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Utilization of silicon dioxide powder from industrial wastes as novel filler in rubber isolator application

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Abstract

The silicon dioxide powder (SP) was an industrial waste and obtained from the silicon metal industry in Thailand. The effect of SP loading on cure characteristics, mechanical, dynamic and endurance properties in natural rubber were investigated and compared to calcium carbonate ($CaCO_3$) and unfilled natural rubber, respectively. Results revealed that the addition of SP significantly affected the cure characteristics and mechanical properties. An increasing content of SP increased the hardness, modulus, tensile strength and tear strength due to a higher SP-rubber interaction but decreased the elongation at break since higher SP in rubber matrix resulting in lesser mobility of rubber chains. For the curing behavior, the faster cure time was observed since more heat transfer to the compound occurred. The rubber product performance in terms of dynamic and endurance properties of rubber isolator were also determined. It had been found that SP not only improving the damping characteristics but also enhancing the number of cycles until fracture. Moreover, adding the bis-(3-triethoxysilylpropyl)-tetrasulphide (TESPT) showed higher reinforcement efficiency of SP. This can directly react to silanol groups on the SP surface and also reduce hydrogen bonding of SP particles. So, TESPT can reduce accelerator adsorption and SP-SP interaction, leading to better processability. Besides that, TESPT is a sulphur-based rubber silane. It can contribute sulphur atoms from molecule and then form covalent bonds with natural rubber chains which leads to enhance the crosslink density. Influence of filler type on rubber isolator, the SP imparts greater reinforcement than $CaCO_3$. All obtained results suggested that SP can be fully replaced the commercial $CaCO_3$.

1. Introduction

Filler is used in the rubber industry for many purposes such as to improve strength and enhance the rubber mechanical properties. Many types of filler are used in natural rubber such as carbon black [1,2], silica [3-7], clay [8,9], calcium carbonate [10-13], etc. Silica, composed of silicon dioxide (SiO_2), is a non-black filler, having reinforcing capability comparable to carbon black. It provides better heat build-up, durability, mechanical properties and so on. Nevertheless, the carbon black or silica production process normally consumes a high thermal energy which contributes to the global greenhouse effects. Recently, rubber scientists have tried to utilize silicon dioxide from natural resources such as rice husk ash (RHA) [14,15]. RHA is obtained from the burning process of rice husk. However, the main disadvantage of RHA production is a low percent yield due to rice husk containing about 75% of organic matter. The other source with a potential mass production is fly ash (FA) [16-19]. FA is a coal combustion product which is collected from the exhaust gases and contains silicon dioxide around 45% to 50%. The low silicon dioxide content is not considerable interest. Therefore, the new filler is silicon dioxide powder (SP) which is presented in this work. The SP is an industrial waste from the silicon metal industry. It has a very high content of silicon dioxide in the range of 90% to 95%. Due to environmental problems and then require proper management to eliminate the waste material. Implementation of SP in rubber products may be a good solution since it is a waste utilization in silicon metal industries and also possibly make higher value added on rubber products i.e rubber isolators. Rubber isolator is designed to reduce vibration from machines and noise control. Effectiveness of the vibration control is a function of the rubber spring constant, damping constant and loss factor. The purpose of this research, to use the SP as filler in natural rubber. TESPT is a silane coupling agent that used to improve SP performance [20,21]. In this work, the natural rubber is filled with TESPT treated SP compared to SP (no silane), $CaCO_3$ and unfilled natural rubber, respectively. The effect of different types of fillers on mechanical properties and cure characteristics are studied. Furthermore, the rubber isolator which is reinforced by SP and other filler on the endurance and dynamic properties are also discussed and has not been reported elsewhere.

