

CHAPTER 1 : INTRODUCTION

1.1 Tyre Technology

1.1.1 Functions of a Pneumatic Tyre

A pneumatic tyre is a composite structure of compounded rubber, fabric and steel ¹. It is fitted to a rim and wheel to support a vehicle and its load on a cushion of compressed air which is contained within the tyre. The principle of a pneumatic tyre is to confine compressed air to form a cushion between the vehicle and road ¹.

The pneumatic tyre performs a variety of functions that are essential to the effective operation of most modes of transportation which includes the following ^{2,3}:

- i. Supporting the vehicle load.
- ii. Transmitting driving and braking forces to the road surface.
- iii. Producing lateral forces for cornering and vehicle handling control to help guide the direction of travel.
- iv. Providing safety through maneuverability, durability, wet and dry traction, snow traction and high speed performance.
- v. Maintaining dimensional stability by undergoing only inappreciable change of size or shape upon inflation
- vi. Providing economy through long tread life (wear resistance) and low rolling resistance (energy consumption).

To perform these functions, the tyre must have enough rigidity to develop substantial forces in all directions, enough flexibility to be able to envelope obstacles without sustaining damage and a long fatigue life in flexing from a doubly curved shell to a flat surface and back ².

1.1.2 Tyre Classification

Tyres can be classified by the type of vehicle on which they are applied ². Major classifications include automobile, truck, off-road, farm, aircraft and race tyres. Other classifications include bicycle, motorcycle and industrial tyres. These tyres are designed to meet a wide spectrum of service and environmental conditions.

1.1.3 Tyre Construction

Tyres generally have layers of cord-reinforced plies, each containing a series of equally spaced parallel cords ². In addition to changing the materials used in the various tyre components, a powerful option available to a tyre engineer is that of changing the cord angles in the plies. There are three main types of tyre construction namely bias, bias/belted and radial tyres as shown in Figure 1 ⁴.

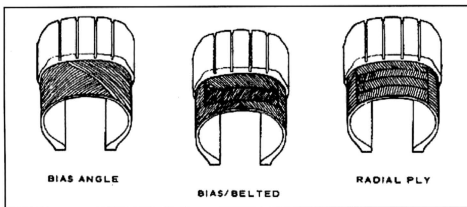


Fig. 1 : Three main types of tyre construction ⁴

In a bias tyre, the reinforcing cords extend diagonally across the tyre from bead to bead. These cords, generally with a bias angle between 30 and 40°, run in opposite directions in each successive layer (ply) of reinforcing material ⁴.

A bias/belted tyre consists of a bias-angle carcass with a circumferential restricting belt under the tread. The carcass angle is generally 25 to 40° and that of the belt between 25 and 30°⁴. The belts reduce both circumferential and lateral deformations of the tread area during service, thereby restricting changes in the inflated tyre profile and reducing tread movement in the footprint. By reducing deformations due to inflation, belts enhance tyre durability by reducing lateral distortion in the footprint during cornering.

A radial tyre has plies of reinforcing cords that extend transversely from bead to bead. There is an inextensible belt composed of several more layers of cord on the top of these plies. The belt cords are low angle (10 to 30°) and act as a restriction on the 90° carcass plies⁴. The radial orientation of the carcass cords results in very flexible sidewalls, which act independently of the belts, thus reducing tread movement in the footprint to less than that in bias tyres.

1.1.4 Tyre Component

Rubber is an essential element of pneumatic tyres; it offers flexibility, low hysteresis, good friction on most surfaces, high abrasion resistance and good impermeability by contained air². The basic rubber characteristics of low resistance to tensile forces necessitates the use of an inextensible yet flexible reinforcement, to avoid excessive tyre deformations upon loading.

The major components of a typical pneumatic tyre are carcass, beads, tread, belts, chafers, inner tube, inner liner, sidewall, shoulder and crown which perform distinctly different functions in service². These components are shown in Figure 2.

