International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 04 April 2024
Page No: 952 - 958
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0133

Mechanical, Electrical and Thermal Behavior of Liquid Silicone Rubber Based Composites

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Abstract
Manufacturers' primary emphasis in diversifying sectors is on environmentally friendly materials. It aims to produce electrical and electronic appliances. These material solutions are necessary to improve insulator performance and functioning as they get smaller, lighter, and more dependable. High-voltage devices, transformers, and other electrical components are well-insulated by silicone rubber. Silicone rubber not only retains its electrical qualities when exposed to external conditions such as moisture and temperature variations, but it is also safer and cleaner than its competitors. This paper primarily focuses on comparative analysis of the mechanical, electrical, and thermal characteristics of adding several ceramic nano-fillers, such Al_2O_3, Mullite, and Cordierite, to a liquid silicone rubber (LSR) matrix for suggested electrical insulation applications.
Keywords: *Analysis; Cordierite; Electrical Insulation; Liquid Silicone Rubber; Mechanical.*

1. 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 Figure 1 [2]. 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.

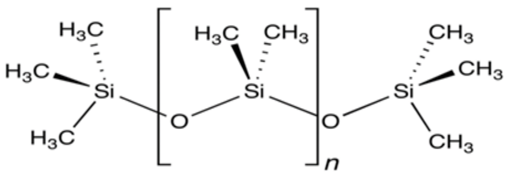

Figure 1 Structure of Silicone Rubber

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

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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]. Aluminium oxide (Al_2O_3) has several qualities, such as good strength, stiffness, outstanding dielectric qualities, improved heat conductivity, and wear resistance [4]. Cordierite ceramic is a magnesium aluminum silicate material with the general formula 2MgO. $2Al_2O_3$. $5SiO_2$. (Al_2O_3, SiO_2, and MgO are the high surface area inorganic fillers corresponding to an oxide composition of 51.3% SiO_2, 34.9% Al_2O_3, and 13.8% MgO) [5,6,7]. Cordierite ceramics are hi-tech ceramic materials having low thermal expansion coefficients, good high-temperature performances, strong dielectric properties, high specific surface areas, and good adsorption capabilities. These benefits have led to cordierite ceramics being used in high-tech industries like bio-ceramics, low-temperature heat radiation, and electronic packaging. It has been widely employed in applications requiring thermal shock resistance [8]. Mullite is an aluminosilicate ceramic with the stoichiometric composition $3Al_2O_3$. $2SiO_2$. It is usually composed of 71 to 76 wt.% Al_2O_3 and 23 to 24 wt.% SiO_2. Superior strength, high thermal stability, low density, and good chemical stability are just a few of the excellent qualities of mullite. The presence of two inorganic elements, alumina (Al_2O_3) and silica (SiO_2), in these mullite materials makes them useful for both traditional and technical applications, including structural, electrical, optical, and high-temperature applications [9]. The following qualities should meet the performance requirements of outdoor insulation materials:

i. High insulation resistance to prevent leakage current.
ii. To avoid electrical breakdown, dielectric strength should be high.
iii. High mechanical strength is required to withstand the handling by mechanical means.
iv. Lowest thermal conductivity should be a requirement for the best insulation materials [10].

2. Methodology

The cast moulding procedure was utilised in this study to manufacture composite samples with varying filler loadings. The matrix, filler, and catalyst were all weighed precisely to three decimal places. The composites were then mechanically stirred at room temperature for 50 minutes at a speed of 2100 rpm. The catalyst was then added to the binder and properly mixed before being put in a vacuum degassing chamber for 5 to 10 minutes, or until all air bubbles were removed. After spraying the mould release agent, pour the composite binder into the mould and let it to dry at room temperature. In this study, three distinct composite sample combinations, including Al_2O_3/ LSR, Cordierite/ LSR and Mullite/ LSR, were created. For each combination, three distinct composition blends were created by adding varied weight percentages of nano filler (5, 10, 15) to LSR. The mechanical, electrical, and thermal properties of all composite samples were investigated and compared to pure LSR. Figure 2 provides a quick description of the methodology.

