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A Research on the Utilization of Precipitating Silica Particles in Natural Rubber, Chloroprene Rubber and Styrene Butadiene Rubber

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Abstract – Precipitated silica (PSi) suspensions were used for preparing silica/natural rubber (NR) masterbatches via a latex system. Then, both types of dried silica/NR masterbatch were mixed with other rubber chemicals on a two-roll mill. The results showed that well-dispersed FSi suspension could be prepared by either using the ultrasonic bath or agitator bead mill, while only the agitator bead mill could give well-dispersed PSi suspension. Also, the amount of silica loss in the masterbatches was clearly less than in silica-filled NR prepared by using a conventional method, and the color of the uncompounded FSi/NR masterbatches was lighter than that of the PSi/NR masterbatches. Additionally Precipitated silica is promising non-black filler for rubber vulcanizates.

It can be used to replace carbon black partly in tyres to reduce the rolling resistance of tyres and hence to bring down the fuel consumption. However, silica is not compatible with the commonly used olefinic hydrocarbon rubbers and hence mixing and homogeneous distribution of silica in rubber is difficult. Coupling agents are often necessary for proper binding of rubber and silica. Coupling agents facilitates filler incorporation and enhances the properties of the final product. The coupling agents also improve the processing behaviour by reducing the specific surface energy and the solubility parameter of the silica.

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INTRODUCTION

Incorporation of precipitated silica in rubber is quite different from that of carbon black. Carbon black is reinforcing filler for hydrocarbon rubbers. Since both are hydrophobic substances, mixing and reinforcement problems do not usually arise when these two are mixed. Precipitated silica, which is of mineral origin is one of the most promising alternatives to carbon black as for as reinforcement is concerned. Precipitated silica is used as reinforcing filler and have particle sizes as small as the carbon black besides an extremely reactive surface. Different types of synthetic silica are; precipitated, pyrogenic, aerogels and hydrogels. Of these varieties, precipitated silica and pyrogenic (fumed) silica are being used for elastomer reinforcement. Pyrogenic silica is too active and expensive. Precipitated silica is a promising non-black filler for rubber vulcanizates. It can be used to replace carbon black partly in tyres to reduce the rolling resistance of tyres and hence to bring down the fuel consumption.

However, the silica surface has a tendency to absorb moisture due to its hydrophilic character. This adversely influences the curing reaction and hence the properties of the final product. The hydroxyl groups on the surface of the silica control surface acidity. This intrinsic acidity can influence vulcanization. The higher moisture content increases the dispersion time of silica into the rubber. Absorbed water can decrease cure time, tensile strength, bound rubber content and also abrasion resistance.

Rubber articles under severe service conditions undergo different types of degradations like ozone, oxidation etc. Although ozone is present in the atmosphere at concentration normally in the range 0-7pphm, it can severely attack unsaturated rubber products under stress. The general subject of protection of rubber against ozone attack has been reviewed by a number of authors. Several theories have appeared in the literature regarding the mechanism of antiozonant protection. The “scavenger” model states that the antiozonant blooms to the surface and preferentially reacts with ozone so that the rubber is not attacked until the antioxidant is exhausted.

The protective film theory is similar except that the ozone–antiozonant reaction products form a film on the rubber surface that prevent ozone attack. A third “relinking” theory states that the antiozonant prevents scission of the ozonised rubber recombines several double bonds.

During recent years there has been a gradually increasing demand for antidegradants to give optimum protection of rubber goods. Derivatives of p-phenylenediamine (PPD) offer excellent protection to rubber vulcanizates as antioxidants, antiozonants and antiflex cracking agent. P-phenylenediamine antidegradants function as primary antioxidants and are recognized as the most powerful class of chemical antiozonants, antiflex cracking agents and antioxidants. PPD′s are extensively used in tyres belting and molded and extruded rubber products as antiozonants and antiflex cracking agent. PPD′s are also used as polymer stabilizer.

