone resistance of EPDM [3].

Rubber blends can be prepared by various methods, such as, synthesis, latex or solution blending, combinations of these methods, mechanical and mechanochemical mixing methods, and powder mixing in some case [5]. For economic reasons mechanical blending is a common practice.

2.1.1 Mechanical blending

Mechanical blending provides enormous homogeneity of two rubbers, which differ in solubility. Rubber mixing operation by mechanical blending consists of three concurrent processes; simple mixing, laminar mixing, and dispersive mixing, which can be presented by four physical changes [6].

2.1.1.1 Incorporation or wetting stage

In this first stage, during the mixing process surface area of the rubber increases for accepting filler aggregates. The composition of the blend is made uniform throughout the batch. This process is sometimes called distributive mixing.

2.1.1.2 Dispersion

In this step, filler aggregates are gradually broken down and then dispersed to surrounding surface of rubber and a pseudochemical reaction occur. High stresses are needed to achieve this situation which if brought to completion gives maximum strength properties to vulcanizate. Accordingly, the extruders used in the rubber industry are most often employed in an auxiliary capacity to improve distributive mixing and to shape the rubber. Dispersive mixing is carried out in internal mixers or, for small batches, often on open-roll mills.

2.1.1.3 Distribution

In this step homogenization increasingly occurs through the mixing cycles. The factors have been considered relate to distribution of entities between phase of the blends, distribution of fillers between the blends, distribution of plasticizer between the blends, and distribution of crosslinks between the blends

2.1.1.4 Plasticisation

In this last stage of mixing rheological properties are adjusted to meet fabrication requirements.

Although developments in the design of rubber mixers were not expressly carried out to improve rubber-rubber blending, the optimal distribution and dispersion of carbon black and the other ingredients of a rubber formulation are controlled by the same mechanism pertinent to the blending of rubbers.

2.1.2 Mixing equipment for mechanical blending

The high shearing force required to blend high, macromolecular-weight rubbers are provided by only open-roll mills, internal mixer, and extruders. For this section, we shall explain only open-roll mills and internal mixer, used in this research.

2.1.2.1 Open-roll mill

A two-roll mill consists of two opposite rotating parallel rollers placed close to another with the rolls lying in a horizontal plane so that a small gap or nip exit between the cylindrical surfaces. The nip was made adjustable by moving “adjustment” at the front roller. The rollers have different speeds, the front roll is usually slower and the back roll is faster. The compound reaching the nip is blended, and homogenizing the additives to give an adequate distribution of the ingredients and flow through the nip in of the direction of roll motion. A schematic diagram of two-roll mill is shown in Figure 2.1 [7].

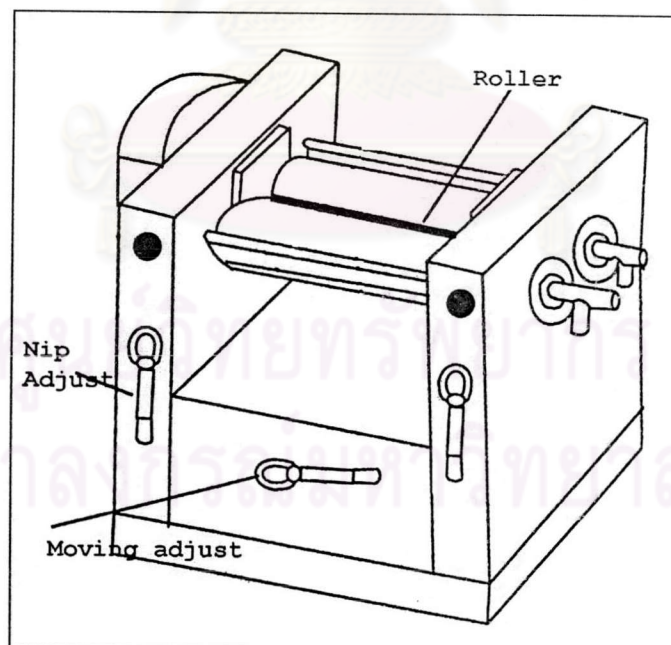


Figure 2.1 Schematic diagram of two-roll mill

2.1.2.2 Internal mixer

An internal mixer consists of two horizontal rotors inside the jacket. A floating ram that forces the material into the mixing chamber contains rotors of complex shape, moving at different speeds. In the design of internal mixers these developments include an increasing number of wings, on the mixer rotors to increase the quantity of high shear areas inside the mixer. Then allowing the rotors to intermesh so that dispersive shearing occurs not only between the rotor tip and the walls, but also between the rotor themselves.

It is often important to efficiently cool the rubber in an internal mixer in order to maintain high viscosity. Controlling temperature in general requires the capability for efficient removal of heat by drill passages that allow flow of the cooling close to the inner surface of the mixing chamber. A schematic section of the internal mixture is shown in Figure 2.2.

