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Effect of Filler Materials in Silicone Rubber for the Electrical Insulation Applications: A Review

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Abstract

The chief focus of manufacturers over a diversification of industries is on eco-friendly materials. It is aimed at manufacturing electrical and electronic appliances. These material solutions are required to refine the insulators' performance and functionality as they become progressively smaller, lighter in weight, and more reliable. Silicone rubber is an excellent insulator for high-voltage equipment, transformers, and other electrical components. Silicone rubber not only steadily sustains its electrical properties while subjected to environmental conditions such as moisture and temperature fluctuations, but it is also safer and cleaner than its competitors. This review mainly focuses on the mechanical, thermal, electrical, and chemical properties of incorporating various fillers into a silicone rubber matrix for recommended electrical insulation applications.

Keywords: Silicone rubber, electrical properties, thermal properties, mechanical properties, chemical properties, micro composites, nano composites, fillers.

INTRODUCTION

Silicone rubber is an elastomer, a rubber-like material, which is comprised of a silicone polymer carrying oxygen, hydrogen and carbon which are combined with silicon. Its structure consistently forms silicon-oxygen links popularly known as siloxane backbone. As compared to various natural rubbers, Silicone rubber retains special features like solitary molecular structure. They support both organic accompanied by inorganic properties, and can exhibit superior properties, such as ozone resistance, chemical stability, abrasion resistance, heat resistance, weatherability, electrical insulation, owing to the Si–O bond along with its inorganic properties [1]. The structure of the silicone rubber is displayed below in the Fig.1 [2].

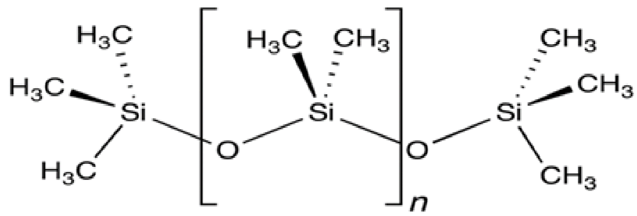

Figure 1. Structure of silicone rubber

Silicone rubbers typically exist as single-part or dual-part polymers that may restrain filler materials from enhancing their characteristics to minimize their cost. Silicone rubber is predominantly unreactive, durable, also unexposed to utmost environments. At the moment, exposure to ecological conditions, notably rain, ultraviolet rays, and wind for a long duration, results in substantially everlasting physical properties. Moreover, it can resist the extreme temperatures ranging from -50°C to 350°C (from −67°F to 572 °F) while maintaining its functional properties. In addition to the previously mentioned qualities and its simplicity regarding fabrication and shaping, silicone rubber was adopted by various firms to produce a variety of products for the electronics industry, aviation industry, aerospace industry, bakeware industry, cookware industry, cable accessories industry, automotive industry, medical devices industry, veterinary industry, molding industry, semi-conductors industry, and toy manufacturing industry [3]. Chennakesava Reddy et al. [4] referred to silicone as a thermoset because they can be either solids or liquids at average room temperature. Once it has cured, it is unable to be reprocessed or remelted. Over fixing, they configure 3D molecular chains, eminently called cross-linking. The number of cross-links increases its thermal stability and rigidity. The usually added basic fillers and additives to the silicone rubber are mentioned in the Fig.2 [2].