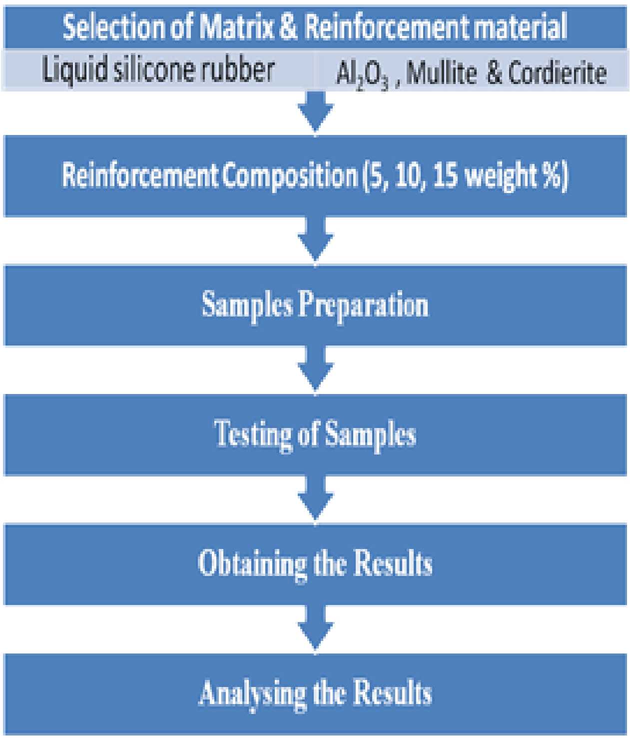

Figure 2 Steps Involved in Methodology

3. Results and Discussion

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3.1. Results

The Figure 3 represents the list of experiments carried out on all the combinations of the samples as well as on the pure LSR samples.

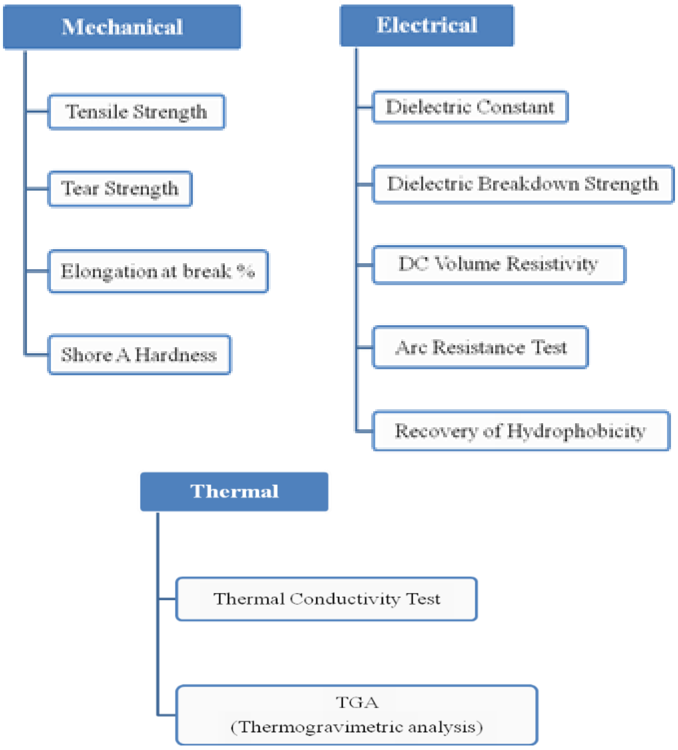

Figure 3 List of Experiments Performed on the Samples

3.1.1. Mechanical Characterization

Tensile Strength: This specifies the amount of force or stress that a material can endure before breaking. The test standards in accordance with ASTM D412 and the tested samples are displayed in Figure 4.