Rubber blends have gained much attention in the rubber industry because, when properly formulated, the blend could combine the best features of the individual blend partner. Desirable outcome is therefore easily obtained. Natural rubber (NR) is widely known to possess good mechanical properties such as high tensile and tear strengths due to its ability to crystallize upon stretching. The elasticity and dynamic properties of NR are also excellent.

However, due to the existence of numerous reactive double bonds on the molecular backbone, NR is highly susceptible to degradation by thermal aging and ozone attack. In addition, oil resistance of NR is relatively poor, compared to some polar synthetic rubbers such as chloroprene rubber (CR) or acrylonitrile butadiene rubber (NBR). To overcome such shortcomings, NR is frequently blended with synthetic rubbers such as NBR or CR. Recently, blends of NR/CR have been extensively studied. The incorporation of CR into NR helps to improve oil and thermal resistance of NR. As CR and NR are cured in different manners, careful adjustment of the cure system must be taken into account to avoid maldistribution of crosslinks within the two phases. Cure system of NR/CR blend therefore generally includes sulfur, thiourea derivatives with the addition of other conventional accelerators . Apart from the curing system, the difference in polarity of the blend partners could also bring about high interfacial tension which is detrimental to the mechanical properties of the blend. The addition of suitable compatibilizer is therefore recommended.

It has currently been reported that precipitated silica, widely used as reinforcing filler for most rubbers, could form strong interaction with CR through hydrogen bonds. The presence of silica in CR could also give rise to additional crosslinks due to the chemical reaction between the silanol groups on silica surface and the allylic chlorine atoms in CR. These reports confirm that silica interacts with CR in a special manner which is different from the most commonly used filler, carbon black. It is therefore interesting to use silica as reinforcing filler for this CR/NR blend. In the present study, the effect of blend ratio on properties of silica-filled CR/NR blend was investigated. The mechanical properties as well as the resistance to aging, oil and ozone of the blends were focused.

ANTIOXIDANT MODIFIED PRECIPITATED SILICA IN NATURAL RUBBER

Natural rubber of grade ISNR-5, conventional zinc oxide, stearic acid, precipitated silica, antioxidants IPPD [N-isopropyl-N′-phenyl-p phenylenediamine], 6PPD [N-(1,3-dimethylbuty1)–N′-pheny1-pphenylenediamine], DPPD [N,N′-diphenyl-p-phenylenediamine], naphthenic oil, diethylene glycol (DEG), cyclohexylbenzothiazyl sulfenamide (CBS), tetramethylthiuram disulfide (TMTD), sulphur.

Antioxidant (1phr) was mixed with precipitated silica (50phr) in torque rheometer (Brabender plastic order) at 50 rpm for above the melting temperature of antioxidant for 5 minutes. Antioxidants used in this study, to modify silica are IPPD, 6PPD and DPPD.

Compounds were prepared by mill mixing on a laboratory size (16 x33 cm) two–roll mill at a friction ratio of 1:1.25 as per ASTM D 3184-89 (2001). After complete mixing of the ingredients the stock was passed out at a fixed nip gap. The samples were kept overnight for maturation.

The cure characteristics of all mixes were determined using Rubber Process Analyzer as per ASTM standard D 2084-01. Subsequently the rubber compounds were vulcanized upto the optimum cure time at 150°C in an electrically heated hydraulic press. The mouldings were cooled quickly in water at the end of the curing cycle and stored in a cool dark place for 24 hrs prior to physical testing.

Physical properties such as tensile strength, modulus, elongation at break, tear strength, hardness, abrasion loss, heat build-up, compression set and flex resistance were studied as per the relevant ASTM standards. Antioxidant modified silica vulcanizates showed better abrasion resistance. This is due to the strong adhesion of silica particles on rubber chains. Hardness also showed the same improvement. Compression set are found to be comparatively low for antioxidant modified silica composites. This indicates lower elasticity of antioxidant modified silica vulcanizates.

