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Original Research Article

The Electrical and Mechanical Properties of EPDM-SiR Composites Loaded with Micro Silica

Amir Alber[1*], Loai Nasrat[2], Hanafy Ismail[1], Medhat Hassan[3]
[1]Department of Electrical Power and Machines, Faculty of Engineering, Ain Shams University, Cairo, Egypt
[2]Department of Electrical Power, Faculty of Engineering, Aswan University, Aswan, Egypt
[3]Department of Polymer Chemistry, Atomic Energy Authority, Cairo, Egypt

***Corresponding Author:** Amir Alber
Department of Electrical Power and Machines, Faculty of Engineering, Ain Shams University, Cairo, Egypt

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Abstract: As a replacement for porcelain and glass, two fundamental polymer compositions—silicone rubber (SiR) and ethylene propylene diene monomer (EPDM)—as well as a combination of these two compositions—have been used for outdoor electrical insulation applications. There is widespread agreement that improving a composite's insulating properties by adding micron-sized particles is possible. To enhance these composites when used for outdoor electrical insulation, various fillers such as alumina trihydrate and silica are used. In this study, the effect of micro filler Silica with various contents on the electrical and mechanical properties of blending of SiR and EPDM with different weight ratios was studied. Test samples were prepared using two roll mill. To analyze the electrical characteristics, AC breakdown tests were conducted following IEC 60243-1 Standard. Tensile strength and elongation at break were carried out according to ASTM D-412 for assessing the mechanical properties. This experiment demonstrates an increase in dielectric breakdown strength of all EPDM/SiR composites filled with Silica micron particles till 30 Phr filling content behind this value the breakdown strength was decreased. Regarding mechanical parameters, the micro silica composite exhibited enhanced Tensile Strength to till only 10 Phr, contrarily, doping micro silica deteriorates the Elongation at break for all microcomposite samples.

Keywords: Dielectric Strength, Silicone Rubber, EPDM, Tensile Strength, Elongation at Break, microfiller, Silica.

INTRODUCTION

To ensure the safe operation of electrical equipment in high voltage (HV) power networks, the insulation should have superior dielectric breakdown strength and suitable mechanical properties [1, 2]. Polymers have been extensively employed as outdoor electrical insulating materials in the area of electrical engineering since the 1930s owing to their superior electrical properties, simplicity of installation and transportation, ease of manufacturing, and low weight [3-7].

Silicone rubber (SiR), ethylene propylene diene monomer (EPDM), and a blend of these two polymers have been often utilized in the production of insulators as well as in power delivery cables. Extensive research is being done on high-voltage outdoor insulation utilizing a silicone and EPDM polymeric blend [8-13].

The characteristics of polymeric insulating materials may be tailored to fit specific applications by adding filler particles. Although fillers may help to keep material costs down, their primary function is to enhance a material's electrical and physical qualities [14-16]. Because of their improved mechanical and electrical properties and thermal stability, SiO2 has been concentrated to rectify polymer composite properties [17].

This work focuses on studying the effect of doping micro-Silica filler on the electrical and mechanical properties of different combinations of EPDM-SiR composites.

MATERIALS

Silicone Rubber, Ethylene Propylene Diene Monomer, and Dicumyl Peroxide 4-methoxy phenol (99% Active) as curing agents were purchased from the local market. The density of SiR and EPDM is 1.6 g/cm3 and 0.8 g/cm3 respectively. SiR is provided in sheets while EPDM is in blocks. DCP is obtained in pellets form. The micro-Silica was obtained from Loba Chemie Company (laboratory & fine chemicals) India. The average size of micro silica is 100-300 Micron.

Micro Composites Preparation

The blending of SiR and EPDM was performed by a two-roll mill. EPDM is rolled through the roller for 5 minutes. Then, EPDM was mixed for 25 minutes with SiR. Dicumyl Peroxide (98% active type) was added as a crosslinking agent between the two polymers with an amount of 4 Phr. Micro silica with (10, 20, 30, and 40) Phr was doped directly to the blend, and mixing was continued till it gets properly dispersed (10-15 minutes). Figure 1 depicts the blending preparation for the final sheet. Table 1 shows the mixing formulation.