2. Experimental

2.1 Materials

The ribbed smoked sheets (RSS#3) was manufactured by Thai Hua Rubber Public Co., Ltd. TESPT was used as a silane coupling agent which manufactured by Evonik Industries. Zinc oxide (ZnO) was an activator and supplied by Thai-Lysaght Co., Ltd., the co-activator was stearic acid which purchased from Chemmin Corporation. The antioxidant was 2,2,4-trimethy1-1,2-dihydroquinoline (TMQ), obtained from Kawaguchi Chemical Industry. N-tertiarybutyl-2-benzothiazole sulfennamide (TBBS) and diphenyl guanidine (DPG) used as a rubber accelerator and sulphur which were purchased from Sunny World Co., Ltd. Calcium carbonate, namely, Omyacarb-1T was manufactured by Surint Omya Chemicals Co., Ltd (average particle size 1 µm, specific gravity of 2.7 and surface treated with stearic acid at around 1.1 wt%). The new alternative filler in this research was SP; it was an industrial waste from the silicon metal industry.

2.2 Characterization of silicon dioxide powder (SP)

The chemical compositions and functional groups of SP were characterized by wavelength dispersive X-ray fluorescence (WDXRF) and fourier transform infrared spectroscopy (FTIR), respectively. The morphology such as particle shape and structure were studied by SEM at 10,000x. Also, the specific surface area of SP was analyzed by surface area analyzer whereas the particle size distribution was determined by particle size analyzer.

2.3 Formulations and compounding

Compound formulations were showed in Table 1. The contents of TESPT and DPG used in formulation were calculated based on the specific surface area of SP according to Equation (1) and (2) [22].

$$TESPT\ content\ (phr) = 0.00053 \times Q \times CTAB \quad (1)$$

$$DPG\ content\ (phr) = 0.00012 \times Q \times CTAB \quad (2)$$

where Q was SP content (phr), CTAB was the specific surface area of SP (14.16 $m^2 \cdot g^{-1}$).

A compound was mixed by kneader of 3 liters. The RSS#3 was masticated with ZnO and stearic acid in the mixer for 2 min. Then, TMQ and filler such as SP or $CaCO_3$ were added and mixed with TESPT for 4 min. After ram up and down, mixed again for 2 min. The rubber accelerators i.e., TBBS, DPG and Sulphur were added on a two roll mill at room temperature.

2.4 Cure characteristics and mechanical properties of rubber isolator

Rubber compound was measured at 150°C for 30 min by moving die rheometer (MDR). The cure characteristics such as the maximum torque (M_H), the minimum torque (M_L), the differential torque (M_H-M_L), the optimum cure time (t_{90}) and the scorch time (t_{S2}) were determined. The rubber mechanical properties such as hardness (HS), tensile strength (TS), 100% and 300% modulus (M100 and M300), elongation at break (EB) and tear strength (TR) were also determined. The specimens were prepared by compression molding at 150°C based on the optimum cure time (t_{90}) values. A universal tensile testing machine was used for measure properties at 23 ± 2°C with dumbbell shaped samples, according to ASTM D412 method. The tear strength was measured according to ASTM D624 method. The hardness test was investigated by a hardness tester according to ASTM D2240 method.

2.5 Dynamic properties of rubber isolator

The rubber isolator was vulcanized by molding at 150°C based on t_{90} and kept under room temperature for 24 h before testing. The dynamic properties such as static spring constant (Ks), dynamic spring constant (Kd), dynamic to static coefficient (η), damping constant (C) and loss factor (tanδ) were carried out. For Ks testing, it was examined at 23 ± 2°C by autograph machine. Ks was equal to the slope of the load vs. displacement curve. The testing load was applied in the range of 0 N to 5 N on the rubber isolator but calculation the Ks in the range of 45 N to 55 N according to Equation (3).

$$K_s = \frac{F_2 - F_1}{D_2 - D_1}\ (N \cdot mm^{-1}) \quad (3)$$

where Ks was static spring constant ($N \cdot mm^{-1}$), F_1 was load at 45 N, F_2 was load at 55 N, D_1 was lower displacement (mm) and D_2 was upper displacement (mm).

Table 1. Rubber isolator formulations.