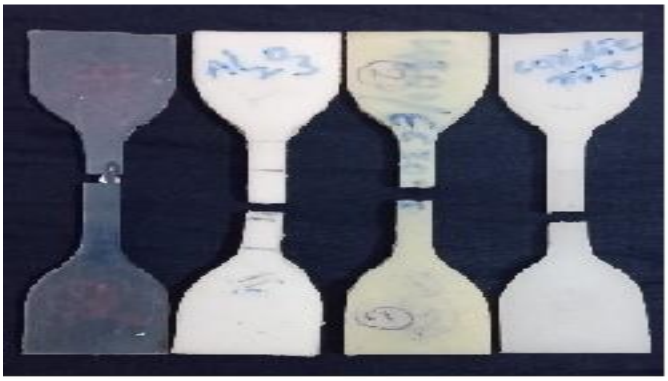

Figure 4 Tensile Strength-Tested Samples

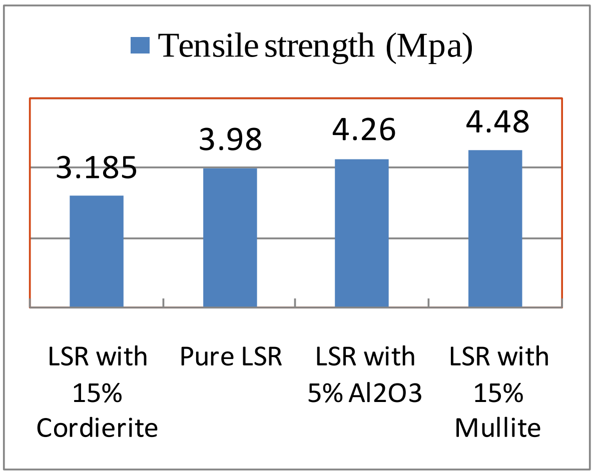

Figure 5 Maximum Tensile Strength Values from Each Combination

Tear Strength: An essential mechanical characteristic of rubber goods is tear strength, which is used to describe the tear resistance. A higher tear strength rating implies that the sample has greater tear resistance. The test standards in accordance with ASTM D624 and the test samples are displayed in Figure 6.

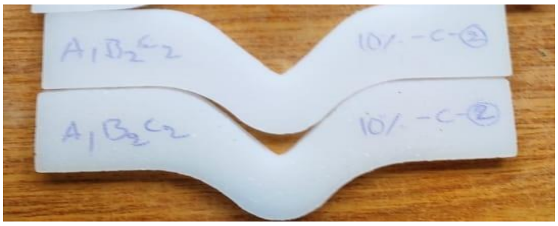

Figure 6 Tear Strength Test Samples

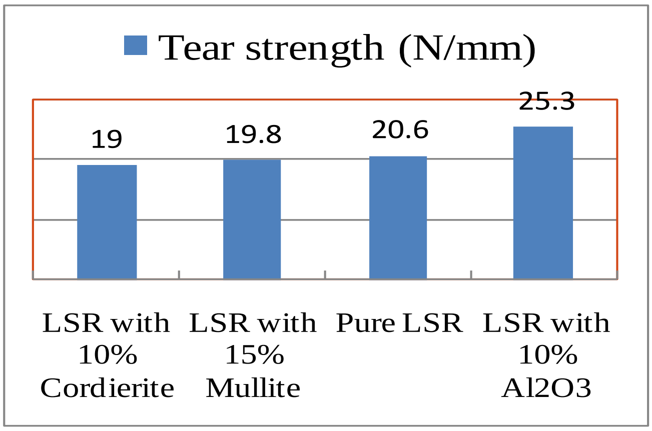

Figure 7 Maximum Tear Strength Values from Each Combination

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Elongation at Break Percentage: Elongation at break (EAB) is a measurement of a material's ductility. This statistic indicates how far a material can be stretched in percentage of its original dimensions before breaking.

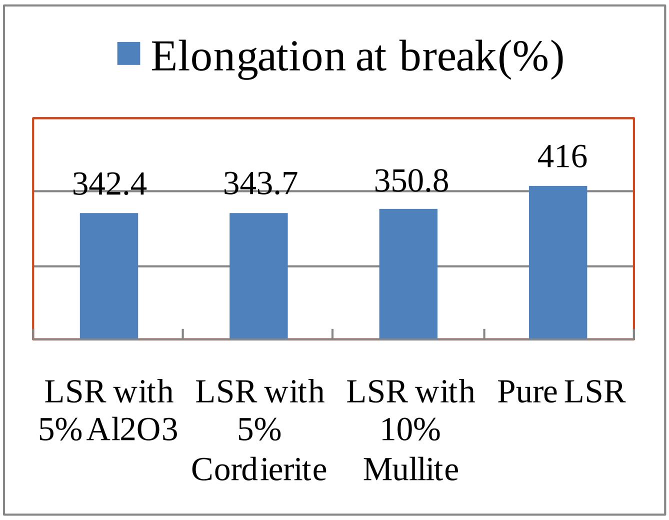

Figure 8 **Maximum % EAB Values from Each Combination**

Shore A Hardness: A material's resistance to indentation is referred to as its hardness. A higher value suggests more resistance. Test criteria based on ASTM D2240.