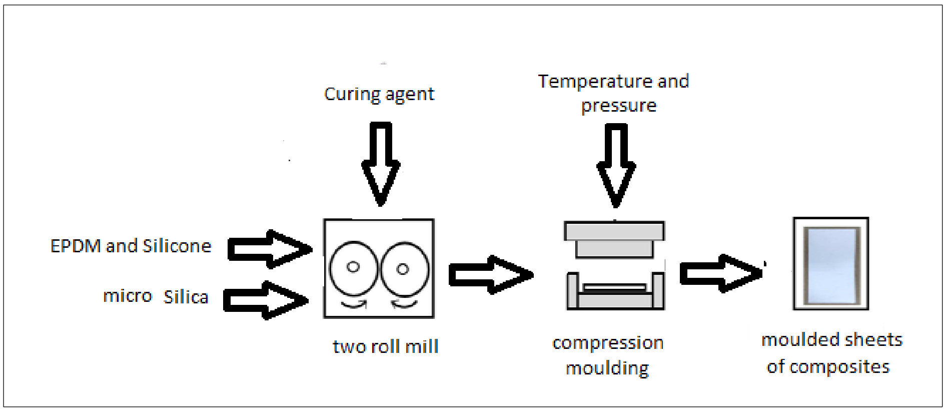

Figure 1: illustration of composite preparation for the final sheet

Table 1: Composition of Micro silica filled EPDM / SiR Composites

Blend notation	EPDM (wt. %)	SiR (wt. %)	Micro SiO2 (phr)
B	25	75	0
B_{10}	25	75	10
B_{20}	25	75	20
B_{30}	25	75	30
B_{40}	25	75	40
C	50	50	0
C_{10}	50	50	10
C_{20}	50	50	20
C_{30}	50	50	30
C_{40}	50	50	40
D	75	25	0
D_{10}	75	25	10
D_{20}	75	25	20
D_{30}	75	25	30
D_{40}	75	25	40

Dielectric Strength Test

Electrical breakdown strength, also known as dielectric strength, is an important topic of study in both academic and industrial settings. The dielectric strength of insulation material is defined as the maximum voltage that an insulation material can sustain. In other words, it assesses the ability of insulation material to withstand decomposition under voltage stress. When a voltage is applied, the insulation breaks, resulting in a discharge through the insulation. The dielectric strength is generally expressed in kV/mm. the sample is a disc with a 5 cm diameter and 1 mm thickness. Ten samples for each composite were tested to reduce errors. The breakdown strength is calculated by equation (1):

$E = U/d$ (1)

Where:
E: Breakdown Strength
U: the breakdown voltage
D: sample thickness

Weibull plots are used to display the dielectric strength data from this study. The value P is the Weibull cumulative distribution function, which is obtained from Eq. 2:

$$P(x) = 1 - \exp\left[-\left(\frac{E}{\alpha}\right)^{\beta}\right] \quad (2)$$

Where the scale parameter of α signifies the voltage at which 63% of all samples have broken down, and the Weibull module indicating the distribution width is denoted by the shape parameter β which indicates the statistical distribution of the results. E is the measuring value of the breakdown strength.

For a small sample size of samples (N<20), a superior approximation recommended by the IEC 62539 standard for the calculation of the i-th cumulative probability (Pi) corresponding to the i-th failure event is provided in equation (3):

$$Pi = \frac{i - 0.44}{n + 0.25}$$

Where n is the number of samples and i the rank of the measured data (i=1 to n) and n=10 (the number of tested samples).

Mechanical Test

For a polymeric insulator to function reliably, mechanical properties are just as crucial as electrical ones. Mechanical properties basically define the strength and stiffness of the material. Tensile strength and percentage elongation at break are the most commonly performed mechanical tests. Tensile strength and percentage elongation at break of the micro composites are tested at room temperature as per ASTM D-412. The tensile strength and elongation at break are measured using a dumb-bell shape with a length of 5cm and a thickness of 1mm in a Universal test machine (HD-B604-S) at room temperature. Three dumb-bell-shaped samples for each composition were used and the average of them was calculated.

Results and Discussion

Breakdown Strength

Figures from 2 to 4 are given the Weibull plots of the cumulative probability of breakdown against the AC breakdown field strength of EPDM/SiR composite samples (B, C, D) loaded with (10, 20, 30, and 40) Phr of micro silica with 95% confidence intervals. Two Weibull parameters obtained from Weibull distribution plots are summarized in Table 2.