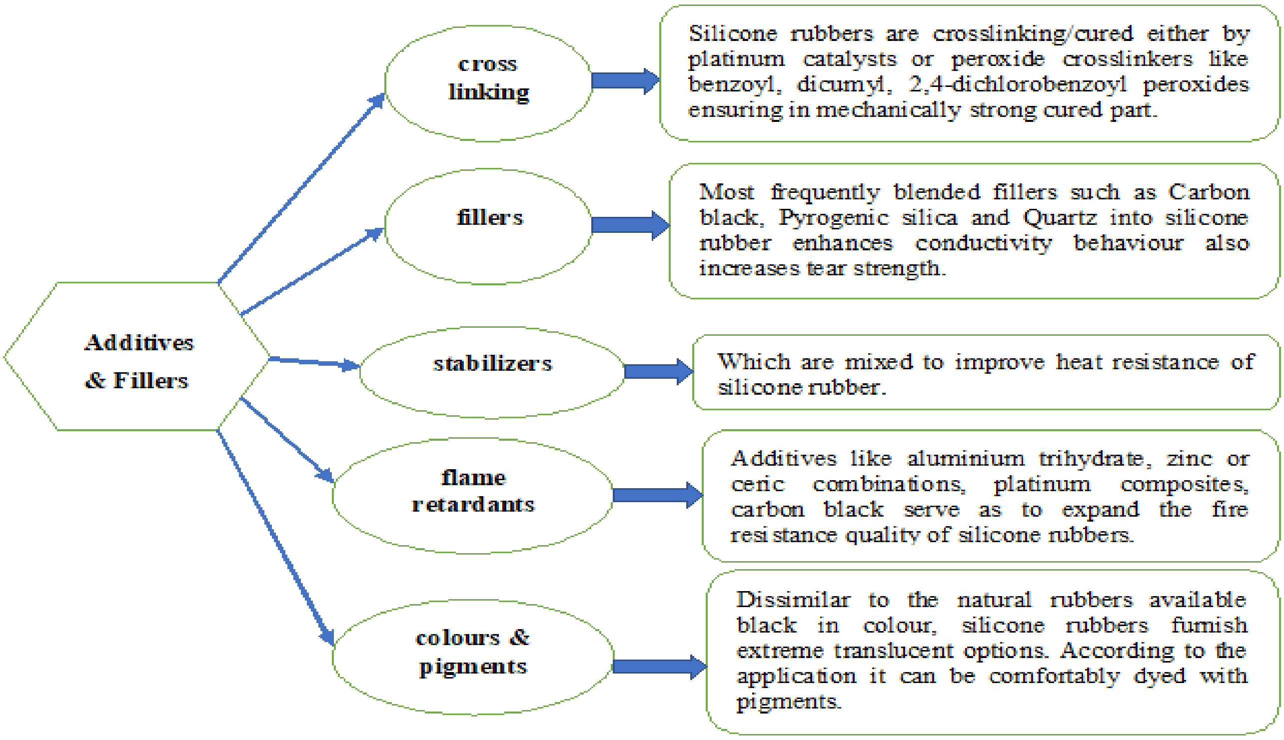

Figure 2. Basic fillers & additives blended with Silicone Rubber

The primary purpose of an insulating material is to separate conductors without transferring a current from one material to another and also to protect people from energized wires and other components. Over time, electrical insulation can deteriorate due to the number of stresses from electrical, mechanical, and environmental elements, which affects the material's service life. However, the most harmful physical threats to insulators are mechanical loads, ultraviolet radiation, and vandalism. Airborne pollutants can also cause serious issues because they can land on the insulator's surface, leading to leakage, dry band arcing, and flashover. Also, windblown dirt and sand can cause 'ceramic glaze to deteriorate. More durable liquid silicone rubber provides surfaces that are less prone to erosion from such abrasive particles [2]. Nanocomposites furnish the prospective in order to achieve a variety of approaches to polymers. Nano fillers are merged to polymeric substances on account of their outstanding properties correspondingly withstand inflated temperatures, preserve dimensional stability, refine barrier property, increase fire retardancy. Strengthening thermomechanical would enhance the surface hydrophobicity, upgrade electrical conductivity, magnify relative permittivity, together with to improve thermal conductivity. Hence, SR (silicone rubber) composites can be used in high voltage applications [3,5]. Aging deteriorates the properties of silicone rubber for outdoor insulator applications. In order to expand its survival expectancy besides that to improve preferred properties, predominantly focused on slowing down the aging process perhaps, attained through constituting micro-nano size filler materials towards the silicone rubber polymer [6,7, 8].

1. LITERATURE SURVEY

1.1 Mechanical Properties

Phenyl silicone rubber (PMVQ) and Methyl vinyl silicone rubber (MVQ) matrix materials are reinforced with CeO_2 and graphene in 2phr and 0.8phr, respectively. The composite with PMVQ as matrix presented best results than MVQ [9]. Influence of 5% weight concentration of ZnO (zinc oxide) nanofiller blended with silicone rubber showed highest values especially for hardness & tensile strength compared to the same weight percentage of SiO_2 (silicon dioxide) along with ZnO & SiO_2 combinations blended with silicone rubber also this combination displayed better % elongation at break [10]. The tensile strength, elongation at break concerning silicone elastomer without reinforcement are relatively poor against silicone rubber combined with precipitated silica & fumed silica (white carbon black). Shore, A hardness as for silicone elastomer, continuously increased by increasing reinforcement quantity. Shore hardness showed higher values for fumed silica composites at every dosage of reinforcement against precipitated silica composites [11]. Silicone rubber coupled with two different grades of precipitated silica such as Z142 & Z132, besides increased silica loading tensile strength, modulus & hardness raised, and elongation at break lowered on account of polymer-filler interrelations and filler distribution. Fumed silica(A150) stacked silicone rubber composites manifested almost the same trends, just as precipitated silica to the extensive range of lower granule size [12]. LSR (liquid silicone rubber) with 35wt% of TiO_2 (titanium oxide) loading combination obtained the best elastomer, despite that, too high concentration of TiO_2