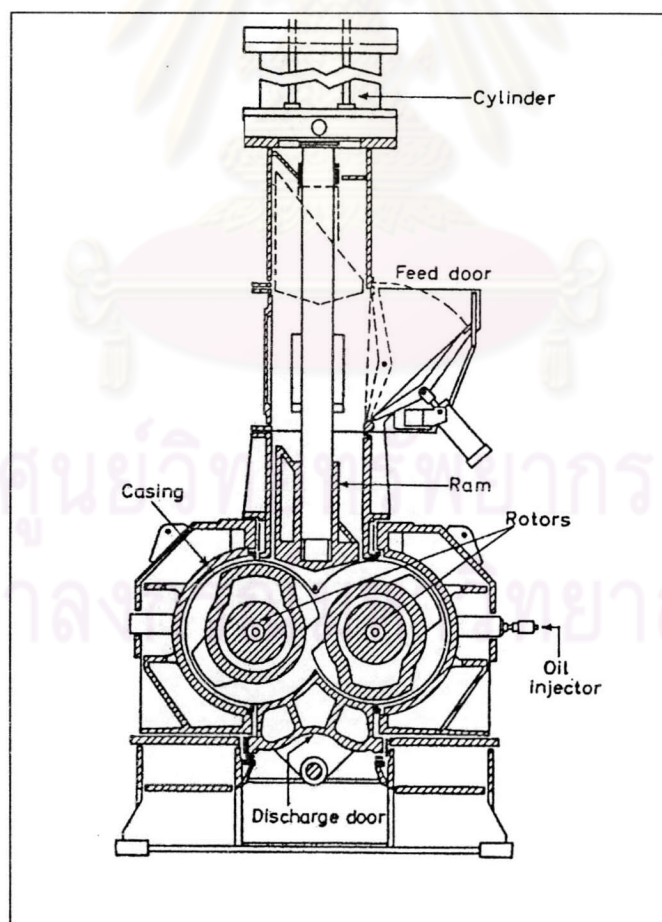


Figure 2.2 Schematic section of the internal mixer

2.2 Natural rubber

2.2.1 Production

Natural rubber is obtained from the milky secretion (latex) of various plants, but the only important commercial source of natural rubber (sometimes called Para rubber) is the tree *Hevea Brasiliensis*, native to Brazil. Over 80% of natural rubber come from Southeast Asia, the most is from Malaysia, Indonesia and Thailand [8]. To soften the rubber so that compounding ingredients can be added, the long polymer chains must be partially broken by mastication; mechanical shearing forces applied by passing the rubber between rollers or rotating blades. The efficiency of mastication carried out below 353 K (in an open two-roll mill) or above 393 K (in an internal mixer) [9]. Adding compounded with other ingredients, e.g., fillers and pigments such as carbon black for strength and whiting for stiffening, antioxidants, plasticizers, usually in the form of oils, waxes, or tars, accelerators and vulcanizing agents. The compounded rubber is sheeted, extruded in special shapes, applied as coating or molded, then vulcanized.

Most Para rubber is exported as crude rubber and prepared for market by rolling slabs of latex coagulated with acid into thin sheets of crepe rubber or into heavier, firmly pressed sheets that are usually ribbed and smoked. An increasing quantity of latex, treated with alkali or ammonia to prevent coagulation, is shipped for processing in manufacturing centers. Most of the rubber imported into the United States is used in tyres and tyre products; other items that account for large quantities are belting, hose, tubing, insulators, valves, gaskets, and footwears.

2.2.2 Properties of natural rubber

Natural rubber is a polyterpene, it consists of isoprene molecules linked into loosely twisted chains. The monomer units along the backbone of the carbon chains are in a *cis* arrangement (see Figure 2.3) and it is this spatial configuration that gives rubber its highly elastic character. Unvulcanized rubber is soluble in a number of hydrocarbons, including benzene, toluene, gasoline, and lubricating oils. Rubber is water repellent and resistant to alkalis and weak acids. Rubber's elasticity, toughness, impermeability, adhesiveness, and electrical resistance make it useful as an adhesive, a coating composition, a fiber, a molding compound, and an electrical insulator. From Table 2.1, some physical properties of natural rubbers are shown.

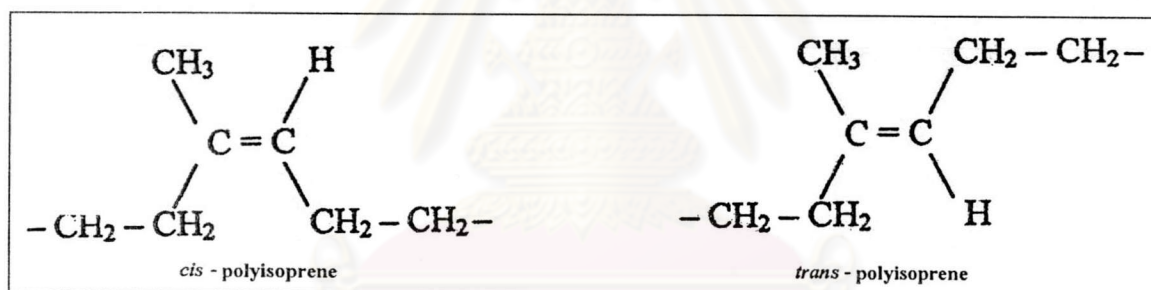


Figure 2.3 *Cis*- and *trans*- configurations of polyisoprene

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table 2.1 Average physical properties of natural rubber

Properties	Value
Density, kg m^{-3}	930
Mooney viscosity	50-90 ML1+4 at 373K
Refractive index, n_D	1.52 at 293 K
Heat of combustion, kJ kg^{-1}	44,800
Thermal conductivity, $\text{W m}^{-1}\text{k}^{-1}$	0.134
Dielectric constant, kHz	2.37
Volume resistivity, ohm cm	10^{15}
Dielectric strength, kV/mm	1

2.3 Ethylene propylene diene monomer (EPDM) and ethylene propylene monomer (EPM)

Ethylene propylene rubbers are produced by a polymerization process, using anionic co-ordinated catalyst systems developed by Natta and his research team at Milan. They are commonly identified in two types: EPM for copolymers and EPDM for terpolymers where “E” and “P” mean ethylene and propylene, respectively; and “M” for a saturated chain of the polymethylene type. In case of EPDM, “D” means that units derived from a diene rubber are in the polymer with the residual unsaturation in a side chain [8, 9]. The copolymers consisting of ethylene and propylene units are saturated therefore, they cannot be vulcanized by conventional means. The terpolymers containing a small amount of unsaturated monomer are being developed so they can be vulcanized by peroxides and sulfur system.

2.3.1 Structure and properties

The ethylene-propylene copolymers (EPM) and terpolymers (EPDM) are hydrocarbon rubber. They are resistant to polar solvents but dissolve or swell in hydrocarbons and have excellent resistance to phosphate ester-type hydraulic fluids. Copolymerization of ethylene and propylene provides unsaturation sites for crosslinking inside chain pendants from the saturated backbone. 1,4-Hexadiene (1,4-H), dicyclopentadiene (DCPD), and ethylelidene norbornene (ENB) have been used as the third monomer. Some physical properties and their chemical structure are given in Table 2.2 and Figure 2.4, respectively.