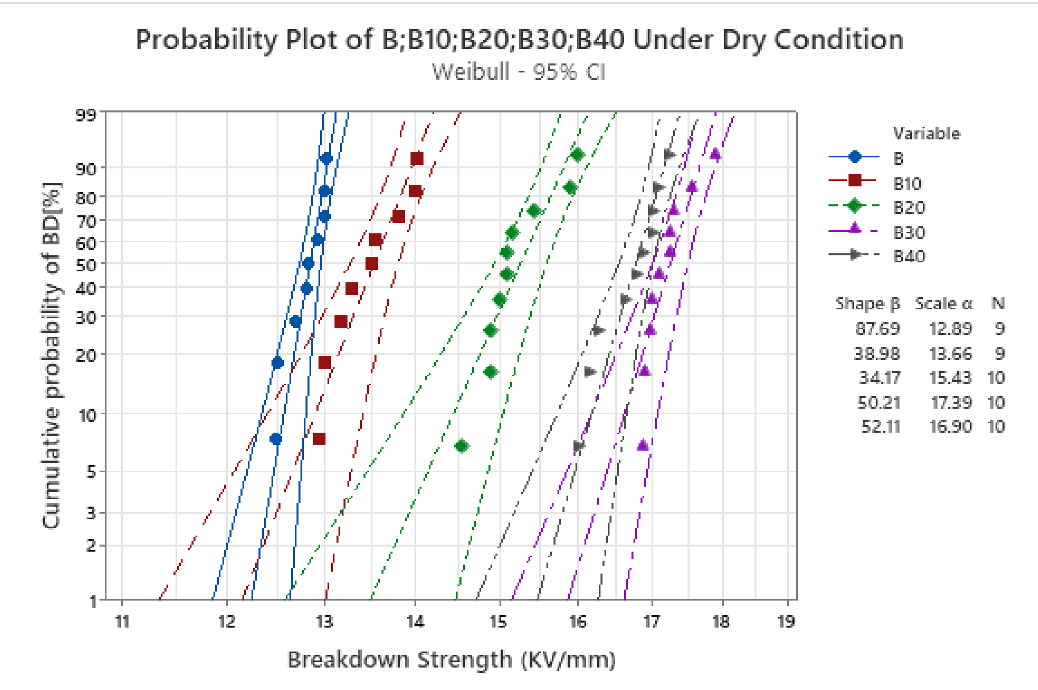

Figure 2: Weibull plot dielectric strength of sample B loaded with Micro Silica

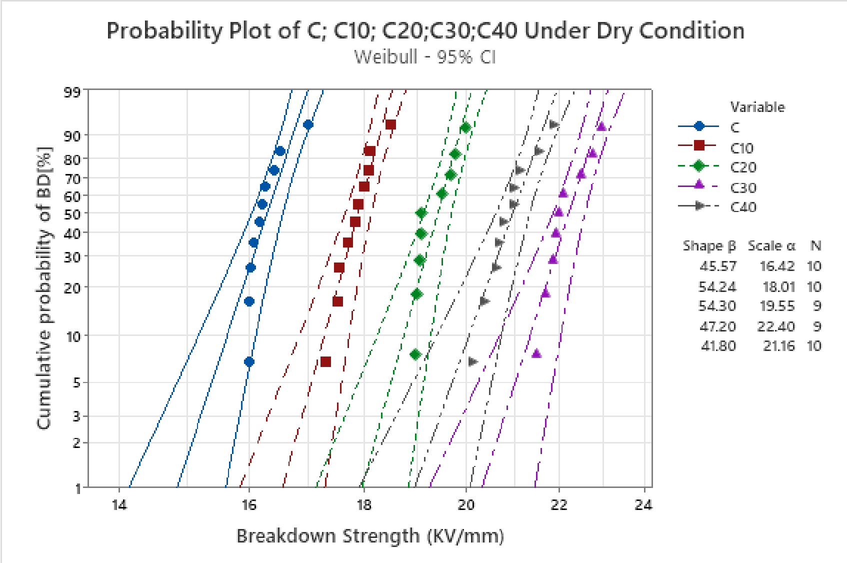

Figure 3: Weibull plot dielectric strength of sample C loaded with Micro Silica

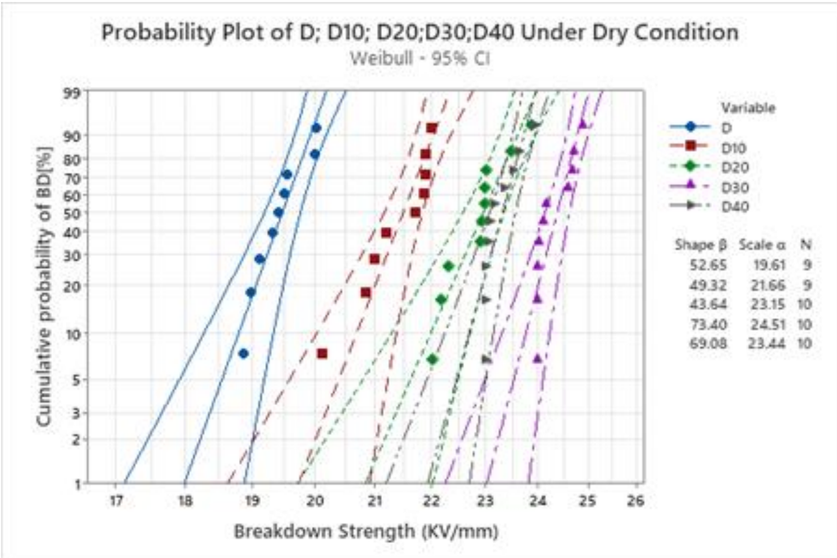

Figure 4: Weibull plot dielectric strength of sample D loaded with Micro Silica

Table 2: The 2 Weibull Parameters of SiR/EPDM microcomposite samples

Code	Weibull Parameters	
	Scale (α) KV/mm	Shape (β)
B	12.89	87.69
B_{10}	13.66	38.98
B_{20}	15.43	34.17
B_{30}	17.39	50.21
B_{40}	16.91	52.36
C	16.42	45.57
C_{10}	18.01	54.24
C_{20}	19.55	54.30
C_{30}	22.40	47.20
C_{40}	21.16	41.80
D	19.61	52.65
D_{10}	21.66	49.32
D_{20}	23.15	43.64
D_{30}	24.51	73.40
D_{40}	23.44	69.08

From figures 2 to 4 and table 2, we can conclude that:

1- The breakdown strength of SiR/EPDM unfilled composite samples was found to be improved as the weight percentage of EPDM was increased. The lowest unfilled composite is sample B (25% EPDM) with 12.89 kV/mm and the highest one is sample D (75% EPDM) with 19.61 kV/mm.
2- For all microcomposites samples, the breakdown strength is increased until 30 Phr loading of micro particles, and then it begins to decline.