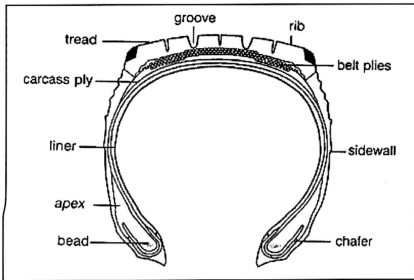


Fig. 2 : Major components of a typical pneumatic tyre ²

Each component of a tyre is required to provide some performance attributes for customer satisfaction and/or for fabrication in a specific manufacturing process. In the tyre, these components are dynamically deformed as the tyre rotates through the footprint. The speed, load-deflection, temperature and environment will relate to properties required of the compound ². Some of the fundamental compound properties are stiffness, dynamic (elastic and viscous) modulus, hysteresis, heat build-up, heat capacity, heat of diffusion, tear and compound stability. These properties are, in turn, related directly to fundamental elastomer, carbon black reinforcement and cure properties.

1.2 Tyre Compounding

Compounds are mixtures of materials such as elastomers, carbon black and/or silica and a cure system ². Other ingredients are added to aid process, to develop specific properties or to provide compound stability.

The objectives of compounding are ⁵:

- i. to facilitate processing and fabrication;
- ii. to ensure quality with minimal reject rate;
- iii. to achieve the required properties in the vulcanizate, and
- iv. to provide durability at competitive cost.

Hence the compound formulation has to be carried out within the constraints imposed by the ingredients. These ingredients could be several times more expensive than the base rubber, of limited availability and varying in quality from different suppliers. Other factors which need to be considered in rubber compounding are product specifications, processing, storage capacities, health and safety.

Very often, compounding also involves a compromise. An ingredient added to maximize one property might detract from another. For example, a reinforcing carbon black improves abrasion resistance but leads to increase hysteresis, and attempts to restore resilience by increasing crosslink density may in turn reduce the tear strength.

The compounding ingredients and properties requirement are very different for each type of tyre construction, application and component in the tyre. Table 1 shows the different properties required for different components in a tyre ⁶.

Tyre Component	Compound Requirements
(a) Tread	<ul style="list-style-type: none"> • Resistance to abrasion • Good wet and dry traction • Resistance to chunking, tearing and groove cracking • Low heat build-up • Low rolling resistance • Good extrusion characteristics
(b) Sidewall	<ul style="list-style-type: none"> • Excellent flex fatigue resistance • Resistance to kerb cutting • Good weathering performance • Good extrusion characteristics
(c) Belt	<ul style="list-style-type: none"> • Good adhesion to steel or fabric • Good retention of adhesion upon ageing • Good tear strength • Moderate to high modulus • Good flex resistance • High green strength and tack
(d) Carcass/Ply	<ul style="list-style-type: none"> • Good adhesion to carcass cords • Good tear strength • Good flex resistance • Excellent ageing performance • Good green strength and good tack • Excellent calendaring behaviour
(e) Apex	<ul style="list-style-type: none"> • Very high hardness • High modulus • Low compression set
(f) Inner Liner	<ul style="list-style-type: none"> • Excellent ageing performance • Good flex resistance • Good tear strength • Excellent permeability resistance • Good tack and green strength

Table 1 : Compound requirements for different components in a tyre ⁶

The choice of rubber compound ingredients in tyres are influenced by a number of factors. Foremost among these will be cost. The tyre manufacturing industry is highly competitive and often, once minimum requirements have been satisfied, the compound formulation will be playing a role secondary to that of tyre design and usage. Even so, compounding does assume some importance in the following aspects ⁵:

- i. treadwear and other aspects of durability
- ii. vehicle safety
- iii. fuel economy
- iv. changes in carcass reinforcement
- v. ease of fabrication

Properties contributing to safety include the resistance shown by the tyre to skid on icy and wet roads. Resistance to heat build-up in larger tyres is necessary which might otherwise lead to early failure in the form of tread lift or more seriously, blow-out. At the same time, it is desirable that the rolling resistance of the tyre should be as low as possible because this can increase demands upon fuel consumption ⁵.

Tyre compounds are unique engineering materials in that large deformations are possible and deformations are translated into heat. Tyres operate under dynamic conditions and it is necessary to understand the effect of stiffness, hysteresis, flexural strength and tear resistance in terms of what occurs in the tyre service ².

1.3 Filler Reinforcement in Tyre Compounds

Reinforcement of rubber compound is generally described in terms of the effect on rubber properties such as modulus, tensile strength, abrasion resistance, tear resistance etc. ^{7, 8}. The amount of reinforcement derived from adding a filler depends on the combination of its surface area as well as its surface chemistry ⁷.