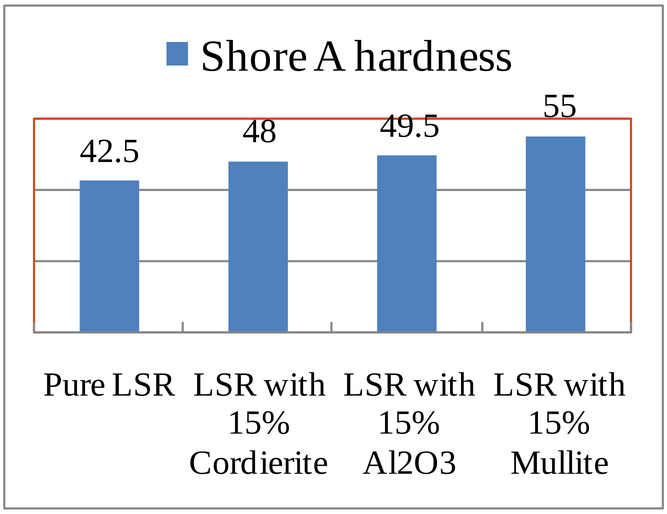

Figure 9 **Maximum Shore A Hardness Values from Each Combination**

3.1.2. Electrical Characterization

Dielectric Constant: A dielectric constant describes the degree to which a material polarizes in the presence of an electric field. The dielectric constant of an insulating substance should be as low as possible. Test guidelines as per ASTM D 150.

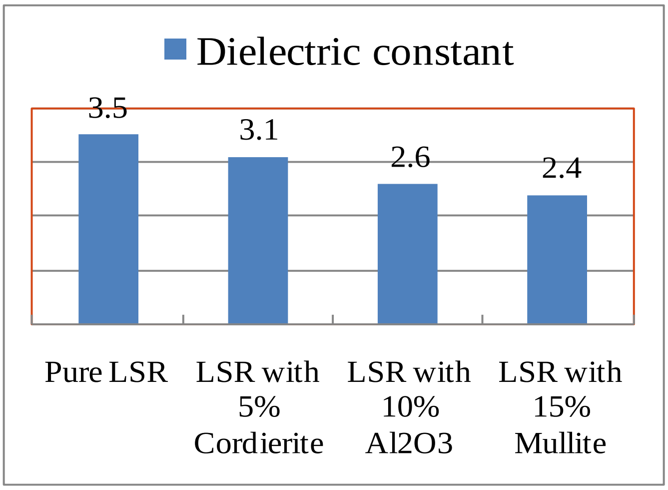

Figure 10 **Minimum Dielectric Constant Values from Each Combination**

Dielectric Breakdown Strength: The dielectric breakdown strength, expressed in kV/mm, is calculated by dividing the breakdown voltage by the sample thickness. Guidelines for testing based on ASTM D 149.

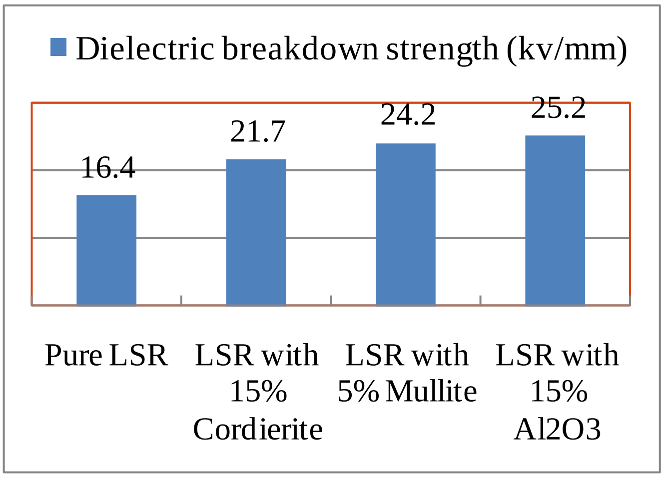

Figure 11 **Maximum Dielectric Breakdown Strength Values from Each Combination**

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DC Volume Resistivity: Volume resistivity is an essential consideration when picking a material for electrical insulation applications since it functions as a barrier to leaking current thru out the body of a dielectric substance. The IEC 60093 test standards are used.