3- The highest breakdown strength of the micro filled composites is seen in 30 Phr which is 17.39 kV/mm for sample B_{30}, 22.40 kV/mm for sample C_{30}, and 24.51 kV/mm for sample D_{30}.
4- An increase in breakdown strength is for sample B loaded with (10, 20, and 30) Phr micro silica is 0.77, 2.54, and 4.5 kV, for sample C is 1.59, 3.13, and 5.98, for sample D is 2.05, 3.54, and 4.9 KV compared to unfilled sample respectively.
5- Adding 40 Phr micro silica to SiR/EPDM composite samples (B, C, and D) will increase the breakdown strength of all samples compared to unfilled samples. However, the dielectric strength declined compared to 30 Phr filler loading.
6- The reduction of dielectric strength for 40 Phr is 0.48, 1.24, and 1.07 kV for samples B_{40}, C_{40}, and D_{40} compared to 30 Phr loading respectively.
7- The induced shallow traps, which prevent the buildup of space charge, are thought to be responsible for the minor improvement in dielectric strength that has been achieved with the inclusion of a micro filler. However, the introduction of defects caused by the high ratio of micro fillers is the process causing the breakdown strength for the micro-scale filler to decline beyond 30 Phr [18].

Mechanical Properties

Tensile Strength

The relation between the tensile strength of SiR/EPDM samples loaded with Micro Silica SiO2 is shown in Table 3 and Figure 5.