(>35wt%) loading, destroyed the polymer chains moreover reduced OH-group surface density of TiO2, which declined the elastomer properties consequently due to photocatalytic properties of TiO2 [13]. BN (boron nitride) filled SR composites declining the tensile strength followed by elongation at break values against unfilled SR. [14]. Effect of loading level of fillers such as nano Boron Nitride, nano Silicon Nitride (SN) & synthetic Nano Diamond (ND) over silicone rubber matrix enhanced the mechanical properties. Howsoever, tensile strength plus strain at break, especially for Boron Nitride stuffed SR composites, exposed decremental values @ 1.5, 2.0vol% of filler depositing quantities, specifically caused by voids in addition enormous agglomerates established into the interior of composites [15]. SS-SIR (spherical shaped SiO2/silicone rubber) composite illustrated superior mechanical properties by contrast IS-SIR (irregular shaped SiO2 /silicone rubber) and ATH-SIR (aluminium hydroxide/silicone rubber) combinations. Since the structure of SiO2 particles enacts a major aspect [16]. Incorporating different fillers like ATH (aluminium trihydrate), SiO2, Al2O3 (aluminium oxide), Si3N4 (silicon nitride), CaCO3 (calcium carbonate), CaSiO3 (wollastonite) enhanced the mechanical properties of the SR, higher cross-linking takes place owing to the chemical reaction between reinforcing particles and SR matrix, uniform distribution of the particles in the base material, effect of particle sizes of the micro & nanofillers, interaction between the molecules of filler and base polymer escalates [17-25]. Inclusion of large concentrations of optical fibre scrap as a filler in LSR/hardener composite evinced recommended results. Furthermore, this compound can be used to manufacture mobile phone body & pouch applications discussed by Sammaiah [26-28]. Compared to pure silicone rubber, a certain loading level of MgO (magnesium oxide), ZnO nanofillers into the SR matrix exhibited good mechanical properties [29]. Enhancement in mechanical properties observed by including graphene particles into SR matrix [30].

The following Table 1. Represents tensile strength, elongation at break %, shore A hardness values of silicone rubber composites with different filler loadings.

Table 1. Tensile strength, Shore A hardness, Elongation at break values of SR blended with variety of fillers

No	*Silicone Rubber with variant fillers & filler concentration*	*Tensile Strength (Mpa)*	*Elongation at Break %*	*Shore A Hardness*
1	PMVQ/2phr CeO2/0.8phr Graphene	7.38	213	:
2	SR/5wt%ZnO	4.86	137.21	78
3	SR/5wt%SiO2	:	136.32	76
4	SR/40phr fumed silica	8.2	320	73(60phr)
5	SR/50phr precipitated silica	7.3	350	68(60phr)
6	LSR/35wt% TiO2	0.85	190	:
7	SR/2wt%BN	4.28	:	:
8	SR/1.0vol% BN	2.7	400	:
9	SR/1vol% SN	:_	420	:
10	SR/2vol% ND	4.0	480	:
11	SS-SIR	6.6	380	62
12	IS-SIR	6.5	317	63
13	ATH-SIR	3.4	321	59
14	RTV-SiR/5µm ATH	4.56	:	79
15	RTV-SiR/ATH/SiO_2	:	:	63
16	RTV-SiR/SiO_2	:	:	55
17	SR/Si_3N_4/nano-Al_2O_3	4.1	379.7	:
18	LSR/10wt% Al_2O_3	:	421.33	:
19	80% LSR /15% optical fibre scrap /5% hardener	3.2128	:	56
20	SR/10wt%MgO	3.5	:	:
21	SR/0.7wt% functionalized graphene	2.46	171.89	:

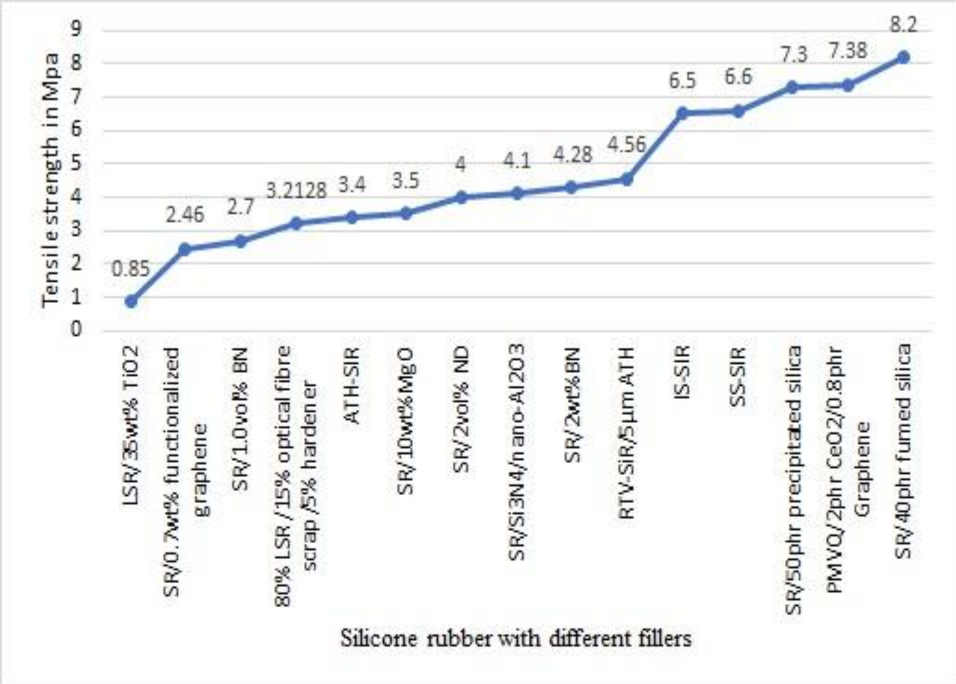

Figure 3. Tensile Strength values of different SR composites

The tensile strength values for silicone rubber with 2vol% of ND, nano Al2O3, 2wt% of BN, 5µm ATH are representing almost same values shown in the Fig.3. Also, from fig.3. SS-SIR, IS-SIR are showing the very closer values of tensile strength means that the shape of the SiO2 particles is not influencing the tensile strength.