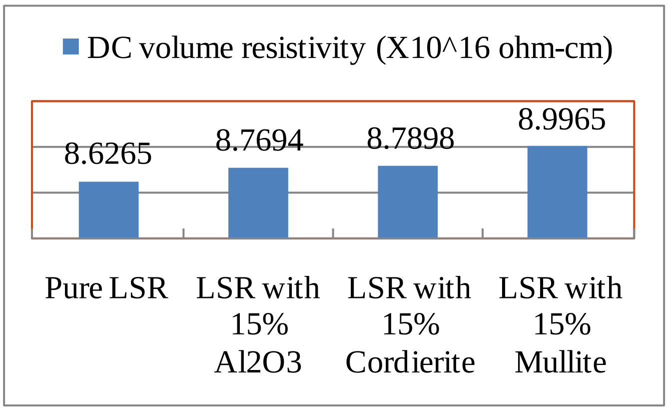

Figure 12 Maximum DC Volume Resistivity Values from Each Combination

Arc Resistance: Arc resistance is described as an insulating material's capacity to endure a low current, high voltage arc while resist the formation of a conducting channel over its surface. It precisely monitors the time an electrical arc can exist on the surface of an insulator before the material breaks down in seconds as per ASTM D 495 test standards.

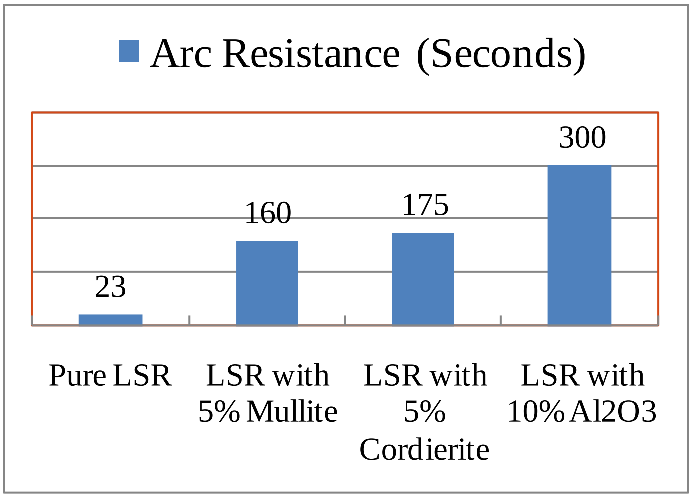

Figure 13 Maximum Arc Resistance Test Values from Each Combination

Recovery of Hydrophobicity: As per IEC 61109 test standards water diffusion test was performed on all samples. Within 28 hours, all of the examined samples were recovered & identified to be of HC_1 grade.

3.1.3. Thermal Characterization

Thermal Conductivity: A substance's capacity to conduct heat is indicated by its thermal conductivity. Low thermal conductivity is ideal for an insulating substance. The ASTM E 1530 test standards are used.

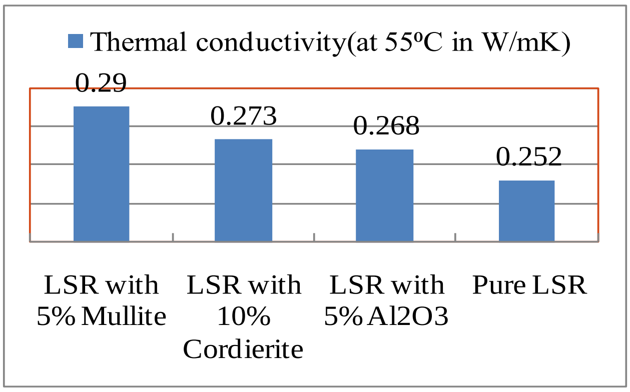

Figure 14 Minimum Thermal Conductivity Values from Each Combination

Thermal Stability: Thermo gravimetric analysis (TGA) is an effective technique for determining the thermal stability of materials. Here, we compare the thermal stability of all combinations of composite samples with pure LSR, taking pure LSR thermal stability as a hundred percent.