The number of flex cycles required for crack initiation was noted and it is comparatively high for antioxidant modified silica vulcanizates, indicating that antioxidant modification improves the distribution of antioxidant and silica in rubber.

PRECIPITATED SILICA REINFORCED NATURAL RUBBER COMPOSITES

Commercial applications of elastomers often require the use of particulate fillers such as carbon black and silica.u For the composite to be effective there must be a strong interaction between the matrix and the reinforcing phase and this can be achieved using a filler with large surface area-to-volume ratio. Optimally this means using small fillers with a large aspect ratio. Recently particles with nanoscale dimensions have become the subject of extensive research. But the key issues for the nano particles, which ultimately determine their usefulness as fillers, are their effective dispersion in the matrix and the nature of the interface with the matrix}, Precipitated silica is one of the promising non-black fillers for rubber. It improves mechanical properties and the material properties of elastomers. However, the mixing of silica with the commonly used olefinic hydrocarbon rubbers is a challenge as these materials are not very compatible in various aspects.

In order to achieve excellent reinforcement, it is important to incorporate very fine silica particles and to disperse them well in the rubbery matrix. Recently the sol-gel technique, which can generate in situ reinforcing particles, has been widely applied for the synthesis of hybrid organic - inorganic materials.20 TIUs process, which consists of hydrolysis and condensation of an alkoxy silane such as tetra ethoxy silane (TEOS), is expected to yield small and well-dispersed particles within the polymer matrix. The structure and morphology of the filler depends on the reaction conditions and essentially on the nature of the catalyst. A representative procedure is a method in which water and a catalyst are impregnated in to rubber swollen in TEOS and silica synthesis in rubber matrix is carried out. In situ precipitation of silica was done in Poly dimethyl siloxane (PDMS) by swelling PDMS in TEOS for different periods and then hydrolysing the TE05 by immersing the swollen mass in 2 wt % Diethylamine.

Natural rubber latex was filtered and stabilized with non-ionic stabilizer vulcastab VL, mixed with required amount of sodium silicate, stirred for one hour and then kept overnight. A saturated solution of ammonium chloride was added drop wise with constant stirring to precipitate silica. Latex containing silica was coagulated as crumbs by the addition of 2% acetic acid. The crumbs were washed with water till the washings were neutral and free from chloride, pressed to remove water and dried in an air oven at 70°C for 48hrs.

The precipitation of silica was repeated at different concentrations using different quantities of sodium silicate and ammonium chloride. The amount of silica in the sample was experimentally determined out by igniting the rubber in a known weight of the sample in a muffle furnace.

The mixing of silica with commonly used olefinic hydrocarbon rubbers like NR, SBR, BR, etc is a challenge as these materials are not very compatible in various aspects. Such shortcomings can be overcome by the use of coupling agents such as silanes, titanates and zirconates. Of these coupling agents silanes are widely used.] Several silanes with appropriate functionality, such as alkoxyl silyl groups, have been successfully used as coupling agents. They provide a bond between the filler and the polymer by forming a chemical link. This facilitates filler incorporation and also enhances the properties of the final product by increasing the dispersive component. The application of a coupling agent greatly improves the processing behaviour by reducing the specific surface energy and the solubility parameters of the silica. However, these improvements are accompanied by other problems like

- Ethanol formation
- Higher processing temperature and
- Higher cost of the product.

