Research on EPDM Matrix Nonlinear Insulation Composites

Changming Li[1*], Qinglang Chen[1], Chunpeng Yin[1], Baozhong Han[1,3]

([1] Key Laboratory of Engineering Dielectric and its Application, Ministry of Education, Harbin University of Science and Technology, Harbin, 150080; [2] Chengde Power Supply Company, State Grid Jibei Electric Power Company Limited，Chengde, 067000; [3] Shanghai Qifan Wire and Cable Co., Ltd., Shanghai, 200008）

Corresponding Author: Changming Li

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Abstract. In order to develop non-linear material used for the reinforced insulation in HVDC cable accessory, non-linear EPDM composites were fabricated by adding conductive nano fillers to improve the conductivity characteristic of EPDM. The conductivity and the DC breakdown strength of composites were tested under 25 ^{o}C and 70 ^{o}C, respectively. The influences of types, portions and compounds of nano inorganic fillers on the conductivity were researched and the results indicated that after adding proper portion of nano SiO_2, the mechanical properties of EPDM were improved. Adding nano SiC, carbon black and graphite could make the nonlinear electrical conductivity better. Adding nano SiC, carbon black and graphite all could make a great influence on the breakdown strength of composite material.

1. Introduction

HVDC cable has many advantages such as low loss, large transmission capacity, unrestricted transmission distance, high operational stability coupled with the ability to connect asynchronous power grids etc. Its application plays a more and more important role in real life [1-3].With HVDC technology developing day by day, XLPE insulated HVDC cable not only maintains the absolute superiority in connecting the mainland power grid across the wide strait, but also expands the application in the interconnection of asynchronous onshore grids, isolated load transmission, increase of metropolitan power capacity, transmission of renewable energy, and other aspects [4-7].

Cable accessories are regarded as an important part of the cable system and the weakest part of the line. According to statistical results, the failure of cable accessories takes up 70% of the total. Compared with plastic insulated AC cable accessories, the production of DC cable accessories is more difficult, which is mainly because its electric field distribution is more complex. Besides, the surface between the cable insulation and the accessories easily enhances the accumulation of space charge, which may lead to serious distortion of the electric field distribution [8-10]. Under DC voltage, the electrical conductivity properties of XLPE insulation commonly used in high-voltage DC cable will drastically change with temperature and electric field, and meanwhile, the change of electrical conductivity of ordinary silicon rubber or ethylene propylene rubber under the same condition is small, which leads to two orders of magnitude difference between the conductivity of XLPE and rubber [11]. As the DC field in the composite insulation distribute as the resistance, when ordinary rubber is used as reinforced insulation for DC cable accessory, its internal electric field distribution may be seriously uneven, so the accessories insulation is easy to breakdown.

A large number of research shows nonlinear dielectric material can be fabricated by adding micro and nano inorganic fillers such as zinc oxide, barium titanate and silicon carbide to polymer insulation. Since the nonlinear conductivity and dielectric constant of the non-linear insulation material significantly increase with the electric field in a certain range, it has a great ability in homogenizing the electric field distribution. Boettcher B, Daniel W and other experts used silicone rubber with nonlinear conductivity fabricated by adding pressure-sensitive zinc oxide as the material of stress control body, and then the electric field distribution at the end of insulation shielding was obviously improved [12]. Studies reported that ABB company had developed a

HVDC cable joint consisting of a nonlinear material layer, and it could keep the similar electrical conductivity and dielectric constant with XLPE and silicone rubber under running temperature rise and temperature gradient, which ensured uniform electric field distribution, inhibited the generation of space charge and greatly improved the long running reliability of HVDC cable line [13]. In this paper, nanocomposites were fabricated by adding nano-SiC, graphite and carbon black to EPDM. The conductivity and DC breakdown strength of the composites were studied to explore and develop nonlinear insulation material suitable for reinforced insulation in HVDC cable accessories.