Table 2.2 Average physical properties of EPDM

Properties	Value
Density, kg m^{-3}	860
Mooney viscosity	60-70 ML1+4 at 373 K
Heat capacity, kJ kg^{-1}	2.18
Thermal conductivity, $\text{W m}^{-1}\text{k}^{-1}$	0.36
Dielectric constant, kHz	2.2-2.4 at 1000 cycles
Volume resistivity, ohm cm	10^{16}
Dielectric strength, kV/mm	30-35

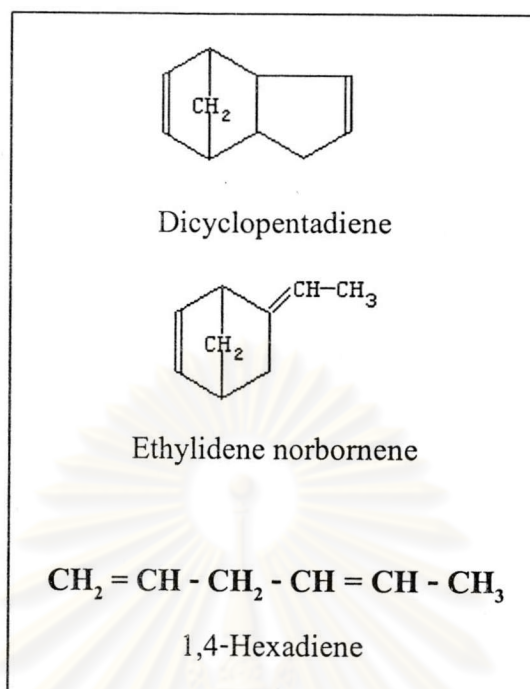


Figure 2.4 Some structures of the third monomer for EPDM

2.3.2 Classification

The most important and significant parameters which are characteristics of ethylene propylene rubbers available in commercial are the following attributes:

2.3.2.1 The ethylene-propylene ratio, or a propylene content

Propylene content between 25-55% by weight. Usage of a low propylene content will produce polymers with high green strength; the medium and higher values of propylene will produce softer and more elastic polymers [10].

2.3.2.2 The type and amount of third monomer (in the case of EPDM)

The third monomer can be classified by unsaturation content. For common uses, ethylidene norbornene gives the rapid vulcanization, followed by dicyclopentadiene, and 1,4-Hexadiene, which gives good recycling characteristics and ease of recycling.

2.3.2.3 Molecular weight (Mooney viscosity)

The lower molecular weight polymer is used with the lower amounts of filler to give high quality product. The high molecular weight polymer is used for the production of low cost compounds or for improved processability.

2.3.2.4 Nature of other additives

There is a multiplicity of types or grades of EPDMs from many suppliers. The various types of EPDM were developed in order to give the best choice on such properties as viscosity range, staining properties, perhaps some information on curing rate. Such as Mooney viscosity of EPDM was decreased by adding with paraffinic or naphthenic oil.

2.3.3 Applications

The applications of EPDM are more well-known in automotive sector, electrical insulation, building, domestic appliances, etc. The largest field of use is in the automotive industry for tyre sidewalls to improve their ozone, heat and chemical resistance. However, there are still some disadvantages. It is not tacky like other rubber products, therefore, EPDM is not being used in the manufacture of tyres. In this case, it is necessary to add tackifier to the compound such as low molecular weight resins, because mechanical properties of the unfilled EPDM rubber are quite poor. The most useful application of reinforcement fillers is to improve mechanical properties of EPDM is carbon black.

2.4 Compatibility method

The achievement of compatibilisation as modification of blends is to produce a desirable set of properties by addition of a third component (compatibilizer) or by inducing *in situ* chemical reaction between blend components [11]. These can be divided in three categories, namely “mechanical,” “physical” and “chemical”. The aim of mechanical

compatibilization is the development of non-equilibrium morphology, which in one respect, is relatively stable and reproducible. Physical compatibilization, use of this method by control of crystallization or addition of compatibilizer. The last compatibilization method is chemical compatibilization, involving with the chemical reaction by modification of rubber structure to enhance miscibility.

2.4.1 Compatibility limitations

The morphology of a rubber blend depends on the nature of the blend components (i.e., their mutual compatibility and rheological properties) and of the method employed to produce the blend. It is necessary to distinguish between compatible blends and ones that are truly miscible. The former are homogeneous in a macroscopic scale i.e., miscible only in technological sense. We usually mean that the rubbers can be mixed together and vulcanized to give useful products. Three types of incompatibility have generally been noted as follows [12]:

2.4.1.1 Thermodynamics incompatibility

Thermodynamics incompatibility is one of compatibility limitations of dissimilar rubber blends. The good composition can be achieved if the surface-energy mismatch between polymers is small enough to allow to the formation of very small microdomains of the individual polymer phase and if there is sufficient adhesion between the phases.

2.4.1.2 Viscosity incompatibility

In case of viscosity mismatch, derived incompatibility occurs in rubber blends. This effect can improve quality of the blend by adjusting extender-oil and filler concentrations in the dissimilar rubbers and adjusting the individual raw polymer viscosities. Further conclusions with regard to rubber blending were that finess of dispersion varied according to the polymer viscosities and the degree of mixing involved.

2.4.1.3 Cure-rate incompatibility

Cure-rate incompatibility is encountered when the rubbers are both vulcanized by the action of the same curing ingredients but at reactions, which are significantly different for each of the two rubbers. This can be due to differences between the reactivities of the rubbers or due to differences between the solubilities of curatives in rubbers.

2.4.2 Compatibility improvement

There are many methods for enhancing the miscibility of rubber blends. Mechanical and physical compatibilization are chosen in this research. The physical compatibilization is the best known method by addition of compatibilizing agent, or homogenizing agent.

2.4.2.1 Compatibilizers

The way to improve miscibility of a blend is addition of compatibilizer, i.e., block or graft copolymer whose chemical structures are chosen for their adhesion to the blend components of interest.

Three effects of compatibilizer are:

- 1) Reduce the interfacial tension in the melt through an emulsifying effect leading to an extremely fine dispersion of one phase in another.
- 2) Increase the adhesion at phase boundaries, giving improved stress transfer.
- 3) Stabilize the dispersed phase against growth during annealing by modifying the phase boundary interface.

2.4.2.2 Homogenizing agent

Homogenizing agent is a low molecular weight polymeric resin used to improve in blending two or more rubbers. This homogenizing resin blend contains

portions that are compatible with aliphatic, naphthenic and aromatic parts of the rubbers in a blend. For example, low molecular weight resins are marketed by Behn Meyer Company as a homogenizing agent. These are sold as ULTRABLEND 4000 (for dark colored compounds) and ULTRABLEND 6000 (for light colored compounds). The specification of this homogenizing agent (ULTRABLEND 4000) is given in Appendix A. Application of the low molecular weight polymeric resin is to improve the homogeneity of rubber blends of different polarities or different viscosities. It is quickly absorbed by the polymer matrix to wetting out the surfaces, which leads to a fast incorporation of other compound ingredients. Struktol Company and Bayer Company also marketed this resin blend. Struktol 40MS is the trade name of Struktol Company and its constituents are similar to that of Ultrablend4000.