Table 3: Tensile strength (MPa) of SiR/EPDM composite samples loaded with Micro Silica

Acronym	Tensile Strength (MPa)			Average Value
	1st test	2nd test	3rd test	
B	3.21	3.03	4.38	3.54
B_{10}	4.23	3.97	3.86	4.02
B_{20}	2.97	2.78	2.69	2.81
B_{30}	2.43	2.36	2.54	2.44
B_{40}	2.05	1.98	2.13	2.05
C	2.22	2.10	3.03	2.45
C_{10}	2.67	2.98	3.12	2.92
C_{20}	1.52	1.64	1.96	1.71
C_{30}	1.36	1.21	1.29	1.29
C_{40}	0.97	1.03	0.92	0.97
D	1.05	1.37	1.32	1.25
D_{10}	1.74	1.26	1.55	1.52
D_{20}	1.47	1.33	1.29	1.36
D_{30}	1.11	1.15	1.32	1.19
D_{40}	0.97	0.6	0.83	0.8

From Figure 5 and Table 3, it can be investigated that :

1- The tensile strength was improved by increasing the weight percentage of SiR to the unfilled composites.
2- Adding micro silica SiO_2 filler with 10 Phr has a maximum value of tensile strength for all SiR/EPDM composite samples (4.02 MPa for sample B_{10}, 2.92 MPa for sample C_{10}, and 1.52 MPa for sample D_{10}).
3- The addition of micro silica SiO_2 with more than 10 Phr deteriorates the tensile strength for sample B and sample C compared to pure samples.
4- Sample (D_{20}) will slightly enhance the tensile strength compared to the pure sample (D), but it is lower than the sample with 10 Phr (D_{10}).
5- Optimum micro filler SiO2 percentage to improve the tensile strength is 10 Phr for all SiR/EPDM composite samples.

Elongation at break

Table 4 and Fig.6 clear the values of elongation at break of SiR/EPDM composite samples loaded with different concentrations of micro silica SiO_2.

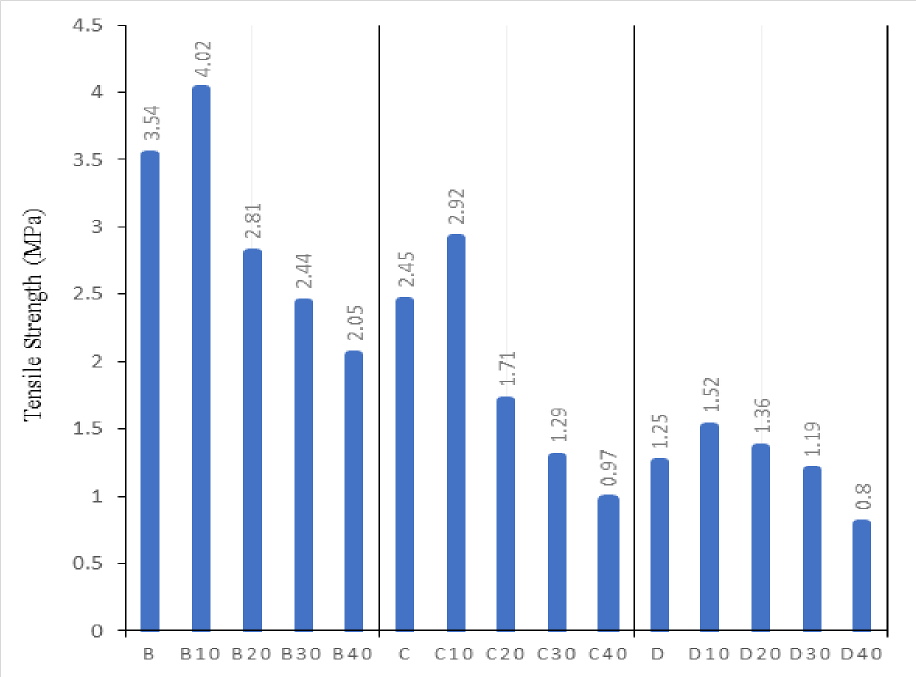

Figure 5: Tensile strength (MPa) for SiR/EPDM composite samples loaded with Micro Silica

Table 4: Elongation at break for SiR/EPDM composite samples loaded with Micro Silica

Acronym	**Elongation at Break (%)**			**Average Value**
	1st test	2nd test	3rd test	
B	690.49	820.35	644.14	718.33
B_{10}	436.49	404.05	308.61	383.05
B_{20}	378.27	376.92	388.3	381.16
B_{30}	393.44	355.29	340.89	363.2
B_{40}	261.89	222.27	196.08	226.78
C	498.67	533.45	512.37	514.83
C_{10}	562.27	452.87	454.58	489.91
C_{20}	541.243	284.97	262.24	362.82
C_{30}	253.12	329.99	304.86	294
C_{40}	259.31	250.66	254.28	254.75
D	288	397.47	276.56	320.71
D_{10}	247.92	233.85	281.73	254.50
D_{20}	257.3	259.25	190.74	235.76
D_{30}	235.7	209.45	244.06	229.74
D_{40}	190.77	147.47	122.63	153.62