2. Experimental Method

2.1 Materials

EPDM was obtained from U.S.A. Nano SiO_2 has an average diameter of 12 nm and a specific surface area of about 200 m^2/g. Nano SiC has an average diameter of 40 nm. Carbon black-1 has an average diameter of 47 nm and a specific surface area of about 48 m^2/g. Carbon black-2 has an average diameter of 95 nm and a specific surface area of about 20 m^2 /g.

2.2 Experiment Equipment

Tab.1 Main equipment

Name of Equipment	Number	Place of Production
Open Mixer	XL-157/345	Harbin
Plate Vulcanizing Machine	XLB25-D	Huzhou
Vacuum Drying Oven	DZ-3BC	Tianjin
Material Universal Testing Machine	CMT	Shenzhen
Electro-thermal Blowing Dry Cabinet	101-2AB	Tianjin
Tablet Punching Machine	CP-25	Shanghai
Pico Ammeter	EST122	Beijing
HVDC Power Supply	HB-Z103-2AC	Tianjin

2.3 Sample Preparation

EPDM and nano fillers were mixed evenly according to the designed proportions using an open mixer. A suitable amount of EPDM matrix composites was put in the mould and molded using a plate vulcanizing machine, and then kept for 30 min at 175 ^{o}C and 15 MPa to ensure that the materials were fully vulcanized. After cooling down under the same pressure, aluminum foil electrodes were pasted respectively on both sides of the sample according to the requirements of three electrodes test. The test electrode radius was 25 mm, the inner and outer radius of the protect electrodes were 27 mm and 37 mm, respectively, and the radius of HV electrode is 37 mm.

2.4 Dielectric Property Test

Electrical Conductivity Test: Samples were placed in the shielding box and connected with a power supply and a pico-ammeter through the electrodes. Firstly the temperature of the shielding box was set as 25 ^{o}C, the voltage was applied to the sample from low to high with the maximum voltage up to 10000 V, and the current through the sample were recorded. Then the temperature of the shielding box was set as 70 ^{o}C, and the same procedures as above were repeated orderly.

DC Breakdown Strength Test: Standard cylindrical electrodes were used. The diameter of high voltage is 25 mm, the rising rate of voltage is about 1 kV/s, and the thickness of the sample and the breakdown voltage were recorded. The output voltage of HVDC generator was from 0 kV to 60 kV.

3. Results and Discussion

3.1 The influence of nano SiO_2 content on mechanical properties of EPDM

The tensile strength and elongation of pure EPDM is low, and nano SiO_2 was added to improve the mechanical properties. 2.8 phr DCP, 1 phr stearic acid, 5phr ZnO and different fractions of nano SiO_2 were added into 100 phr EPDM, respectively. Then the mechanical properties of different materials were tested and shown in Fig.1 and Fig.2.

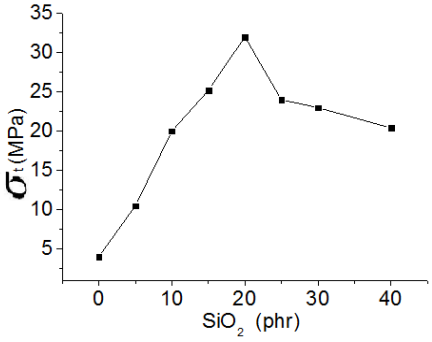


Fig.1 The relationship between SiO2 content and tensile strength of EDPM matrix composites