2.5 Vulcanization

After mixing, rubber compounds must be vulcanized or cured. The vulcanized rubber is the conversion of a fully mobile entanglement of rubber macromolecules into a chemically stable network by the insertion of covalent bonds or crosslinks to give an elastic material. The rubber will lose its tackiness and become more resistant to swelling by organic liquids and extend over a greater range of temperature. The effect of stretching of unvulcanized and vulcanized rubber can be illustrated in Figure 2.5 (a and b) [6].

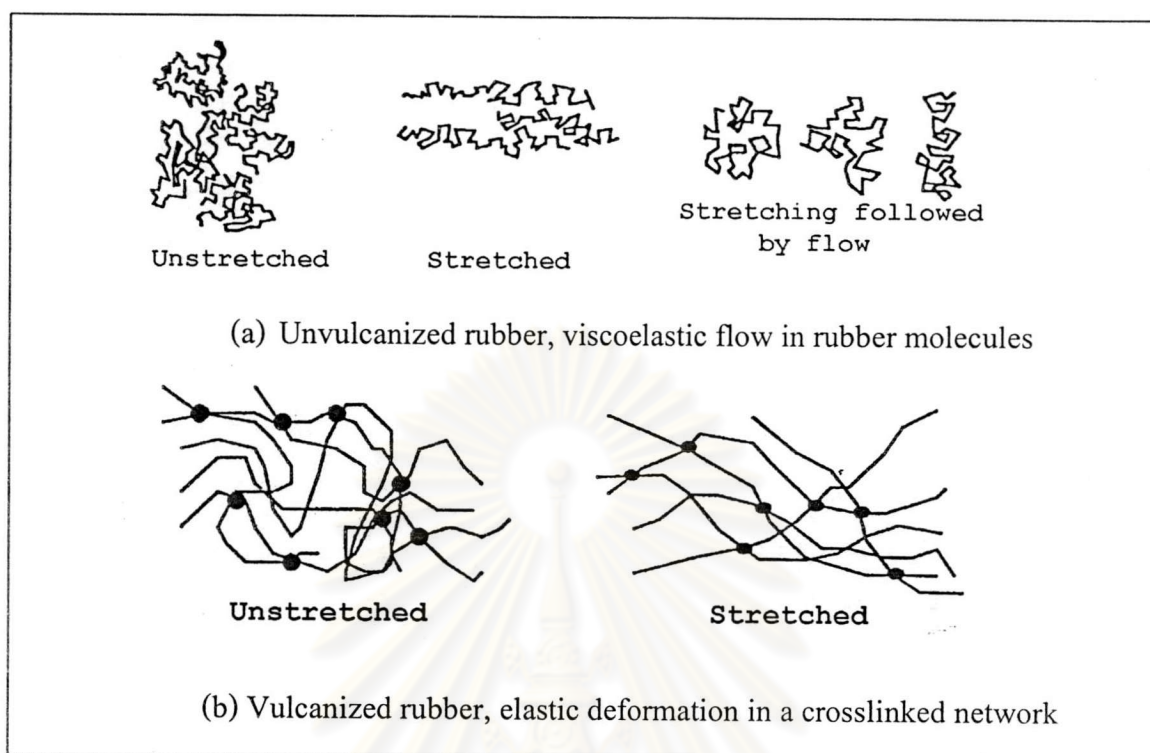


Figure 2.5 A concept of rubber vulcanization

There are four curing agents widely used as follows:

- 1) Sulfur systems,
- 2) Peroxides or free radical vulcanization system,
- 3) Urethane crosslinkers,
- 4) Metallic oxides (used in vulcanizing neoprene only).

Sulfur is a curing agent most commonly and widely used both for natural rubber and synthetic rubber containing unsaturation. Peroxides can crosslink both of saturated and unsaturated rubber but there are some disadvantages. Peroxides are rather hazardous chemicals and require more attention to safe storage. In this research the sulfur systems are used for vulcanizing both of NR and EPDM, which have pendant unsaturation that allows sulfur vulcanization. The last three curing systems will not be discussed here.

2.5.1 Sulfur vulcanization

Sulfur vulcanization is the most widely used method for crosslinking unsaturated rubber e.g., natural rubber (NR), styrene butadiene rubber (SBR), butadiene rubber (BR), ethylene propylene diene rubber (EPDM), etc. The various chemical structures present in a vulcanized natural rubber of the following type are shown in Figure 2.6. Generally, monosulfide, disulfide and little cyclic linkage in the curing system indicate the effective vulcanization.

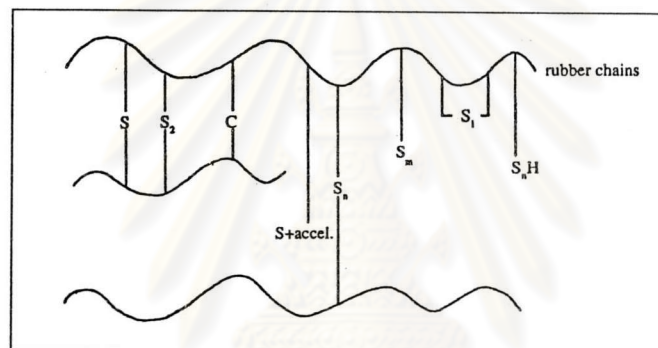


Figure 2.6 Sulfur crosslink structures (S = monosulfide, S_n = polysulfide, S₁ = main chain bound sulfur chains, S_nH = thiol groups, S + accel. = sulfur donor accelerator residues, C = carbon-carbon crosslinks, and S_m = cyclic sulfur structures)

2.5.2 Accelerated sulfur systems

On its own, sulfur is not a very good vulcanizing agent. It is slow and inefficiently used even at elevated temperatures [10]. The main reason for using accelerators is to control scorch and promote a cure rate for vulcanization. The changes in the amount or types of accelerator can reduce the time required for a vulcanization.

The accelerated sulfur vulcanization systems can be classified into three types [9]:

- 1) Conventional systems containing high sulfur/accelerator ratios

- 2) Efficient (EV) systems containing high accelerator/sulfur ratios
- 3) Semi-EV systems that are intermediate between (a) and (b)

Conventional systems give vulcanizates which possess excellent properties like strength and resistance to fatigue and abrasion, and are satisfactory for many applications. For a good heat-ageing resistance, the EV system is essential because semi-EV systems may be chosen as a compromise between cost and performance.

For this study, semi-EV system was chosen for vulcanization and the types of accelerators are thiazoles and thiurams.