Surface area is related to the particle size and shape which determines the physical potential to make contact with the rubber chains and reinforce. Surface chemistry determines how the filler will react with the rubber molecules as well as how it will affect the other chemicals in the compound ⁹.

Reinforcing fillers are generally small in particle size and chemically active. When they are properly dispersed in an elastomer, they provide a high surface area uniformly distributed throughout the rubber matrix as is requisite for full reinforcement ⁷.

Reinforcing fillers are arbitrarily defined as those ranging below 50 nm in mean particle diameter ⁷. Precipitated silica and finer particle size carbon black are the most commonly used reinforcing fillers in tyre compounds.

Carbon black is the accepted generic name for a family of fine carbon pigments which are produced by thermal decomposition of hydrocarbons. Precipitated silica is a white reinforcing filler produced from the reaction of sodium silicate and sulphuric acid.

1.4 Precipitated Silica as a Filler in Tyre Compounds

Precipitated silica, as a white reinforcing filler, has been used in the rubber industry for a long time ¹⁰. Whereas it was able to replace up to 100% of carbon black in shoe sole compounds, its use in tyre compounds had been limited to several types of compounds and at a much lower filler loading ¹⁰.

Silica cannot completely replace carbon black as the main filler in tyre compounds especially the tread compound. This is due to its poor cure characteristics and poor processability besides imparting very low failure properties to the filled rubber. Such behaviours of silica in rubber have always been associated with its weak polymer-filler interaction and strong filler-filler interaction; both are related to the chemistry and physical chemistry of surface ^{10, 11}.

Wolff ¹⁰ reported that rolling resistance was reduced by 30%, wet traction was virtually unchanged and the treadwear index was decreased only by 5% when a silane-modified precipitated silica was used to entirely replace N220 carbon black in a natural rubber truck tread.

Wolff ¹² showed that partial replacement of carbon black with precipitated silica together with silane coupling agent, TESPT, in a natural rubber off-the-road tread compound resulted in improved abrasion resistance of earthmover tyre tread compounds.

Walker ¹³ concluded that partial replacement of natural rubber with styrene butadiene rubber, carbon black with precipitated silica and use of a semi-efficient vulcanization cure system enhanced the compound chipping/chunking resistance and tear strength. In this case, silane coupling agent is not used in the formulation.

Bomal et. al. ¹⁴ studied the use of precipitated silica and silane coupling agent in a natural rubber farm tread compound formulation. He concluded that :

- i. use of precipitated silica beneficially increased compound elongation-to-break, energy-to-break and cut growth resistance.
- ii. use of carbon black increased hysteresis more than an equal loading of precipitated silica
- iii. use of precipitated silica in addition to carbon black was required to maintain abrasion resistance
- iv. use of silane-modified precipitated silica did not improve compound physical properties such as elongation-to-break, energy-to-break and cut growth resistance

Byers ¹⁵ studied a natural rubber/styrene-butadiene rubber/butadiene rubber compound and found that use of increasing amounts of precipitated silica coupled with an organosilane and decreasing amounts of carbon black significantly lowered the compound tangent delta at 60°C, a measurement that is a predictor of rolling resistance. Higher levels of accelerator were required to maintain the other compound properties, including laboratory abrasion.

Evans, Waddell and coworkers ¹⁶ studied the use of precipitated silica in a silica-filled passenger tyre tread compound with and without the use of a bifunctional silane coupling agent. He concluded that the use of precipitated silica (no coupling agent) in place of N110 carbon black improved scorch safety, elongation-to-break and cut growth resistance values but adversely increased minimum torque and cure time. The use of a silane coupling agent at 10% based on the level of precipitated silica, beneficially reduced minimum torque, increased hardness and modulus values.

However, elongation-to-break and cut growth resistance, both improved by use of precipitated silica, were greatly reduced when silane coupling agent was incorporated. Tangent delta values at -30°C, 0°C and 60°C - predictors of ice traction, wet traction and rolling resistance, respectively - showed that these tyre properties should be improved by use of precipitated silica. Here, use of coupling agent further improved rolling resistance and ice traction but reduced predicted wet traction.