So viable alternative methods or materials for overcoming the problems associated with the silica reinforcements of rubbers are therefore a current research priority. Surface modification of silica, so as to increase the silica-rubber bonding, is a method used for the better reinforcement. Various modifications have been done to improve the reinforcing ability of the silica, which include heat treatment, polymer grafting on silica surface and chemical modification. Esterification of silica surface by methanol, ethanol and butanol is also reported. In all these works silica surface is made hydrophobic and then incorporated in the rubber matrix. Varkey et al have reported the feasibility of using epoxidised natural rubber as a reinforcement modifier for silica filled rubbers. Use of epoxidised rubber seed oil as a coupling agent and a plasticizer in silica-filled natural rubber compounds, was studied by Reethamma et a1. The study revealed that the epoxidised rubber seed oil caused the hydrophobation of silica, which increased its degree of dispersion and the formation of chemical bonds with the rubber, thereby, ensuring strong polymer-filler interactions.

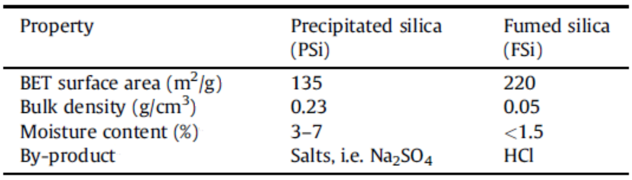
Epoxidised Natural rubber is a modified form of natural rubber with inherent reinforcement with silica. Unlike NR, epoxidised natural rubber (ENR) can be reinforced with silica without silane coupling agent. ENR (50 mol%) is found to have high interaction with the silanol groups of silica. In ENR the epoxy groups are randomly distributed along the hydrocarbon chain backbones, giving increased polarity and it frequently facilitates reinforcement by silica without the need of a coupling agent. Nanoclay reinforcement of ENR is also reported. It has been reported that by using ENR as a component together with silica, it is possible to achieve improvement in mechanical properties with respect to similar NR compounds.

Epoxidised natural rubber in small proportions is used as a reinforcement modifier for silica-filled nitrile rubber (NBR). Two cure systems were used: N-cyclohexyl- 2-benzthiazyl sulfonamide (CBS) alone and in combination with diphenyl guanidine (DPG). Chemical interaction or chemical crosslink between epoxy group and silanol groups has been proposed to explain the unusual reinforcement.

Silica is one of the reinforcing fillers widely used in rubber compounds. It not only improves tear strength and abrasion resistance but also reduces rolling resistance in tires when compared to the traditional carbon black.

Synthetic amorphous silica can be mainly categorized into two types, precipitated silica (PSi) and pyrogenic silica or fumed silica (FSi). They differ from each other in manufacturing process and particle dimensions. PSi is made by acid precipitation of sodium silicate while FSi is produced by hydrolysis of silicon tetrachloride in a flame. Generally, FSi is used in silicone rubber, especially for medical applications and insulating materials in wires and cables because of its high purity and low moisture.

Also, FSi-filled products are more transparent. Although, FSi offers the smaller particle size, which could impart a higher degree of reinforcement, it is infrequently used in tires and mechanical rubber goods because it is more expensive than PSi. In addition, FSi is a fluffy powder and has very low bulk density. Hence, the direct addition of the as-received FSi powder into dried rubbers such as natural rubber (NR) and styrene butadiene rubber (SBR) would be very difficult because a lot of FSi would float in the air causing a significant loss of silica in the rubber compounds.



Property	Precipitated silica (PSi)	Fumed silica (FSi)
BET surface area (m^2/g)	135	220
Bulk density (g/cm^3)	0.23	0.05
Moisture content (%)	3–7	<1.5
By-product	Salts, i.e. Na_2SO_4	HCl

Table 1 Typical properties of precipitated silica and fumed silica.

Additionally, the workplace would be dusty and unhygienic. Several attempts have been made to eliminate such problems by using FSi in the form of a suspension. However, if there is a lack of proper distribution of silica in the latex, a dramatic reduction in the mechanical properties of the vulcanizates would be observed. Therefore, an appropriate tool is necessary for initially dispersing the silica prior to mixing with rubber. Mora-Barrantes and coworkers pre-treated the FSi by firstly dispersing it in ethanol by using an ultrasonic probe and subsequently treating with silane. Then, the pre-treated FSi was dried before mixing with SBR using the conventional method.