Ingredients	Unfilled	SP 30 phr (TESPT)	SP 50 phr (TESPT)	SP 70 phr (TESPT)	SP 70 phr (no silane)	$CaCO_3$ 70 phr
RSS#3	100	100	100	100	100	100
Silicon dioxide powder (SP)	-	30	50	70	70	-
Calcium carbonate ($CaCO_3$)	-	-	-	-	-	70
ZnO	5	5	5	5	5	5
Stearic acid	1	1	1	1	1	1
TMQ	1	1	1	1	1	1
TBBS	1	1	1	1	1	1
TESPT	-	0.22	0.37	0.52	-	-
DPG	-	0.05	0.08	0.12	-	-
Sulphur	2	2	2	2	2	2

In the case of Kd, C and tan δ testing, it was measured by rubber isolator dynamic characteristic tester at 23±2°C. A sinusoidal mechanical excitation of the rubber isolator was executed whereby force at 25 Hz with amplitude held constant at 0.25 mm. The Kd, C and tan δ were reported and calculated according to Equation (4) to (7).

$$K_d = |K^*| \cos\delta \ (N{\cdot}mm^{-1}) \quad (4)$$

$$K_i = |K^*| \sin\delta \ (N{\cdot}mm^{-1}) \quad (5)$$

$$l = \tan\delta = \frac{K_i}{K_d} \quad (6)$$

$$C = \frac{K_i}{\omega} \ (N{\cdot}s{\cdot}mm^{-1}) \quad (7)$$

where Kd was dynamic or storage spring constant ($N{\cdot}mm^{-1}$), Ki was loss spring constant ($N{\cdot}mm^{-1}$), |K*| was absolute value of complex spring constant ($N{\cdot}mm^{-1}$), tanδ was loss factor, δ was loss angle (rad), C was damping constant ($Ns{\cdot}mm^{-1}$) and ω was angular velocity ($rad{\cdot}s^{-1}$).

2.6 Endurance properties of rubber isolator

Endurance testing was measured by rubber endurance tester. Rubber isolator was placed on the jig and applied the load of 1.5 kN at 3 Hz with amplitude 0.25 mm. For the evaluation of sample, stop testing when found the crack on the surface and recorded the number of cycles until fracture.

3. Results and discussion

3.1 Characterization of silicon dioxide powder (SP)

The WDXRF is used for analyzing the chemical compositions of SP; as showed in Table 2. Based on the WDXRF result shows that the major component of SP is silicon dioxide (SiO_2) about 94.42% and the other contents are also found about 5.58% such as potassium oxide (K_2O), sulfur trioxide (SO_3), calcium oxide (CaO), etc. Therefore, the SP used in this research consists mostly of SiO_2 content. Figure 1 illustrates the functional groups of SP. It is found that the absorption peak at 802 cm^{-1} and 1,094 cm^{-1} which is attributed to the Si–O vibration and asymmetrical stretching of Si–O–Si vibration, respectively. Also, a weak absorption peak at 1,645 cm^{-1} assigned to the H-O-H bending. Furthermore, the absorption peak at 3,429 cm^{-1} corresponded to the stretching vibration of silanol groups (Si-OH); as characteristic of silica. The SEM image of SP is showed in Figure 2. According to the SEM micrograph, it can be seen that most of their particles are a spherical shape with the average particle size of 0.12 μm and specific surface area of 14.16 $m^2{\cdot}g^{-1}$ which is analyzed by surface area analyzer. Furthermore, the particle size distribution (PSD) of SP is also measured with a Mastersizer 2000 and illustrated in Figure 3. The PSD result shows mostly of particle size distribution in the range of 0.1 μm to 1 μm.

Table 2. Chemical compositions of silicon dioxide powder (SP).

Chemical composition	Concentration (%)
Silicon dioxide (SiO_2)	94.42
Potassium oxide (K_2O)	2.40
Sulfur trioxide (SO_3)	0.94
Calcium oxide (CaO)	0.69
Magnesium oxide (MgO)	0.64
Sodium oxide (Na_2O)	0.39
Alumina (Al_2O_3)	0.19
Phosphorus pentoxide (P_2O_5)	0.16
Iron oxide (Fe_2O_3)	0.06
Lead oxide (PbO)	0.04
Manganese oxide (MnO)	0.03
Rubidium oxide (Rb_2O)	0.02
Zinc oxide (ZnO)	0.01

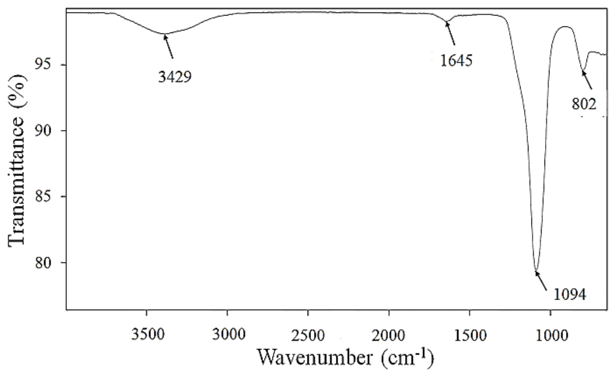

Figure 1. FTIR spectrum of silicon dioxide powder (SP).