Evans and Waddel ¹⁷ performed a three factorial screening design varying elastomers, fillers (titanium dioxide, clay, precipitated silica and talc), ultramarine blue and curatives in a silica-filled SBR compound used for white sidewall. Improvement is observed in tear strength, abrasion resistance and cut-growth resistance while maintaining costs.

Waddel et. al. ¹⁸ varies the level of carbon black, precipitated silica (0-10 pphr) and antiozonant in a NR/BR black sidewall compound. Precipitated silica used as a partial replacement of N330 carbon black significantly improved tear strength, cut growth resistance and resistance to ozone ageing but also afforded lower hardness and modulus compound.

Cochet, Butcher and Bomal ¹⁹ studied the use of precipitated silica in a wire coat NR compound formulation containing a cobalt-boron adhesive. The use of a low surface area, silane-coupled precipitated silica afforded better processing compounds and also reduced heat build-up. Adhesive and physical properties were further improved by using DPG as the co-accelerator for the silane-coupled precipitated silica. Use of higher levels of low surface area, silane-coupled precipitated silica as a

partial replacement of N326 carbon black afforded compounds with much higher tear strength and heat- and salt-aged adhesion values.

Machurat and Bomal ²⁰ used a high-dispersible, low surface area precipitated silica with silane coupling agent as a replacement for the semi-reinforcing carbon blacks in a bromobutyl innerliner. Heat build-up, loss modulus (E''), tangent delta and tensile strength were improved but cure time, hardness and elongation-to-break were adversely affected.

The work mentioned above summarised the use of precipitated silica and silane coupling agent. We can conclude that silane coupling agent is only used in certain silica-filled compounds to improve specific properties. However, the use of silane coupling agent was avoided in compounds where it has the potential of reducing certain properties of the compound. Figure 3 shows the benefits of using reinforcing precipitated silica in individual components of a tyre ²¹.

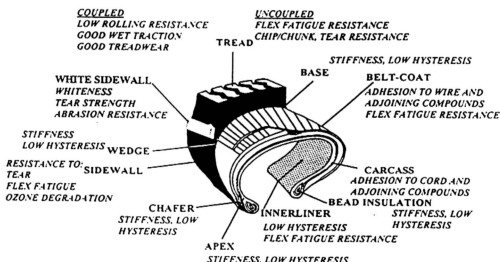


Fig. 3 : Tyre cross-section showing the benefits of using precipitated silica in individual components ²¹

Table 2 was extracted from the work carried out by Tultz et. al. ²². It provides suggestions for optimizing specific properties of a silica-carbon black-filled natural rubber compound with and without the use of silane coupling agent.

	Silica	TESPT
Lower viscosity	Reduce	Increase
Slower scorch	Increase	Reduce
Increased (MH-ML)	Reduce	Increase
Faster t ₉₀	Reduce	Increase
Increased hardness	Reduce	Increase
Higher modulus at 300%	Reduce	Increase
Lower heat build-up	Reduce	Increase
Molded groove tear	Increase	Reduce
Lower G' at 60°C	Increase	-
Lower G'' at 60°C	Increase	Increase
Abrasion resistance	Reduce	Increase

Table 2 : Suggestions for Optimizing Specific Properties ²²

1.5 Surface Chemistry of Precipitated Silica

The surface chemistry of silica is very different from that of carbon black. A comparison is shown in Figure 4. Silica have strongly polar surface character which is formed by a uniform layer of siloxane and silanol groups ^{21, 23, 24, 25}. The reactivity of the surface causes foreign substances like water to be adsorbed on the filler surfaces till they are saturated. This phenomenon has a strong influence on the behaviour of silica as well as its processing characteristics.

Unlike silica, the surface of carbon black consists of a certain portion of unorganized carbon but mainly graphitic basal planes with some functional groups, mostly oxygen-functional groups located on the edges and crystal defects ^{10, 26}. The reactive organic groups present on the surface of carbon black that provides affinity to rubber are missing in silica fillers.