Thiazoles and derivatives of the thiazoles (e.g. MBTS, MBT, ZMBT) are the most popular accelerators [8]. Their good qualities are the effective acceleration provided at the medium and high temperature. It also offers a wide range of curing rates and scorching characteristic. Often, it is used in synergistic combinations with a very fast accelerator such as TMTD in thiuram sulfide type.

2.5.3 Accelerator activators

Activators are substances, which increase effects of the accelerators by activating reactions. It is believed that they can react in some manner to form an intermediate complex with the accelerators. The complex thus formed is more effectiveness in activating the sulfur present in the mixture, thus increasing the cure rate. The most popular activated system is zinc oxide and stearic acid. Accelerator activators are grouped as follows:

- 1) Inorganic compounds: mainly metal oxides, which include zinc oxide, hydrated lime, red lead (Pb_3O_4).
- 2) Organic acids: They are normally used in combination with metal oxide. They are generally high-molecular weight mono-basic acid or mixtures of the following types: stearic, oleic, lauric, palmitic, linseed oil etc.

In a blend, such a disparity in reactivity is reflected in the relative rates of crosslinking reaction during vulcanization, both within and between the two phases, diffusion of curatives towards the faster curing NR phase occurring readily during mixing and curing. The lower solubility of many curatives in EPDM as compared with NR further reduces the propensity towards a crosslink formation in the EPDM phase. Overall, these factors combine to give a blend having a highly crosslinked NR phase and a very poorly crosslinked EPDM phase [3].

2.6 Reinforcing fillers

They are a variety of filler materials for rubber compounding in commercial, such as, carbon blacks, clays, calcium carbonates, talc etc. The use of each filler depends on the particular aim as follows:

- 1) For a cheaper capital and production cost, because the price of some fillers is cheaper than that of rubber.
- 2) Rubber reinforcement such as carbon black increases tensile strength and abrasion in natural rubber.
- 3) For electrical conduction: natural rubber is a good insulation under a flash of electrostaticity, which burns the rubber. Adding a filler decrease the electrostaticity or induces conductivity to the rubber.
- 4) To prolong the ageing of the rubber as such to increase its service life.

2.6.1 Carbon black

The most important synthetic filler for rubber modification is the carbon black. The main purpose is for rubber reinforcement, to increase tensile strength, modulus, abrasion and tear strength. Formerly, it is used to impart electrical conductivity to rubber

compounds. Carbon black is a particulate form of industrial carbon produced by thermal cracking or decomposition of a hydrocarbon raw material. There are five types of carbon black based on manufacturing methods. They are lampblack, channel black, thermal black, acetylene black and oil furnace black [8]. The most important process currently in use is the oil furnace process, which consists of atomizing a heavy fraction of petroleum distillate into a preheated, closed furnace and then cooling and collecting the carbon aggregates formed. This process is efficient and permits a very high degree of control of carbon black physical and chemical properties.

2.6.1.1 Particle size/surface area

To a large extent, the prime particle size of a carbon black determines its dispersibility. This can be attributed to the effect of surface area, which remains a factor despite fusion into primary aggregates. The finer prime particle, the higher the surface area remaining exposed in the primary aggregate. Thus, finer prime particle blacks are more difficult to disperse. The difference in particle size and structure of carbon black controls the typical performance properties (shown in Figure 2.7).

2.6.1.2 Carbon black structure

The term 'structure' refers to the joining together of carbon particles into long chains and tangled three-dimensional aggregate. A carbon black characterized by primary aggregates composed of many prime particles, with considerable branching and chaining, is known as a "high structure black". The higher the structure black, the more irregular the shapes of the aggregates, hence the less these aggregation are capable of packing together. A high structure black would have considerably more space and absorb more oil per unit weight compared to a low structure black of comparable surface area, since the bulkier aggregates would not pack closely. This indicates the higher viscosities and stiffer compounds with increasing structures. For the low structure blacks allow closer packing so the inter-aggregate distances are smaller and consequently attractive forces are higher making dispersion more difficult.