From Figure 6 and Table 4, it can be clearly noticed that the elongation at break was enhanced by increasing the percentage of SiR to the unfilled composite samples. Adding micro silica has a deterioration effect on elongation for all composite samples compared to the pure sample. For sample B, elongation at break decrease with (46.67%, 46.94%, 49.58%, 68.43%) for sample (B_{10}, B_{20}, B_{30}, B_{40}), respectively. For sample C, elongation at break decrease with (4.84%, 29.5%, 42.89%, 50.52%) for sample (C_{10}, C_{20}, C_{30}, C_{40}), respectively. For sample D, elongation at break decrease with (20.65%, 26.49%, 28.37%, 52.1%) for sample (D_{10}, D_{20}, D_{30}, D_{40}), respectively. A reduction in elongation at break may be caused by the adhesion of the micro filler to the rubber polymer matrix, which stiffens the polymer chain and thus increases resistance to stretch when the strain is applied [19].

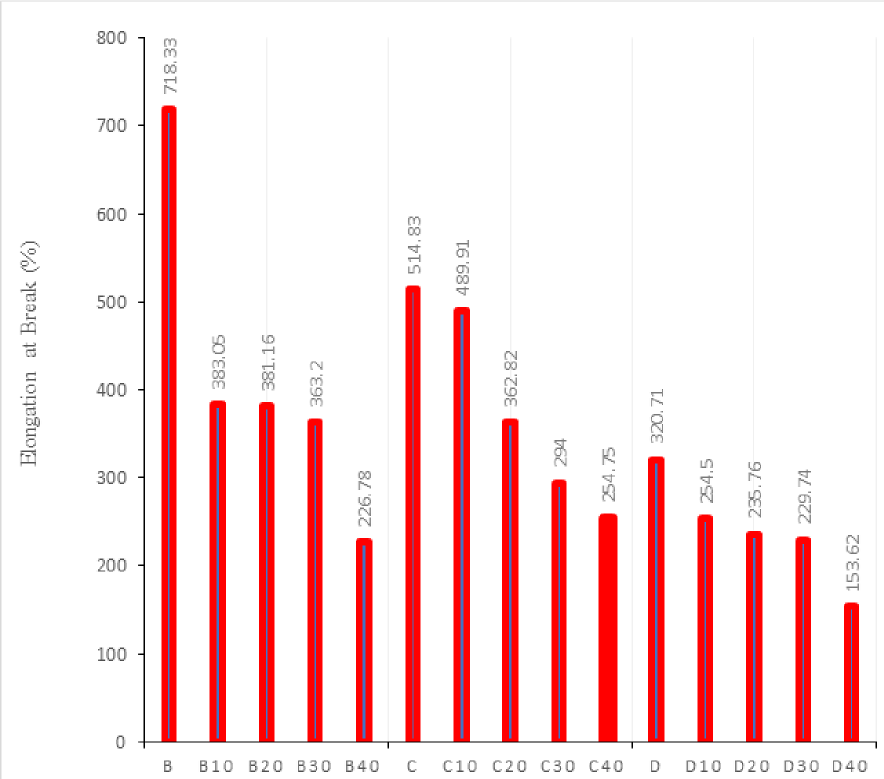

Figure 6: Elongation at break samples SiR/EPDM composite samples loaded with Micro Silica

CONCLUSION

In this work, the electrical and mechanical characteristics of SiR/ EPDM composites with varying micro silica concentrations were examined. This research leads to the following findings: The breakdown strength of SiR/EPDM composite samples without filler was found to be improved as the percentage of EPDM was increased. On the other side, the mechanical properties were improved by adding SiR to the composites. SO, mixtures having equal quantities of SiR and EPDM microcomposites with 10 phr micro silica presented excellent electrical and mechanical properties. However, an addition of more than 50% EPDM and 10 Phr micro silica have an enhancement of the electrical properties but it sacrifices the mechanical properties.

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