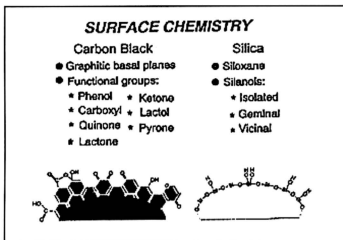


Fig. 4 : Surface chemistry of carbon black and silica ^{10, 26}

The silica surface is capable not only to adsorb water but also chemicals, particularly basic ones. If silica containing compound is accelerated with basic products such as diphenyl guanidine (DPG), di-o-tolylguanidine (DOTG) and other amine accelerators, a portion of the accelerator is taken up by the silica through physical adsorption or chemical interaction and is not available to act as vulcanization accelerator. These compounds need a larger amount of basic accelerator to compensate for the loss due to interaction with silica unless other measures are taken. During vulcanization with tetramethyl thiuram disulphide (TMTD) or peroxides, these adsorption phenomena do not occur.

1.6 Surface Modification of Silica

The presence of surface activity is a pre-requisite for the ability of the structure and surface area of a filler to become effective factors in rubber reinforcement. Surface energy is composed of a dispersive component, γ_s^d , and a specific component, γ_s^{sp} . The specific interaction factor, S_r , describes the ratio between the specific and the dispersive components of surface energy and is helpful for a comparison of carbon black and silica ^{10, 11, 23, 24}.

Reinforcement effect of fillers is caused by rubber-filler interaction and filler-filler interaction where ^{10, 11, 23, 24, 27} :

- i. γ_s^d is a measure of rubber-filler interaction, mainly observed in the range of medium and large deformations
- ii. S_r is a measure of filler-filler interaction, predominantly observed in the range of small deformations

At similar 'structure' and surface area of a carbon black and silica, the main difference between the two fillers is associated with their surface energies ^{10, 11} :

- i. Carbon black possess a high while silica a low dispersive component of surface energy, γ_s^d
- ii. Specific interaction factor, S_r , is high for silica but much lower for carbon black

In the past, the two drawbacks of silica that have prevented its use in tyres were ¹⁰ :

- i. the lower rubber-filler interaction which is responsible for the lower treadwear resistance
- ii. its interference with the sulphur/accelerator vulcanization system resulting in increased scorch time, lower cure rate and lower crosslink density

A stronger rubber-filler interaction is necessary by modifying the surface of silica to increase its compatibility with the hydrocarbon polymer and reduce the tendency of filler reagglomeration.

Surface modification of silica is one of the most effective approaches of changing surface characteristics to meet specific application requirements. Two approaches are frequently practiced in the rubber industry; namely, surface chemical modification and physical modification by adsorption of some chemicals on the filler surface ¹¹.

The former are frequently called coupling agents or bifunctional coupling agents as they provide chemical linkages between the filler surface and polymer molecules ¹¹.

1.7 Effect of Surface Modification by Chemical Reactions

These chemicals generally enhance the degree of polymer-filler interaction; hence, impart improved performance properties to the filled rubber. They include titanate based coupling agents, zirconate based coupling agents and other metal complex coupling agents ¹¹. As far as commercialized coupling agents are concerned, bis[3-triethoxysilylpropyl]-tetrasulfane, TESPT, also known as Si-69 is the most commonly used silane enabling silica to be applied to tyre compounds - tread compounds in particular. The chemical structure of TESPT is illustrated in Figure 5

^{10, 11, 26, 28}

The formation of filler-to-rubber bonds consists of two steps ^{28, 29}:

- i. modification of the filler during mixing, and
- ii. crosslinking reaction between filler and polymer via the organosilane during curing

In the first step, the ethoxy groups of TESPT react with silanol groups on the silica surface, either directly or after a preceding hydrolysis. During the second step, the tetrasulfane group is split due to heat treatment and/or the influence of the sulfur/accelerator system and reacts with the rubber chains by forming mono-, di- and poly-sulphidic covalent bonds ^{10, 11, 28, 29}.

The introduction of covalent bonds between silica and rubber imparts a stronger rubber-filler interaction which leads to considerable improvements in the system's failure properties, especially abrasion/wear resistance. The silanization of silica with TESPT is also able to drastically reduce filler networking tendency by :

- i. Reducing the filler surface energy, both dispersive and specific components. This is due to the reduction in number of silanol groups which are highly polar groups. The remaining silanols are also less accessible to the rubber chains by means of a TESPT layer. This should weaken the strong tendency of silica for filler-filler interaction and thus inhibit or prevent the formation of a silica network. By nature, silane grafts are low in energy and polarity ³¹.
- ii. Increasing the bound rubber content. This would prevent the filler aggregates from flocculating even though the overall viscosity of the compound may be lower than that of the unsilanized compound due to the considerably reduced filler networking ³¹.