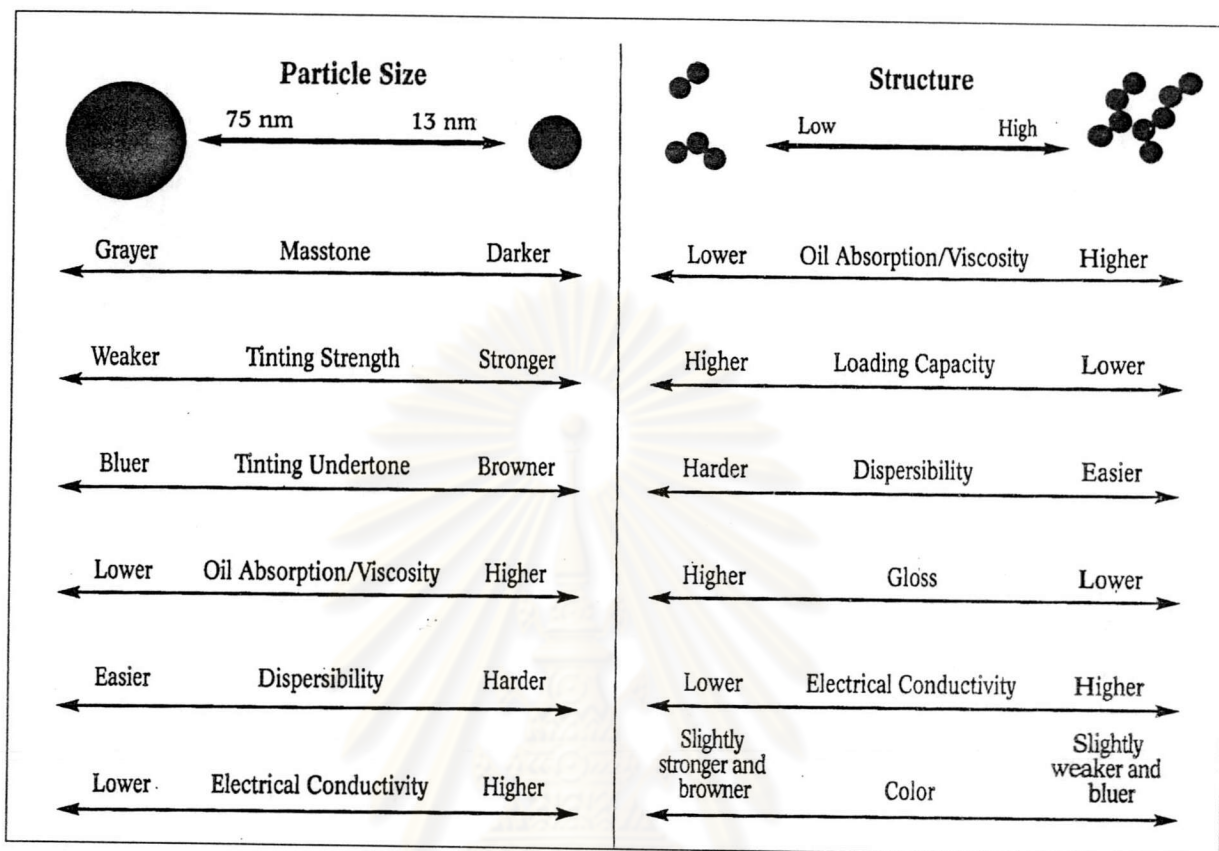


Figure 2.7 Typical properties of carbon black

A grade of carbon black should be selected, i.e., as low a surface area as possible and as high as possible in structure for most effective dispersion. The type of carbon black can be made to match the compound's requirements. For classification purposes the ASTM considers the particle size range of carbon black used in rubber products to be from 1 to 500 nm. The grade identification consists of a letter followed by three digits. The letter is either "N" for normal cure rate or "S" for slow curing blacks. The first digit following the letter indicates the typical average particle size from various suppliers. The last two digits are arbitrarily assigned by ASTM. The six black for common industry use and a good mechanical rubber producer are N293 conductive furnace, N220 intermediate super abrasion furnace, N330 high-abrasion furnace, N550 fast-extruding furnace, N650

general purpose furnace, and N990 medium thermal. High structure and high surface area carbon blacks not only are associated with increased reinforcement in rubber compound but also increased electrical conductivity too. Therefore, the moderate structures and surface area carbon black should be used. From Figure 2.8, the N330, an oil furnace black, is thus chosen for the current research [6].

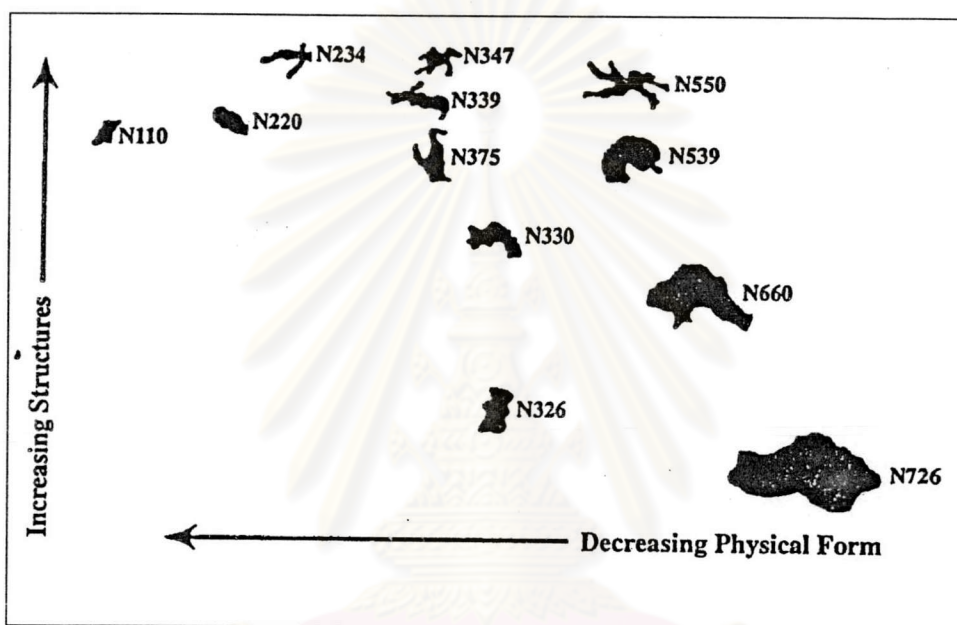


Figure 2.8 Overview in furnace types of carbon black

2.6.2 Silica

Silica is the best reinforcement material of non-black filler (shown in Figure 2.9). They are well known mineral in the industry for the excellent mechanical properties provided in finished products and for the improved adhesion of the compound to metal and fabrics. They are reinforcing fillers giving compounds of high tensile strength, tear resistance, abrasion resistance, and hardness. It can be used in compounds requiring high electrical resistivity and has little effect on cure except in very large amounts. Not only that it can be used for heat-resistant compounds. In combination with reinforcing blacks they improve tear resistant and adhesion to fabrics. Two or four parts of poly(ethylene

glycol) (PEG) should also be added to the compound to avoid any detrimental interaction between silica and the crosslinking system. Because silica fillers do not produce good extrusion properties, it is advisable to use them in conjunction with clay when the compound is to be extruded. Adding silica to a rubber quickly increases the stiffness of mix, so that in practice not more than 50 parts are usually used.