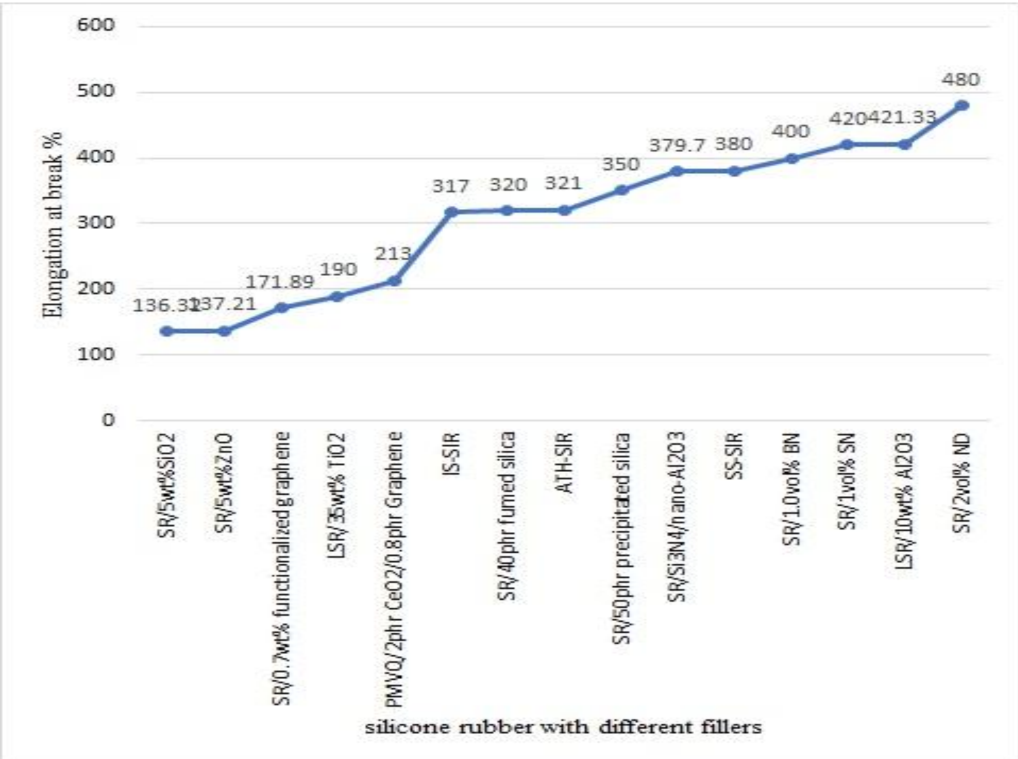

Figure 4. Elongation at Break % of different SR composites

Fig.4. represents elongation at break % of silicone rubber composites with different filler loadings. SR reinforced with 10wt% of Al2O3 is showing higher value of elongation at break % as 421.33% than the hybrid composite material that is SR & Al2O3 reinforced with Si3N4 as 379.7%. Comparing SS-SIR & IS-SIR there is a significance difference in the values as 380% & 317%, therefore the shape of the SiO2 particles influencing the elongation at break %.

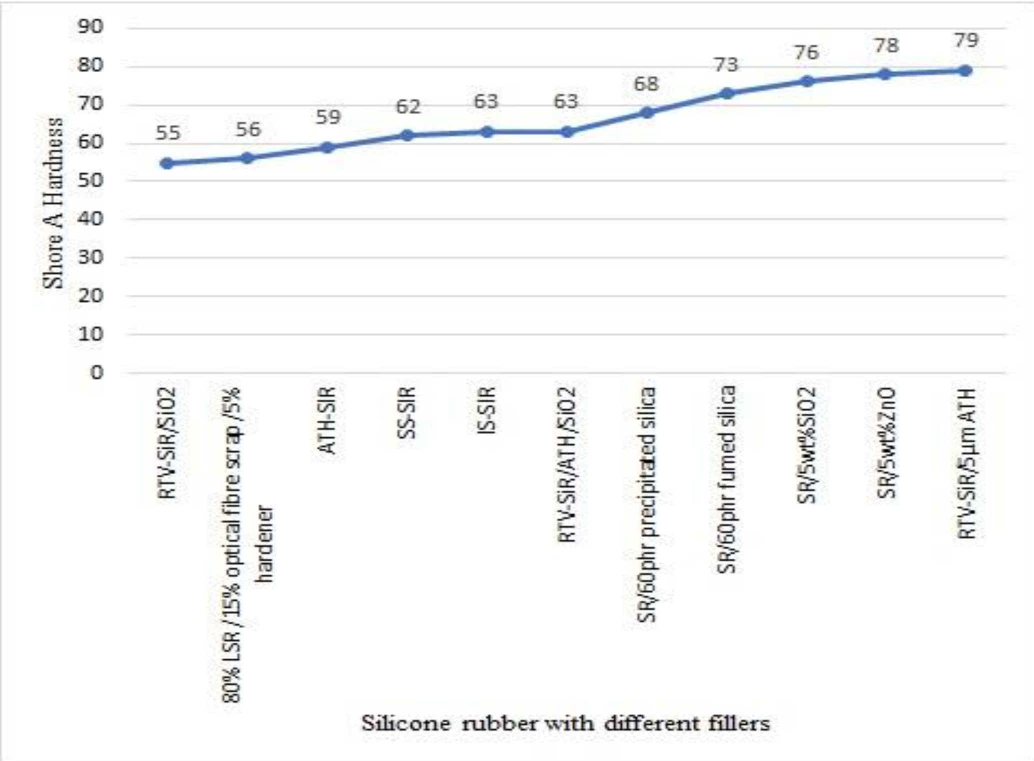

Figure 5. Shore a hardness values of different SR composites

Shore A hardness of RTV-SiR reinforced with SiO2 is showing lesser value as 55, when this combination is mixed ATH its hardness value is raised to 63 potted in the fig.5.