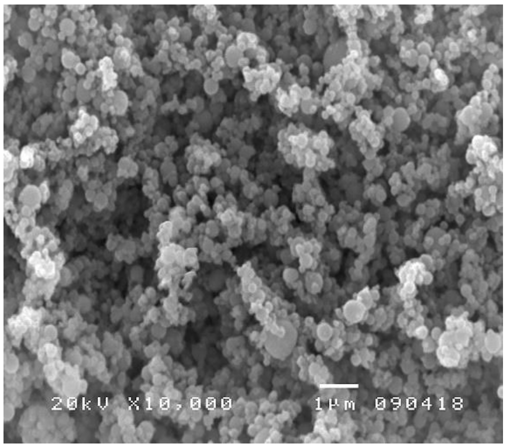

Figure 2. Scanning electron microscope (SEM) micrograph of silicon dioxide powder (SP) at 10,000x.

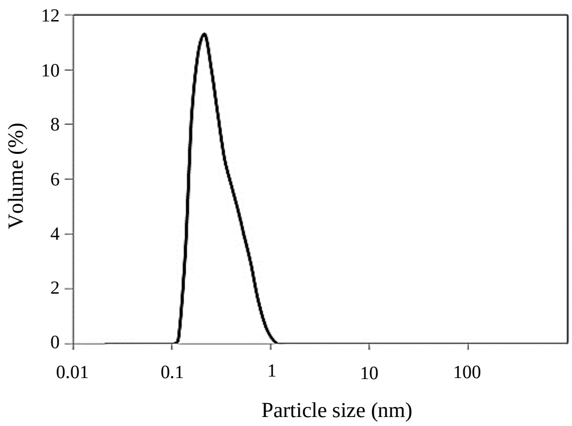

Figure 3. Particle size distribution of silicon dioxide powder (SP).

3.2 Cure characteristics of rubber isolator

The cure characteristics are showed in Figure 4 and summarized in Table 3. As can be seen, the M_H, M_L and M_H-M_L are significantly increased with increasing SP content. This is probably due to the addition of filler and attribute to enhancing the stiffness and viscosity of compound [23]. The increment of M_H (or stiffness) and M_L (or viscosity) by the addition of SP due to more interaction between SP and SP than SP and rubber. For the M_H-M_L result, it can be observed that more crosslink density in rubber chains. It is well known that the M_H-M_L value relates to the crosslink concentration of a network during vulcanization [24]. This phenomenon can be explained through the influence of SP surface treatment by TESPT. The TESPT is a bifunctional silane which can react between SP surface and natural rubber. Because it is a sulphur-based rubber silane. It can contribute sulphur atoms from TEPST molecule and then form additional covalent behaviors of the rubber compound. Thus, resulting in enhanced the crosslink density; as see the possible mechanism of interaction between TESPT treated SP and NR in Figure 5. Moreover, at a similar content (70 phr), the natural rubber filled with TESPT treated SP gives the M_H and M_H-M_L higher than SP (no silane) due to sulphur donor effect derived from TESPT; as explained previously. This result implies the role of TESPT in the enhancement of cure state. While, SP surface treatment by TESPT provides lower M_L than SP (no silane) because the TESPT can directly react to silanol groups on the SP surface and also reduce hydrogen bonding of SP particles. Therefore, the lower of SP and SP particle interaction is occurred. This confirms the surface treatment by TESPT and further supported by the similar results of Sae-oui *et al.* [26]. At the same loading 70 phr, M_H, M_L and M_H-M_L of natural rubber filled with TESPT treated SP increases about 18.6%, 17.1% and 18.1%, respectively compared to $CaCO_3$ loading. It is known that stiffness of compound increases when crosslinks are formed during vulcanization and leads to higher cure state. In addition, the effect of SP content on the cure behavior is also studied. The test result shows that t_{90} and t_{S2} are significantly decreased with increasing SP content. It is clear that the decreasing trend of them is due to higher viscosity of compound and leading to more heat transfer to compound; Attharangsan *et al.* [27] also reported similar results. Meanwhile, at 70 phr, natural rubber filled with TESPT treated SP shows faster t_{90} and t_{S2} compared to SP (no silane) and $CaCO_3$. This is due to the lower adsorption of accelerator on the TESPT treated SP surface [28]. Therefore, it can be concluded that TESPT not only enhances the crosslink density but also can play an important role in reducing vulcanization time. On the other hand, the slowest curing is observed for the unfilled natural rubber than others due to no filler in rubber matrix leading to lesser heat transfer in the compound.