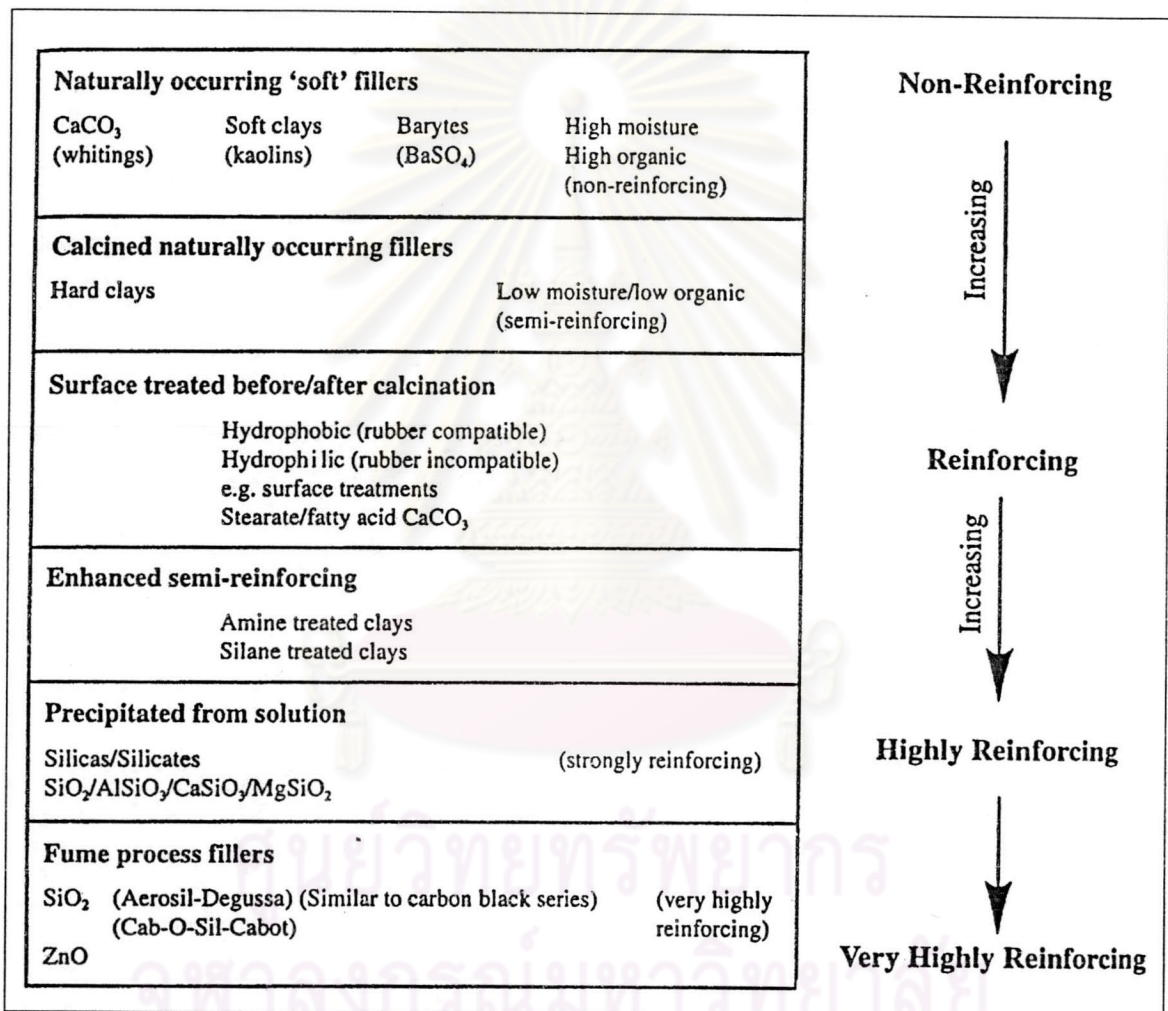


Figure 2.9 Mineral-based fillers for rubber reinforcement

Figure 2.10 shows the effect of silica concentration on tensile and tear strength [13]. The silica concentration at 20 phr gave the highest tensile strength but lower tear resistance and after increased silica concentration more than 20 phr the tensile strength

was decreased. Therefore, the silica concentration at 30 phr will be used in this study in order to get higher tear strength and small decreased tensile strength.

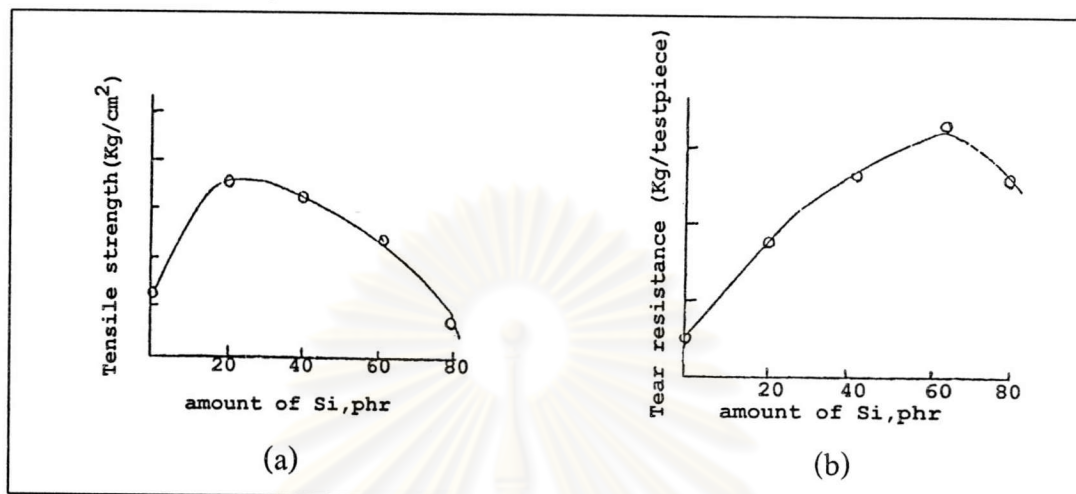


Figure 2.10 Effect of silica on mechanical properties: (a) tensile strength, (b) tear resistance

2.7 Electrical properties

They are several methods for testing electrical properties of rubbers, i.e. volume and surface resistivity (insulation resistance), dielectric strength, permittivity (dielectric constant) and power factor (dissipation factor) [14]. This section discusses some of these properties for general tests on insulating rubbers.

2.7.1 Volume and surface resistivity (insulation resistance)

Resistance of insulation can be explained by Ohm's law (see Equation 2.1). When a current flows through an insulation rubber, heat is generated in the insulated rubber. The heat is the resistance of the insulation to the passage of current [15].

$$I = V/R, \quad (2.1)$$

where R is a constant, called the resistance of the insulation expressed in ohms (Ω),

V is the potential difference between two points of the insulation expressed in volts,

I is the current flowing in the insulation expressed in amperes.

These test methods are used for determinations of the dc insulation resistance, volume resistance, volume resistivity, surface resistance and surface resistivity; of insulation rubber, or the corresponding conductance and conductivity.

2.7.1.1 Volume resistance

The ratio of the dc voltage is applied to two electrodes (on or in a specimen) to the current in the volume of the specimen between the electrodes.

2.7.1.2 Volume resistivity

The volume resistivity is multiplied by that ratio of specimen volume dimensions (cross-sectional area of the specimen between electrodes divided by the distance between electrodes), which transforms the measured resistance to that resistance obtained if the electrodes had formed the opposite side of a unit cube.

2.7.1.3 Surface resistance

The ratio of the dc voltage is applied to two electrodes (on the surface of a specimen) to the current between them.

2.7.1.4 Surface resistivity

The surface resistivity is multiplied by that ratio of specimen surface dimensions (the width of electrodes defines the current path divided by the distance between electrodes), which transforms the measured resistance to that obtained if the electrodes had formed the opposite sides of a square.

The properties usually are considered only for DC potential and its value depends upon time and voltage application, stress and electric field configuration.