1.2 Thermal Properties

Thermal characteristics of MVQ/FKM (fluorine rubber) composites are enhanced contrasted with FKM, due to the molecular links of the MVQ largely built from Si-O binders & FKM made from C-C bonds. Comparatively Si-O binding energy is stronger compared to C-C bond energy [31]. Thermal conductivity with respect to SiR/Boron Nitride composites optimised though there are increments in the level of nano Boron Nitride loading because arising out of the thermal distribution it is observed such that Boron Nitride molecules encounters consequential interdictory impact on thermal accumulation [32]. Vulcanized SR & BN nanoplates combination showed upmost thermal conductivity concerning the composite while sustaining an insulation property in reference to the SR. At lower % filler loading of BN in SR presented least thermal conductivity and presented lower surface temperature [14]. BN & ND particles performed just like catalysts as to encourage thermal deterioration by means of expanding the heat energy on to the periphery of SR matrix, it showed strong influence on the thermal conductivity of SR matrix as BN & ND loading increased. SN nano particles in SR matrix provided better thermal stability [15]. SR/ABN150(Aligned Boron Nitride) exhibited much higher through-plane thermal conductivity which was approximately 6.3 times greater than that of non-oriented SR/BN150 composites & 33 times higher than the pure SR [33]. At a definite temperature SiO_2 filler performed better than ATH fillers in SR matrix, and displayed lower thermal conductivity [16]. Increasing nano-Al_2O3 content in phenyl silicone rubber lessens the thermal conductivity [18]. Thermal conductivity of SR/ZnOw/m-ZnOs hybrid composite at excessive filler loading in SR ensured almost 6.5 times that of pristine SR [34]. Incorporating graphene, within SR creates a network structure, moreover reported excellent thermal properties [30]. Adding SR as a toughener into PA66/PC matrix established the net-like structure, and that improves thermal properties [35]. ACNT's (Amino-functionalized carbon nano tubes) and AGO (Amino-functionalized graphene oxide) add on silicone

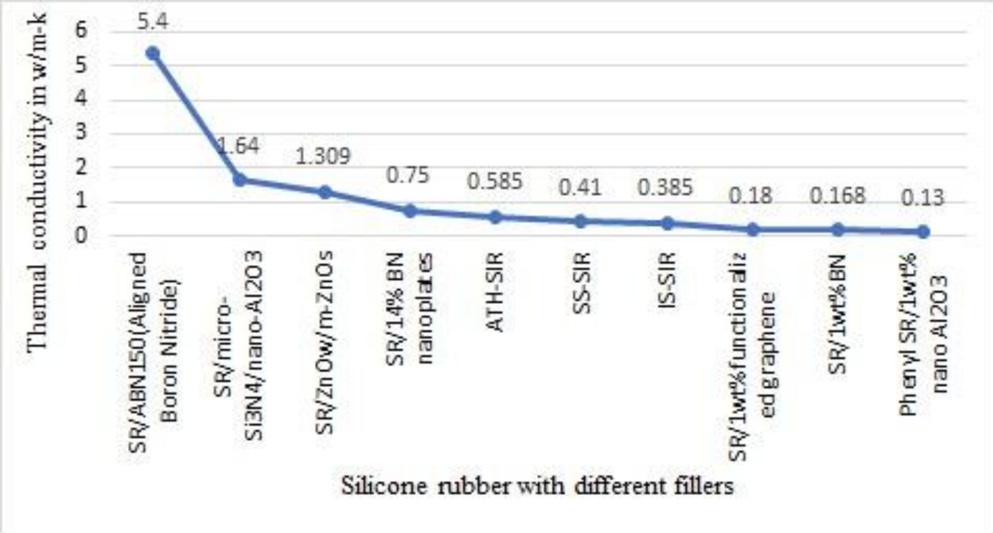

Figure 6. Thermal conductivities of different SR composites

rubber matrix possess remarkable effects upon thermal conductivity pertaining to blends [36].

Thermal conductivity values of silicone rubber composites with different fillers and filler loadings represented in the Table.2.