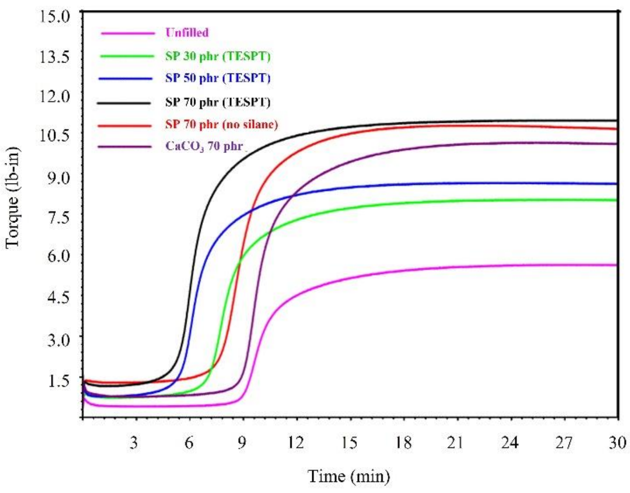

Figure 4. The rheographs of rubber isolator filled with different filler.

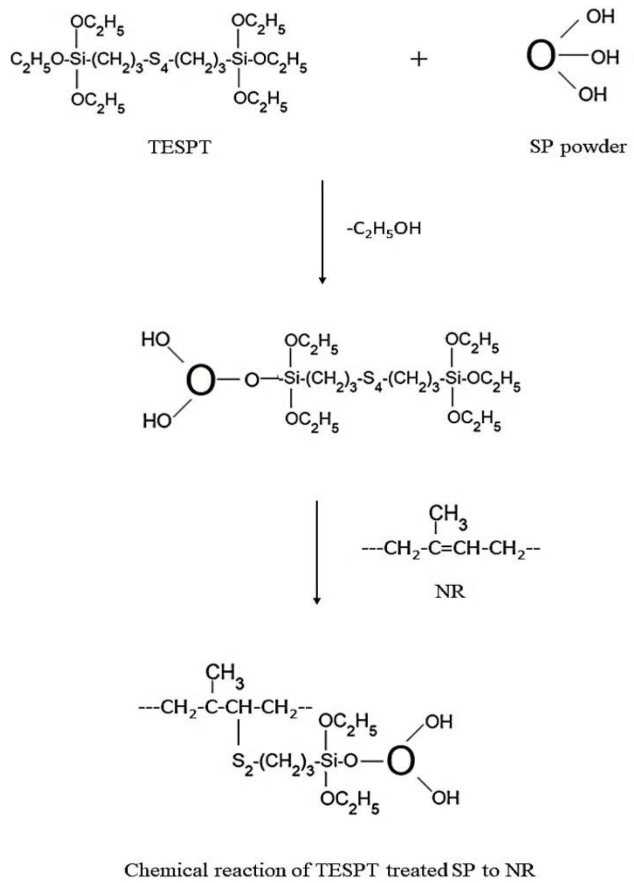

Figure 5. The mechanism of chemical reaction between TESPT treated SP and NR.

Table 3. Cure characteristics of rubber isolator.