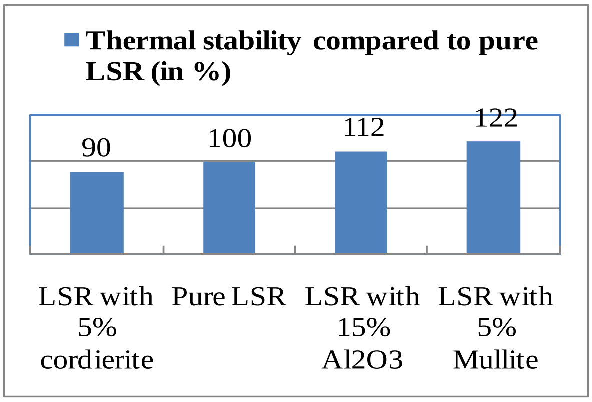

Figure 15 Maximum Thermal Stability Percentage from Each Combination

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3.2. Discussion

Comparing the findings of all the composite samples that were obtained with the results of pure liquid silicone rubber samples is part of the debate. Tensile strength readings are higher for samples having 5% Al_2O_3 and 15% Mullite in LSR than for pure LSR (Figure5). As compared to pure LSR from Figure7 plot, the sample with LSR containing 10% Al_2O_3 had a greater tear strength measurement. The observation in Figure8 indicates that the pure LSR exhibits a larger value of elongation at break % in comparison to all composite sample combinations. Shore A hardness results are higher for samples having 15% Cordierite, 15% Al_2O_3 and 15% Mullite in LSR than for pure LSR (Figure9). As can be seen in Figure10, every composite sample combination shows lower dielectric constant values when compared to the pure LSR. When compared to the pure LSR, all composite sample combinations exhibit greater dielectric breakdown strength values, as illustrated in Figure 11. All combinations of composite samples have higher DC volume resistivity values than the pure LSR, as Figure 12 shows. As Figure 13 illustrates, all combinations of composite samples have arc resistance results that are superior to the pure LSR. All examined composite and pure LSR samples showed identical hydrophobicity properties. Figure14 exhibits that compared to all composite sample combinations, the pure LSR sample has superior heat conductivity. For samples with 15% Al_2O_3 and 5% Mullite in LSR, thermal stability percentages are greater than for pure LSR, as shown in Figure 15.

Conclusions

The following improvements in LSR's mechanical, electrical, and thermal behaviour were achieved by the inclusion of nano fillers. Tensile strength of the LSR improved by 13% with the addition of 15wt% of Mullite nano particles. Mechanical handling requires high mechanical strength.Tear strength of the LSR improved by 23% with the addition of 10wt% of Al_2O_3 nano particles. Greater tear resistance of the sample is indicated by a higher tear strength value. Addition of nano fillers decreases the %elongation at break of LSR by 15%. This shows that all composite samples are less ductile than pure LSR. Shore A hardness of the LSR improved by 30% with the addition of 15wt% of Mullite nano particles. Dielectric constant of the LSR improved by 32% with the addition of 15wt% of Mullite nano particles. Dielectric breakdown strength of the LSR improved by 54% with the addition of 15wt% of Al_2O_3 nano particles. DC volume resistivity of the LSR improved by 5% with the addition of 15wt% of Mullite nano particles. Arc resistance of the LSR improved by 1025% with the addition of 10wt% of Al_2O_3 nano particles. Addition of nano fillers increases the thermal conductivity of LSR by 6%. It indicates that the heat transmission rate through an insulating material is minimal. Thermal stability of the LSR improved by 22% with the addition of 5wt% of Mullite nano particles. In conclusion, our findings indicate that adding nano fillers considerably improves the LSR's performance in insulation applications.

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