They found significant improvement of the mechanical properties of SBR filled with the pre-treated FSi, relative to the pristine FSi. In this work, both PSi and FSi were firstly dispersed in water for preparing silica suspensions by using two different devices, agitator bead mill and ultrasonic bath. These devices are different in dispersing process and operating condition. An ultrasonic bath produces ultrasonic waves, while an agitator bead mill generates high shearing and impacting forces to reduce size of the silica. In addition, the ultrasonic bath is operated in batch mode, whereas the agitator bead mill is operated in circulation mode. After obtaining the well-dispersed silica suspension, it was added into NR latex for preparing the dried silica/NR masterbatches which were finally utilized for compounding by the conventional method. Cure characteristics, mechanical and dynamic properties of NR vulcanizates reinforced by pre-dispersed FSi and PSi were investigated and compared. The effect of bis-(3-triethoxysilylpropyl) tetra sulfide (Si-69) on the properties of the FSi- and PSi-filled NR composites at the highest silica loading was also demonstrated.

ANTIOXIDANT MODIFIED PRECIPITATED SILICA IN CHLOROPRENE RUBBER

Neoprene W, light magnesium oxide, stearic acid, precipitated silica, antioxidant IPPD, dioctyl phthalate (DOP), conventional zinc oxide, Na22. Antioxidant modified silica and neat precipitated silica were mixed with neoprene W as per the formulation.

Compounds were prepared by mill mixing on a laboratory size (16 x33 cm) two roll mill at a friction ratio of 1:1.25 as per ASTM D 3184-89 (2001). After complete mixing of the ingredients the stock was passed out at a fixed nip gap. The samples were kept overnight for maturation.

The cure characteristics of all mixes were determined using Rubber Process Analyzer RPA 2000, as per ASTM standard D 2084-01. Subsequently the rubber compounds were vulcanized upto the optimum cure time at 150°C in an electrically heated hydraulic press. The mouldings were cooled quickly in water at the end of the curing cycle and stored in a cool dark place for 24 hrs prior to physical testing.

Physical properties such as tensile strength, modulus, elongation at break, tear strength, hardness, abrasion loss, heat build-up, compression set, and flex resistance were studied as per the respective ASTM standards.

PRECIPITATED SILICA FILLED RUBBER COMPOSITES

Rubber technology is passing through a major paradigmatic change due to the replacement of carbon black by silica. Silica filled tyres have the great advantage of reduced rolling resistance and as a consequence, reduced fuel consumption. The importance of this development is far reaching in the light of our limited resources of fossil fuels and aggravating environmental problems. A 2% reduction in the rolling resistance can give a fuel saving of about 3 to 4 %. This environmental and economic incentive of silica technology is large enough to overcome the higher production cost due to the difficulty in incorporating silica in rubber and the need for coupling agents. However, if the incorporation of silica is made easier and the need for coupling agents can be dispensed with, silica technology will take a quantum leap in the years to come. This study has been undertaken with the objective of explaining methods that make silica incorporation easier and absolutely more efficient, without any coupling agents whatsoever or as an alternative, adopting cost effective alternatives.

Rubbers in general are seldom used in their pristine form. They are "too weak to fulfil practical requirements because of lack of hardness, strength properties and wear resistance. So they are used with a number of other components called compounding ingredients, which improve the process ability, performance properties and life of the final product. Fillers are used to enhance the performance related properties of rubbers. The fillers used in rubber compounding are characterized by their reinforcing effects, which ranges from inactive, semi active to very active fillers. The designation 'active' or 'reinforcing' refers to the influence of the filler on compound viscosity and failure properties such as tensile strength, abrasion and tear resistance. Structure as well as the surface properties of the filler is the main characteristics that determine the reinforcing effect. Active fillers are characterized by a large relative surface area and a high structure, both properties resulting in a strong antiparticle forces, which negatively influence the processing behaviour due to agglomeration of filler particles during mixing and storage of the compound. The use of reinforcing fillers gives the material unique properties: a combination of high elasticity with high strength.