Properties	Maximum torque (M_H, lb-in)	Minimum torque (M_L, lb-in)	Differential torque (M_H-M_L, lb-in)	Optimum cure time (t_{90}, min)	Scorch time (t_{S2}, min)
Unfilled	5.62	0.40	5.22	14.71	9.77
SP 30 phr (TESPT)	8.03	0.64	7.39	12.03	7.53
SP 50 phr (TESPT)	8.64	0.76	7.88	10.21	5.92
SP 70 phr (TESPT)	10.95	0.89	10.06	10.15	5.69
SP 70 phr (no silane)	10.14	0.97	9.17	12.35	8.53
$CaCO_3$ 70 phr	9.28	0.76	8.52	14.09	9.34

3.3 Mechanical properties of rubber isolator

Table 4 shows the mechanical properties which are filled with different fillers. Test results show that HS, M100, M300, TS and TR are considerably increased with increasing SP content. The increment in the mechanical properties is due to improved dispersion of SP in rubber matrix and resulting in good interaction between SP and NR. In contrast, it is also found that the EB decreased with increasing SP content. It is probably caused by an increment of the SP particles in natural rubber matrix [29]. Such resulting in reduce mobility of rubber chains and poor extension. Furthermore, the effect of SP surface treatment by TESPT is investigated. In particular filler loading at 70 phr, it can be observed that the existence of TESPT exhibits better mechanical properties than without TESPT. This is due to the introduction of TESPT treated on the SP surface and possible to improve the compatibility between the SP particles and natural rubber leading to increase the interfacial interaction of them. In the case of EB result, natural rubber filled with TESPT treated SP has an average EB value of 433%, whereas the SP (no silane) has an average EB is 20% higher, 520%. This similar observation is also found by other research [30]. Moreover, at the same loading 70 phr, natural rubber filled with TESPT treated SP exhibited higher modulus (M100, M300), TS and TR but lower EB than $CaCO_3$. It is due to the presence of more chemical linkage in rubber chains, resulting in greater the rubber stiffness as well as lower extension. The test result shows that natural rubber filled with TESPT treated SP exhibited the highest in mechanical properties. This may be due to the high specific surface area, small particle size and presence of TESPT as well.

3.4 Dynamic properties of rubber isolator

Table 5 shows the dynamic properties which is considered to rubber product performance. Results show that the Ks, Kd and η are gradually increased with increasing SP content. The increment of the Ks and Kd are directly related to the stiffness of rubber isolator. This explanation is normally referred by the spring constant equation because of calculated from the slope of a compression force and displacement curve; as showed in Equation (3). An increase of stiffness resulted in larger numbers of compression force and leading to enhance the Ks and Kd as well. It is also found that Kd higher than Ks in all case. The Kd is depend on frequency and amplitude of the applied displacement when the rubber isolator is vibrated at high frequency (25 Hz). Hence, the rubber molecules will resist quickly motion more than static system, so the spring constant in dynamic system is always higher than static system. For the η result is implied to non-elasticity. It can be seen that the η is effectively increased with increasing SP content. The reason for this is believed to be that an increase the hardness of rubber isolator in order to reduce the mobility of rubber molecules chains. This behavior is probable tendency to low flexibility and attributed to the Kd larger than Ks. Moreover, the surface treatment by TESPT effect has been further studied. The result is indicated that TESPT treated SP is higher Ks and Kd but lower η than SP (no silane). A remarkable increase in Ks and Kd is corresponded to an increase of crosslink density in rubber chains. Thus, it is also attributed to better chain flexibility resulting the deceasing of η [31]. In order to study the benefit of TESPT treated SP compared to $CaCO_3$ and unfilled natural rubber. It has been found that Ks and Kd of rubber isolator which is filled TESPT treated SP show higher than $CaCO_3$ and unfilled natural rubber, respectively because of enhance the chemical crosslinking between SP particles and rubber molecules. Therefore, this is the reason why TESPT treated SP promoted the superior mechanical and dynamic properties of rubber isolator than $CaCO_3$ and unfilled natural rubber. At the same dosage, it is noted that η of TESPT treated SP is the highest value. Two possible reasons can be explained that the first reason is the smaller particle size of SP. Therefore, higher surface of SP show more interaction between rubber and filler and lead to reduced chain flexibility. The second reason is that there are more SP particles in the rubber matrix than unfilled natural rubber and then affects low resilience. The dynamic properties in term of tanδ and C are also discussed; as a measurement of damping property of viscoelastic material which controls the vibration system. It should be noted that the tanδ and C show an increasing trend with increasing SP content. This phenomenon is clearly indicated to reduce the degree of rubber chains motion due to lesser distance between SP particles and increase the internal friction. It is resulting in an increase in the damping capability because more dissipated energy than stored energy and effectively reduces vibration [32]. Chandra *et al.* [33] also reported similar results from DMA technique but studied the silica filled natural rubber composites. At the same time, rubber isolator filled with TESPT treated SP shows the result of tan δ and C lower than SP (no silane) which provides a relatively high rubber-filler interaction. From the earlier discussion, it is directly proportional to the degree of crosslinking in rubber chains and corresponds to good elastic behavior. This means that it shows more elastic phase than viscous phase. However, when compared to $CaCO_3$ and unfilled natural rubber in terms of tanδ and C. The rubber isolator is filled with TESPT treated SP exhibited higher values of tanδ and C compared to those of without them. Due to SP particle is finer than $CaCO_3$ lead to higher interaction between rubber and SP. As a result, reduces chain flexibility and an increment in the damping property are observed. In the case of unfilled natural rubber, no filler in rubber matrix which provides greater resilience, therefore the tan δ is lower than TESPT treated SP.