Table 2. Thermal conductivity values about SR blended with variety of fillers

No	***Silicone rubber with variant fillers & filler loadings***	***Thermal conductivity W/m-k***
1	SR/micro-Si_3N_4/nano-Al_2O_3	1.64
2	SR/1wt%BN	0.168
3	SR/14% BN nanoplates	0.75
4	SR/ABN150(Aligned Boron Nitride)	5.4
5	IS-SIR	0.385
6	SS-SIR	0.410
7	ATH-SIR	0.585
8	SR/ZnOw/m-ZnOs	1.309
9	SR/1wt%functionalized graphene	0.18
10	Phenyl SR/1wt% nano Al_2O_3	0.13

Thermal conductivity for the insulating material should be low, the thermal conductivity values for silicone rubber composites for different filler loading in the descending order plotted in the fig.6. SR reinforced with 1wt% of Al2O3, BN, functionalized graphene is showing approximately same values.

1.3 Electrical Properties

The dielectric permittivity refers to at lower frequencies with higher concentration of TiO_2 into SR matrix attained higher values [37]. Inclusion of certain filler loading of BN nanoplates into SR enhances the breakdown strength, dielectric constant & dropped the dielectric loss of the composites [14]. LSR matrix blended with Al_2O_3 (aluminium oxide) particles predominantly increased breakdown strength by 5KV in contrast to pure LSR [25]. Tracking & erosion resistance of SR has significantly improved by the insertion of larger content of nano particle such as MgO, ZnO, BN, as well as the electrical insulation property enhanced for aligned boron nitride composites, because the heat is carried out quickly on the samples and the temperature growth in the discharge area is restricted [29,32,33]. Higher concentration of nano Al_2O_3 /SR blends exhibited lower permittivity in comparison with virgin SR due to clusters of nano fillers in the matrix and restriction of the movement of the polymer chain [19]. HTV SiR/hybrid SiO_2 combination build strong polymer- filler relationship. Therefore, it exhibited excellent electrical insulation properties [24]. Titania was offering more resistance against tracking and erosion than alumina, in fact that, observed the slight variation between dielectric constant values of titania compared to alumina before and after conducting erosion & inclined plane tracking experiment [38]. The particle sizes of micro AIN (aluminium nitride)/nano SiO_2 employed with silicone rubber not showed utmost variation in the permittivity values [39]. At a specific ratio of micro, nano filler concentration, SR/micro-Si_3N_4 (silicon nitride)/nano-Al_2O_3 hybrid blend can be used in the electrical & electronics applications [20]. Dielectric constant, breakdown strength of nano ZnO filled SR matrix blends displayed maximum values than SR alone, recommended lower filler content effectively influencing the electrical insulation property [40].

Table.3. represents the dielectric constant and breakdown strength values for SR composites with different fillers and filler loadings.

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Table 3. Dielectric constant & Breakdown strength of SR blended with variety of fillers

No	*SR with different fillers & filler concentrations*	*Dielectric constant*	*Breakdown strength (KV/mm)*
1	SR/5wt%TiO_2	3.4	:
2	SR/12wt%BN	4.1	26
3	LSR/10wt%Al_2O_3	:	20
4	ATH-SIR	3.65	:
5	IS-SIR	3.35	:
6	SS-SIR	3.2	:
7	SIR/Alumina	6.05	:
8	SIR/Titania	5.45	:
9	SR/nano ZnO	3.05 (4%)	27.07 (3%)
10	SiR/hybrid SiO_2	:	23
11	HTV SiR/hybrid silica	:	26.6
12	SR/micro-Si_3N_4/nano-Al_2O_3	5.3	85