Silica is a crystalline compound occurring abundantly as quartz, sand and many other minerals and is used to manufacture a variety of materials, especially glass and concrete. Natural silica is non-reinforcing and has been used as a fill's, only to reduce the cost. The synthetic ones are reinforcing and nowadays have particle sizes as small as the carbon black besides an extremely reactive surface.t9 Important natural varieties are silica (amorphous), silica (crystalline), silica diatomaceous (fossil origin) and silica (microcrystalline). Types of synthetic silica are precipitated, pyrogenic, aerogels and hydrogels. Of these varieties, precipitated silica and pyrogenic (fumed) silica are being used for elastomer reinforcement.

Compounding of silica with rubber - Compounding of rubber with precipitated silica is quite different from compounding with carbon black. Carbon black is the ideal filler for reinforcing hydrocarbon rubbers. Since both are hydrophobic substances, mixing and reinforcement problems do not usually arise when these two are mixed. Precipitated silica, which is of mineral origin, is one of the most promising alternatives to carbon black. However, due to the difference in surface energy, when silica is mixed with the commonly used non-polar olefinic hydrocarbon rubbers, leads to mixing and reinforcement problems. Another major problem is that silica-to-silica interaction is high, resulting in the formation of large aggregates ultimately impeding the compound flow character. In the case of both carbon black and silica with lower surfan' area (bigger particle size), viscosity is lower and dynamic properties are better. Fine particle silica could reinforce rubber, but silica filled compounds exhibits higher viscosity and slower cure.

To reduce the viscosity some softeners are used effectively. Natural softeners like vegetable oils and hydrogenated rosin are effective in reducing viscosity, though its mechanism is not fully understood.

Petroleum based aromatic resins are effective in giving smooth extrusion, better tensile strength, tear strength and abrasion resistance. Considerable reduction in viscosity is obtained only with additives that de-agglomerate the silica. Additives such as soluble zinc compounds (eg. zinc octoate), hexamethylene tetramine (HMT), magnesium Oxide ete. are reported to reduce compound stiffness. Activators such as Diethylene glycol (DEG), polyethylene glycol (PEG) and triethanolamine (TEA) are used in compounding, which reduces cure time, compression set and heat buildup and enhances the tensile strength.

Silica reinforcement of synthetic rubbers - SBR is a non-polar synthetic rubber that is the most commonly used general-purpose synthetic rubber. They are produced by the copolymerization of butadiene and stvrene under controlled conditions of reactions using different techniques of polymerisation. Different reaction conditions give different products. Depending on the method of manufacture SBR is divided into emulsion, solution, cold or hot etc. The products vary in chemical nature also since the butadiene polymerise in three different ways namely cis-I, 4, trans-I, 4 and vinyl.

The physical properties of SBR are much inferior to those of NR. Similarly its green strength is also inferior. But the extrusion properties of SBR are superior to those of NR and its stocks have fewer tendencies to scorch in processing. The unsaturation in SBR is less than that of NR and the double bonds are less active chemically than the double bonds of NR. Hence, SBR shows a slower curing than NR and more accelerators or more active accelerator system is required.

ANTIOXIDANT MODIFIED PRECIPITATED SILICA IN STYRENE BUTADIENE RUBBER

It was observed that in situ precipitation of silica in polar synthetic rubber latex NBR has improved the rubber filler interactions and mechanical properties. So the same method was studied in non-polar synthetic rubber latex, Styrene Butadiene Rubber (SBR). SBR is the most commonly used general-purpose synthetic rubber which is a copolymer of styrene and butadiene, and the butadiene unit is composed of cis-l,4-, trans-1,4- and vinyl components. They are produced by the co-polymerization of styrene and butadiene under controlled conditions of reaction using different techniques of polymerization and the product varies with the method of polymerisation.