Table 4. Mechanical properties of rubber isolator.

Mechanical properties	Hardness (Shore A)	Tensile strength (MPa)	100% modulus (MPa)	300% modulus (MPa)	Tear strength ($N \cdot mm^{-1}$)	Elongation at break (%)
Unfilled	38 ± 0.44	16.08 ± 0.20	0.83 ± 0.02	1.67 ± 0.04	32.55 ± 0.34	781 ± 28
SP 30 phr (TESPT)	47 ± 0.50	16.81 ± 0.26	1.35 ± 0.03	4.97 ± 0.15	47.87 ± 0.48	539 ± 15
SP 50 phr (TESPT)	52 ± 0.44	18.20 ± 0.31	1.75 ± 0.05	7.31 ± 0.10	53.22 ± 0.69	467 ± 10
SP 70 phr (TESPT)	56 ± 0.53	19.34 ± 0.32	2.21 ± 0.05	9.81 ± 0.07	57.89 ± 0.52	433 ± 18
SP 70 phr (no silane)	54 ± 0.50	18.49 ± 0.19	1.84 ± 0.04	8.38 ± 0.13	54.40 ± 0.70	520 ± 8
$CaCO_3$ 70 phr	53 ± 0.50	16.49 ± 0.12	1.33 ± 0.01	4.36 ± 0.05	42.14 ± 0.42	576 ± 9

Table 5. Dynamic properties of rubber isolator.

Properties	Static spring constant (K_s) ($N \cdot mm^{-1}$)	Dynamic spring constant (K_d) ($N \cdot mm^{-1}$)	Dynamic to Static coefficient (η)	Damping constant (C) ($N \cdot s \cdot mm^{-1}$)	Loss factor (tan δ)
Unfilled	26.78 ± 0.84	27.86 ± 0.26	1.041 ± 0.028	0.0015 ± 0.0001	0.0083 ± 0.0002
SP 30 phr (TESPT)	38.18 ± 0.40	40.33 ± 0.59	1.056 ± 0.006	0.0052 ± 0.0002	0.0210 ± 0.0001
SP 50 phr (TESPT)	42.33 ± 0.66	45.99 ± 0.84	1.086 ± 0.027	0.0087 ± 0.0001	0.0295 ± 0.0004
SP 70 phr (TESPT)	56.61 ± 0.46	61.97 ± 0.57	1.095 ± 0.006	0.0149 ± 0.0001	0.0387 ± 0.0021
SP 70 phr (no silane)	49.45 ± 0.48	54.43 ± 0.48	1.101 ± 0.007	0.0151 ± 0.0001	0.0400 ± 0.0017
$CaCO_3$ 70 phr	51.97 ± 0.55	55.53 ± 0.38	1.069 ± 0.016	0.0074 ± 0.0002	0.0273 ± 0.0002