1.8 Effect of Surface Modification by Physical Adsorption

When certain chemicals are added to a silica-filled compound, they may be strongly adsorbed on the surface via dispersive interaction, polar interaction, hydrogen bonding and acid-basic interaction. Examples include glycols, glycerol, triethanolamine, secondary amines, DPG and DOTG ^{11, 25, 32}.

Generally, the polar or basic groups of these materials are directed towards the silica surface and the less polar or alkylene groups towards the polymer matrix thereby increasing affinity with the hydrocarbon polymer. Consequently, the filler networking of silica can be substantially depressed resulting in better dispersion in the polymer matrix, lower viscosity of the compound and lower hardness of the vulcanizate ^{11, 32}.

Water adsorbed on the surface of filler particles reduces the reactivity of the silanols. During hot mixing, some of the adsorbed water is removed, leaving a very reactive filler surface. If diethylene glycol (DEG) or PEG is present in the recipe, it can replace the volatilized water and reduce the reactivity of the filler surface ^{9, 25, 33}.

Some of the reactions with silanols can have a profound effect on the *properties of the rubber compound, especially where the chemical involved is an important part of the cure system. Most of the accelerators used in the sulphur cure systems contain an amine group.* Strong adsorption or reaction with filler particles can decrease the amount of accelerator available for vulcanization reactions. This can give slower cure rates and a reduced state of cure ^{9, 33, 34}.

Similar effects can result from the reaction of zinc ions with filler particles, because zinc is involved as an activator in the cure system. These negative effects on the cure system can be reduced or completely removed by adding other chemicals that will tie up the silanol groups and reduce their activity. The effect on cure is considerably more evident with high surface area silica than with low surface area silica as the latter is more active chemically ^{9,33}.

Besides the glycol mentioned earlier, other additives commonly used in non-black compounds include hexamethylene tetramine (Hexa), hexamethoxy methyl melamine (HMMM) and triethanolamine (TEA). These additives should be mixed into the compound prior to the addition of the zinc oxide and accelerators ^{9,33}. Magnesium oxide in nitrile rubber (NBR) and Neoprene compounds also reduces the tendency for the fillers to tie up zinc oxide from the cure system. Other techniques used to adjust the cure of compounds containing non-black fillers include ^{9,25,33}:

- i. increasing the levels of amine accelerators
- ii. addition of zinc oxide in the second mixing stage

Many of these additives also reduce polarity of the filler surface and thus improve the wetting and dispersion in non-polar polymers. Using polar oils or aromatic resins also generally improves dispersion and the properties of compounds containing non-black fillers ^{9,33}.

The addition of silane coupling agents which incur high cost is used primarily to rubber applications where maximum abrasion resistance is required ⁹. PEG (Carbowax) which is often effective in reducing the adsorption of accelerator and generally is lower in cost. Thus, the effectiveness of the accelerator in the compound is not reduced ^{9,33,35}.

A good general rule for silica-filled compounds that do not contain a silane coupling agent is to include PEG at 2 to 4% of the silica level to improve the cure rate and state of cure ⁹.

DEG and TEA are also quite effective in tying up the active silanols and give similar effects at lower levels than polyethylene glycol. However, they are more difficult to handle and tend to produce shorter scorch times ⁹.

Glycols generally show less effect in compounds based on polymers that have increased polarity such as nitrile or neoprene. The more polar polymers probably attach more readily to silanols and reduce their affinity for other chemicals in the compound ⁹.

Byers ⁹ had conducted studies on the use of PEG in SBR compounds. Figure 8 showed the compound formulation used. This experiment compared compounds containing 0, 1 and 2 pphr of PEG with silica loading of 50 pphr. He had shown that the addition of PEG resulted in shorter cure time, t_{90} in the unmilled compound as shown in Figure 9.

The hot remilled compound without any PEG showed considerably slower cure rate because the silanols were more active at reduced moisture levels. This reduces the availability of some of the curative chemicals. PEG addition countered the effect to produce a faster cure rate in the remilled compounds ⁹.