The unsaturation in SBR is less than that in NR and the double bonds are less active chemically than the double bonds of the isoprenoid unit in NR. The compounding of SBR is done in a way more or less similar to that of NR and other unsaturated hydrocarbon rubbers.

All types of SBR require less sulphur than NR for curing· On the other hand, SBR requires more accelerator because of lower unsaturation. Without reinforcing fillers such as carbon black or silica, the physical properties of SBR are much inferior to those of NR. Similarly its green strength is also inferior. Many studies are reported on the silica reinforcement of SBR, comparison with carbon black, rubber filler interactions, bound rubber content, hysteresis loss etc.2,3 A study on the mechanical properties of silica filled SBR systems in relation to the secondary structure formed by silica particles in the systems, which was controlled by a surface chemistry of silica particles was carried out which revealed that the initial modulus of the filled rubber systems increased with the increase of the agglomerates. But the incorporation of silica has the drawbacks, those are explained in the case of NR, in the case of SBR also. So the development of new techniques and materials that facilitate the incorporation of silica is a topic of current research. The use of sol-gel process on SBR to produce silica generated in situ is conducted and found that the sol-gel reactions of tetraethoxysilane (TEOS) in SBR produced in situ silica that has better dispersion due to its formation in place. Reinforcing effect of silica on the properties of styrene butadiene rubber-reclaim rubber blend system was studied by sol-gel technique and conventional method.) Silica incorporation by conventional mechanical mixing in absence of TESPT showed a much higher tensile properties than that of silica incorporated by the in situ sol-gel reaction of tetra ethoxy silane both in presence and absence of TESPT. The effect of oleyl amine on processing and physical properties of SBR compounds filled with silane-silica particles has been evaluated J A silica reinforcement of SBR latex by the sol-gel method of tetraethoxysilane was conducted and found that the particle size and reinforcing behaviour of silica were greatly influenced by the amount of TEOS and (H20/TEOS). The diameter of the silica particles was less than 100 nm.

Styrene butadiene rubber (SBR 1502), conventional zinc oxide, stearic acid, precipitated silica, antioxidant IPPD, naphthenic oil, diethylene glycol, cyclohexylbenzothiazyl sulfenamide (CBS), tetramethylthiuram disulfide (TMTD) and sulphur.

The cure characteristics of all mixes were determined using Rubber Process Analyser RPA 2000, as per ASTM standard D 2084-01. Subsequently the rubber compounds were vulcanized upto the optimum cure time at 150°C in an electrically heated hydraulic press. The mouldings were cooled quickly in water at the end of the curing cycle and stored in a cool dark place for 24 hrs prior to physical testing. Physical properties such as tensile strength, modulus, elongation at break, tear strength, hardness, abrasion loss, heat build-up, compression set and flex crack resistance were studied as per the respective ASTM standards.

CONCLUSION

Well-dispersed FSi suspension can be readily prepared by either using an ultrasonic bath or agitator bead mill, while an agitator bead mill is required for preparing well dispersed PSi suspension having particle size comparable to that of FSi. In addition, SEM results reveal that both DE agglomerated FSi and PSi particles still distribute and disperse well after being processed for preparing the silica/NR masterbatches.

Commercial applications of rubbers require the use of particulate fillers such as carbon black, silica etc. Precipitated silica is one of the promising non-black fillers for rubbers in tyre applications, as it has the great advantage of reduced rolling resistance and as a consequence, reduced fuel consumption. Conventionally silica-reinforced rubber composites are prepared by mechanical mixing of rubber and silica with silane coupling agent, which provides a chemical link between silica and rubber. However, the mixing of silica with the commonly used olefinic hydrocarbon rubbers is a challenge as these materials are not very compatible in various aspects. So viable alternative methods or materials for overcoming the problems associated with the silica reinforcement of rubbers are therefore a current research priority.

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