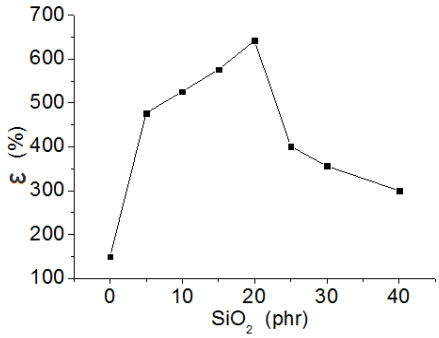


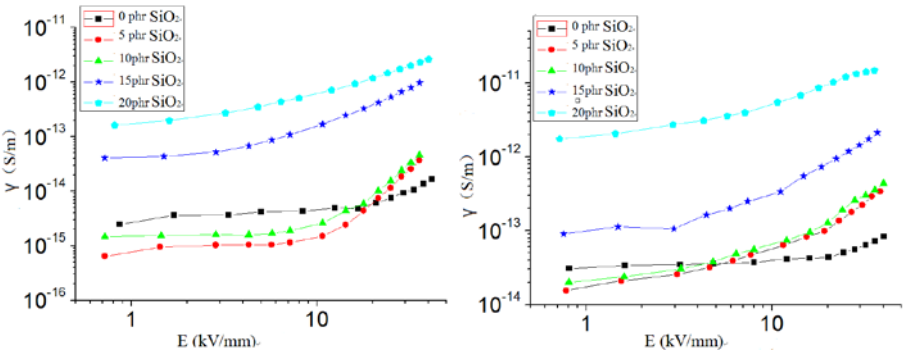
Fig.2 The relationship between SiO2 content and elongation of EDPM matrix composites

As shown in Fig.1 and Fig.2, the tensile strength and elongation of EPDM matrix composites increased with increasing nano SiO_2 content when the nano SiO_2 content was less than 20 phr. And then as the nano SiO_2 content further increased, the tensile strength and elongation of EPDM matrix composites had a tendency to decrease.

3.2 Conductivity properties of EPDM matrix composites

(1) The influence of SiC content on the conductivity of EPDM matrix composites

The conductivity of EPDM matrix composites with different fractions of nano SiO_2 was tested firstly, and the results were shown in Fig.3. As a whole, the conductivity of composites had the same variation trend at 25 ^{o}C and 70 ^{o}C. The conductivity of the composite decreased at first and then increased with the increasing dosage of nano SiO_2. But the conductivity of each material was less affected by the change of the electric field strength. The results also showed that as the testing temperature increased, the conductivity of EPDM matrix composites obviously increased.

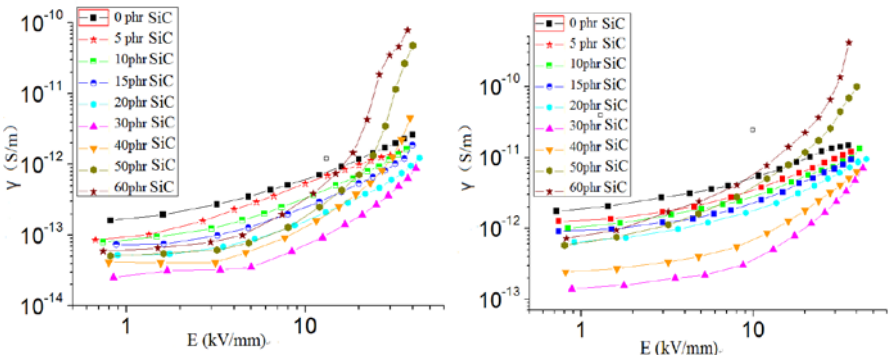


a) 25 oC b) 70 oC

Fig.3 The conductivity properties of EPDM matrix composites

The early results indicated that nano SiC can improve the nonlinear conductivity properties of polymer insulation. Therefore, different fractions of nano-SiC were added in the EPDM matrix composites with better mechanical properties added with 20 phr nano SiO_2. The conductivities of different materials were shown in Fig.4.