Original and Hot Remilled Cmpds	
Formula	
SBR 1500	100
Silica	50
Aromatic Resin	20
ODPA	1
Stearic Acid	1
Zinc Oxide	3.0
Sulfur	2.3
MBS	0.8
TMTM	0.5
DPG	0.5
PEG (Carbowax)	0-1-2

Remilling: 10 Minutes at 120C (Stock 150C)

Fig. 8 : Compound formulation used in the study⁹

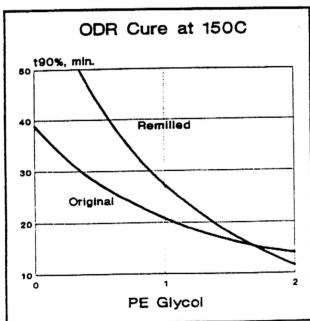


Fig. 9 : Effect of PEG on cure time⁹

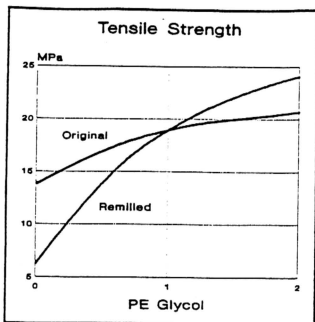


Fig. 10 : Effect of PEG on tensile strength⁹

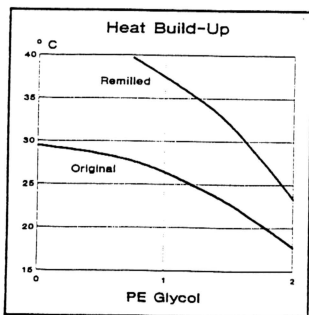


Fig. 11 : Effect of PEG on heat build-up⁹

In the same study, results also showed that PEG can improve tensile strength and reduce heat build-up as shown in Figure 10 and 11 respectively. These effect resulted primarily from an improved state of cure. He had attributed this to the function of PEG in reducing the chemical activity of the silanol groups on the surface of the silica particle and the resultant interactions that reduce the amount of cure system ingredients available for vulcanization ⁹.

Wang ¹¹ showed that increasing concentrations of DEG leads to a drastic decrease in storage modulus, E' , of silica vulcanizates. The high level of E' at low deformation gives an indication of the existence of a stable filler network formed by the silica. The stability of the silica network is responsible for a lesser degree of destruction and re-formation of the silica network during a deformation cycle.

As DEG is mainly physically bound on the silica surface, it can be easily extracted from the vulcanizates with solvent. This phenomenon may be attributed to the restoration of the filler network upon removal of DEG. If the high modulus of the extracted vulcanizates is related to reconstruction of the filler network, then the silica aggregates could be very close to each other or there could be none or very small amount of rubber between aggregates. Another possible interpretation might be associated with very low polymer-filler interaction as DEG could serve as a lubricant like material at the polymer-filler interface thereby reducing the modulus.

Wang ¹¹ is of the opinion that surface modification by physical adsorption of chemicals may not be preferred as they can be extracted by solvent or evaporated at high temperature. In addition, such an approach has rarely been applied in highly reinforced compounds because of the relatively poor polymer-filler interaction.

At this stage, Byers ⁹ had shown that the use of PEG in SBR sulphur cured system with 50 pphr silica had resulted in improved vulcanizate properties of tensile strength and heat build-up. On the other hand, Wang ¹¹ showed that the use of DEG in a natural rubber peroxide cure system with 50 pphr silica showed lower storage modulus, E'.

1.9 Objective

Work had been conducted by Byers ⁹ and Wang ¹¹ on the addition of PEG and DEG respectively. However, there is no report on the effects of PEG on the properties of a silica-carbon black filled natural rubber compound.

This project aim to investigate the effects of adding PEG on processing and physical properties of a silica-carbon black-filled natural rubber truck tread compound. A standard truck tread compound was selected to investigate changes in properties especially hysteresis, abrasion resistance and cut growth resistance, which may contribute towards reducing service return in truck tyres. Two sets of experiment were conducted to study the following :

- i. effects of PEG addition in a silane-modified-silica compound, and
- ii. effects of PEG addition in an unmodified silica compound.