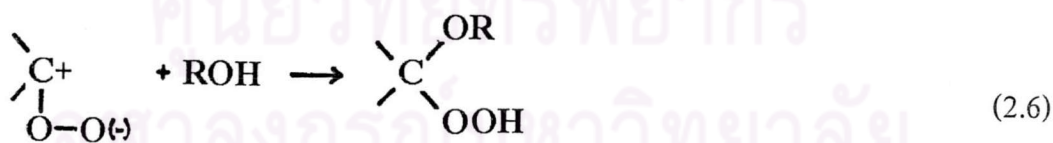
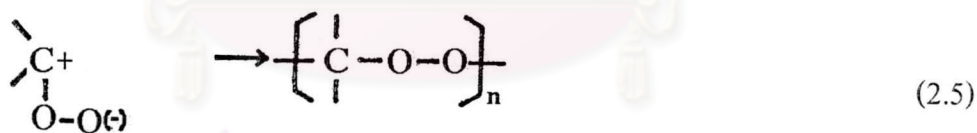
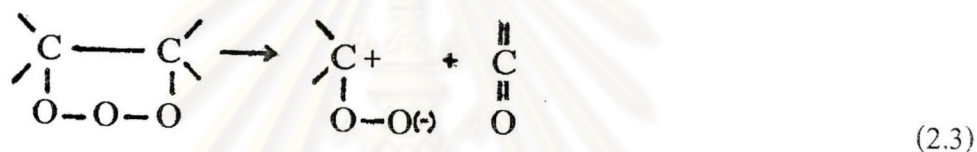
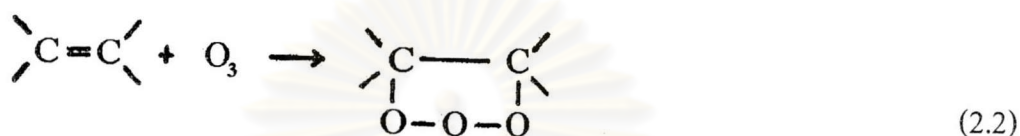
2.7.2 Dielectric strength

The dielectric strength or breakdown strength, is another important factor in determining the usefulness of a particular dielectric [16]. The dielectric strength is defined as the maximum voltage gradient that a material will withstand before its failure and expressed as Volts per unit thickness. The higher the dielectric strength of a material, the better its quality as an insulator. The dielectric breakdown voltage test used to determine suitable material inspection or quality control test. The breakdown caused by electrical discharges may occur in any internal voids or weak spots of a material [17]. Such a breakdown is caused by electrical discharges, which produce high local fields. Within the same medium, increasing test area produces failure at or beyond the electric edge. Discharges may occur in any internal voids or bubbles that are present or may develop. These may cause local erosion or chemical decomposition. Therefore dielectric breakdown test may be used as a material inspection or quality control test, as a means of inferring other conditions, such as, variability or to indicate deterioration processes such as thermal ageing.

2.8 Ozone resistance

The unsaturated structure of the diene hydrocarbon rubber makes them susceptible to attack by ozone. The greater level of double bonds on unsaturated rubber, the higher the lead to ozonation. This can often be noted in natural rubber, but in contrast chloroprene rubber (CR) and ethylene propylene diene rubber (EPDM) are less reactive to ozone. The ozone attack on unsaturated rubber is basically the ozone attack on olefin. The mechanism is summarized in Equations 2.2-2.6 [8]. The resulting product in the initial step gives a bridging of one side of the double bond with both ends of the ozone molecule to form a cyclic ozonide, called an molozonide (Equation 2.2). The molozonide is unstable and

breaks down into a zwitterion and a carbonyl group (Equation 2.3). By recombination of the latter two and in the presence of active hydrogens, three products are possible: a relative stable ozonide (Equation 2.4), a polymeric peroxide formed from the carbonyl oxide (Equation 2.5), or a hydroperoxide (Equation 2.6).



The test method of unsaturated rubber is estimated by attack of ozone. When unsaturated rubbers are exposed, in the stretched state cracking, to an atmosphere containing trace amounts of ozone and created ozonides, the rubber must resist the deterioration that ozone cracking produces. Whatever this method may not give results exactly with those of outdoor exposure tests, a combined testing containing both accelerated ozone and outdoor exposures tests should be carried out.

Ozone resistance of natural rubber can be enhanced by incorporating a chemical antiozonant, such as, paraffin wax or low-unsaturation level rubber, e.g., EPDM and EPM.

2.9 Literature reviews

The use of sulfur and peroxide as curatives accelerated by MBTS and DPG to improve co-vulcanization in EPDM/NR blends was studied by Tobing [18]. The EPDM/NR blends (60:40) showed the good tensile properties, excellent heat ageing, and static ozone resistance resulted from the synergistic sulfur/peroxide cure system. The presence of peroxide in the cure system showed static properties in an autoclave curing.

Cesare [19] studied the use of liquid EPDM blend with NR. The high molecular weight EPDM combined with NR produced the better ozone resistance. In addition, the use of liquid EPDM improved the blend processing due to a lowering of the Mooney viscosity of the compound. In case of liquid EPDM combined with the conventional EPDM and the antioxidant, a higher level of NR (85% by weight) could be used and many of good physical properties and excellent static ozone resistance were obtained. The best composition for static ozone resistance of NR/liquid EPDM/high molecular weight EPDM blend is 85/5/10 and the level of antioxidant is 4.5% by weight.

Bengtsson et al. [20] studied the effect of electrical noise of carbon black filled chloroprene rubber. They found that the samples exhibited a wide range of resistivities from over 107 ohm cm to under 100 ohm cm by carbon black concentrations of 20% to

30% by weight. Of course, the aggregation of the carbon black particles can affect the resistivity.

Ghoneim and Ismail [21] studied the effect from the optimum ratio of EPDM/NR blends and the addition of three reinforcing fillers of carbon blacks of High-Abrasion Furnace Black (HAF), Fast-Extrusion Furnace Black (FAF), and Medium Thermal Black (MT) on electrical and mechanical properties. The EPDM/NR blend of 75:25 ratio yielded the best mechanical properties. The addition of carbon black enhanced both of mechanical and electrical properties. This result validated the use of reinforcing filler of carbon blacks as a conductive material.

Thermal properties of EPDM/NR blends were studied by Traian et al. [22]. Differential Scanning Calorimetry (DSC) and oxygen uptake were used to study on changes in thermal properties of EPDM/NR blends. The presence of natural rubber induced a thermal instability because of the high content of double bonds. The differences between the rate of oxygen consumption become large when the blending ratio is changed in the favour of NR. The higher the natural rubber content, the faster the thermal oxidative degradation.