3.5 Endurance properties of rubber isolator

Endurance properties are an important parameter for rubber isolator evaluation. It is represented the crack resistance when product usage. The aim of this part is studied the crack resistance of rubber isolator which filled TESPT treated SP with various content (30, 50 and 70 phr); as compared to SP (no silane), $CaCO_3$ and unfilled natural rubber. It is displayed in Figure 6 and observed that number of cycles until fracture of rubber isolator is greatly increased as the SP content. This result can be assumed that the enhancement of endurance properties due to increasing modulus result. The modulus is indicated the degree of stiffening material [34] and provides a significant improvement in crack resistance of rubber isolator. The endurance properties of TESPT treated SP are also compared to the SP (no silane). Test result in this work shows that the crack resistance of rubber isolator is filled TESPT treated SP increases from 42,254 cycles to 53,358 cycles until fracture, with an increase up to 26.28% compared to the SP (no silane). It can be explained by a high concentration of crosslink density in rubber networks. As mentioned above, the crosslink density is an important characteristic for improving the crack resistance due to more chemical bonding result in anti-deformation under an applied load. Furthermore, in our research found that superior endurance properties can be obtained by the addition of TESPT treated SP (53,358 cycles) than $CaCO_3$ (31,209 cycles) and unfilled natural rubber (7,933 cycles), respectively.

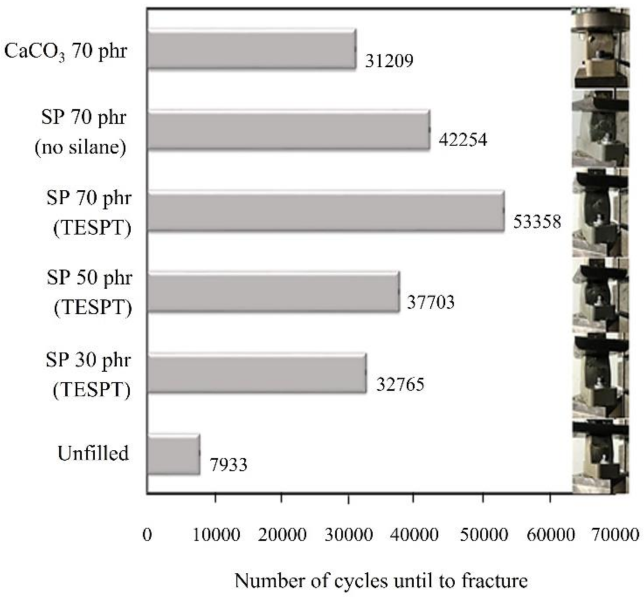

Figure 6. The effect of different filler on endurance properties of rubber isolator.

4. Conclusions

In this research, we attempted to use the SP as an alternative filler in rubber isolator application. The SP consists primarily of 94.42% silicon dioxide (SiO_2). In the spherical shape, it showed the average particle size of 0.12 μm and specific surface area of 14.16 $m^2 \cdot g^{-1}$. Furthermore, the particle size distribution was showed in the range of 0.1 μm to 1 μm. Influence of SP on cure characteristics and mechanical properties were studied. It was found that stiffness and crosslink density were increased but cure rate was decreased with increasing SP content. Also, the mechanical properties of SP were enhanced higher than $CaCO_3$ and unfilled natural rubber, respectively. Additionally, the presence of TESPT in SP filled natural rubber significantly improved the rubber properties more than without TESPT. At the same time, the dynamic and endurance properties of rubber isolator were also carried out. Both properties were considered for the rubber product performance. The dynamic properties of rubber isolator were clearly revealed that damping characteristics were increased with increasing SP content. In all cases of SP loading, it was found that dynamic spring constant is higher than static spring constant because rubber molecules resist quick motion and affect low flexibility. The endurance properties of rubber isolator were greatly improved by the SP loading more than $CaCO_3$ and unfilled natural rubber, respectively. Moreover, TESPT treated SP was capable of enhancing the reinforcement more than SP (no silane). All obtained results suggest that the SP can act as a good novel alternative filler in the rubber industry and show the high potential for fully replacing the commercial $CaCO_3$.

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