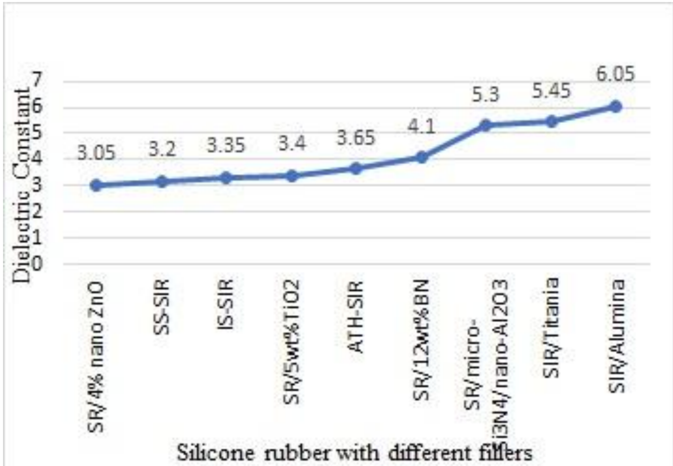

Figure 7. Dielectric constants for different SR composites

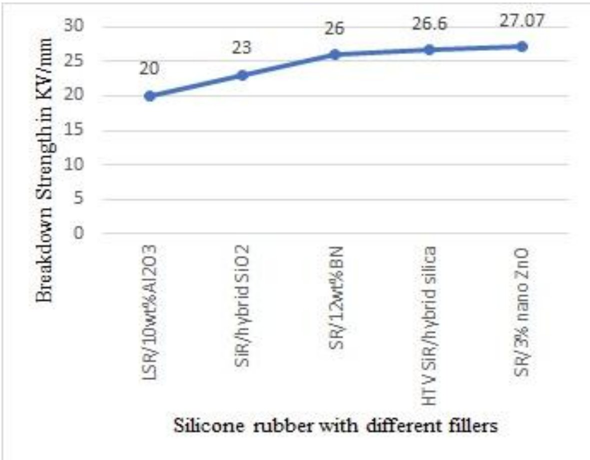

Figure 8. Breakdown strength for different SR composites

From fig.7. it is clear that there is no effect of shape of the SiO2 particles on electrical properties that means SS-SIR & IS-SIR are showing almost same values of dielectric constant. SR reinforced with nano ZnO is showing lower value of dielectric constant but higher value of breakdown strength & SR reinforced with Al2O3 is showing higher value of dielectric constant but lower value of breakdown strength observed from fig.7 & fig.8.

1.4 Chemical Properties

The hybrid composite samples contain LSR/optical fibre scrap/hardener which exhibited good chemical properties before & after 56hrs immersion in the salt solution [NaCl (sodium chloride)] and the acid solution [HCl (hydrogen chloride) & H_2SO_4 (sulfuric acid)]. However, PH value with respect to solution has not changed. No weight change takes place in the samples as per observation [41]. Reinforcement of Al_2O_3 filler in LSR matrix composites tested for its chemical properties, performed salt and acid tests revealed that there is absence of change in the weight about specimens prior to & later than submersion in the NaCl, HCl & H_2SO_4 solutions. Thus, LSR composites are best suitable to be used in the coastal areas and pollutant environmental conditions [25].

GAP ANALYSIS (OR) PROPOSED WORK

This paper throws light on properties of insulating materials used in electrical applications. Different combinations of elements have been discussed above. The combinations of Silicone Rubber with Al_2O_3, MgO, SiO_2 showed better results. For this reason, in my research the combinations of single, double, triple loadings of Al_2O_3 mixing with varying concentrations of MgO & SiO_2 would be taken as fillers into Silicone Rubber furthermore compare the obtained results with pure Silicone Rubber.

CONCLUSION AND FUTURE SCOPE

The following conclusions are extracted from the research work of Liquid Silicone Rubber in addition to various filler materials:

1. LSR is achieved with maximum tensile strength of 8.2MPa in addition to 40phr fumed silica and lower tensile strength of 0.85MPa for the addition of filler material with 35wt% TiO_2.
2. The shore hardness of RTV-SR is 79 with the addition of 5µm ATH filler material and lower hardness is 55 for the addition of SiO_2.
3. The Silicone Rubber shows higher elongation (480%) with the addition of 2vol% ND and lower elongation (136.32%) with the addition of 5wt% SiO_2.
4. The Silicone Rubber showed higher thermal conductivity (5.4W/m-K) with the addition of filler material as ABN150 (Aligned Boron Nitride) and lower thermal conductivity (0.13W/m-K) with the addition of 1wt% nano Al_2O_3.
5. The silicone rubber showed a higher dielectric constant of 6.05 with addition of alumina filler material and a lower dielectric constant of 3.05 due to the addition of 4% nano ZnO.
6. The silicone rubber showed higher breakdown strength of 85 KV/mm due to the addition of micro-Si_3N_4/nano-Al_2O_3(hybrid composite) and a lower breakdown strength of 20 KV/mm due to the addition of 10wt% of Al_2O_3.
7. Liquid Silicone Rubber showed good chemical resistance properties with the addition of optical fibre scrap and hardener. The material is not graded even LSR dipped in chemical solutions (NaCl, HCl and H_2SO_4) for 56 hours. There is no change in PH value of the material.

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COMPLIANCE WITH ETHICAL STANDARDS

The ethical standards are followed in true spirit in writing this paper. The authors have no conflict either with persons or organizations/companies. The authors declare that they have no conflict of interest.

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