From Fig.4, the conductivity of EPDM matrix composites increased with the rising of electric field strength and temperature. When the temperature rose from 25 ^{o}C to 70 ^{o}C, the conductivities of each composite increased about one order of magnitude under the electric field strength of about 0.8 kV/mm. With the increase of SiC content, the conductivity of EPDM matrix composites decreased firstly and then increased. When the content of nano SiC was from 5 phr to 40 phr, the conductivity of each sample was lower than that of sample without nano SiC under the different electric field strength. When the SiC contents were 50 phr and 60 phr, the conductivity of the samples were also lower than that of the sample without nano SiC under low electric field strength. At 25 ^{o}C, when the electric field strength was higher than 17 kV/mm, the conductivity of the samples increased rapidly nonlinearly. The results above suggested that when the additive amount of nano SiC was large, the nonlinear conductivity properties of EPDM matrix composites can be improved.

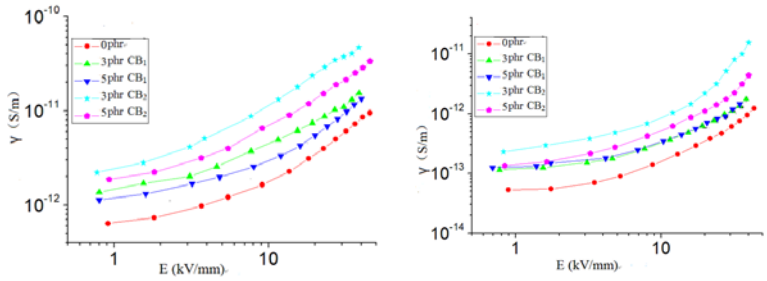


a) 25 oC b) 70 oC

Fig.4 The conductivity properties of EPDM matrix composites filled with nano SiC

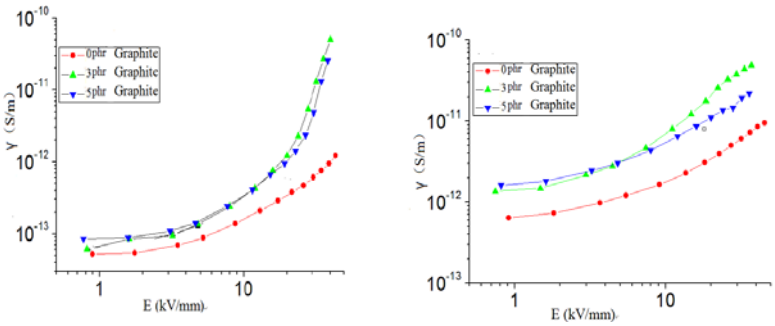
(2) The influence of nano conductive materials on the conductivity of EPDM matrix composites

Since the excessive addition of nano SiC would deteriorate the other properties of the composites, nano conductive materials were used as the filler instead of a portion of nano SiC to improve the conductivity properties. Two kinds of the carbon black and one kind of graphite were chosen as nano fillers. 40 phr nano SiC and 5 phr or 3 phr nano conductive fillers were added in EPDM. The conductivity properties of each material were shown in Fig.5 and Fig.6.



a) 25 oC b) 70 oC

Fig.5 Conductivity properties of EPDM matrix composites filled with nano carbon black



a) 25 oC b) 70 oC

Fig.6 Conductivity properties of EPDM matrix composites filled with nano graphite

The above experiment results showed that when using the same kind of carbon black, the conductivity of EPDM matrix composites increased with the increase of carbon black content. When the content of carbon black was the same, the nonlinear conductivity properties of EPDM matrix composites filled with nano carbon black 2 were better than that of the material filled with carbon black 1. Nano graphite can improve the conductivity properties of EPDM matrix composites, but the content of nano graphite had a little impact on the conductivity of the composite.

3.3 The influence of nano materials on DC breakdown properties of EPDM matrix composites

1) The influence of nano SiO_2 and SiC on DC breakdown properties of EPDM matrix composites

The DC breakdown strength of samples filled with nano-SiO_2 and nano-SiC above mentioned was tested at 25 ℃ and 70 ℃. Ten specimens of each sample were tested. Since the experimental data of different specimens was dispersive, Weibull distribution statistics was used to calculate the breakdown strength of the material. The experimental results were shown in Fig.7 and Fig.8.

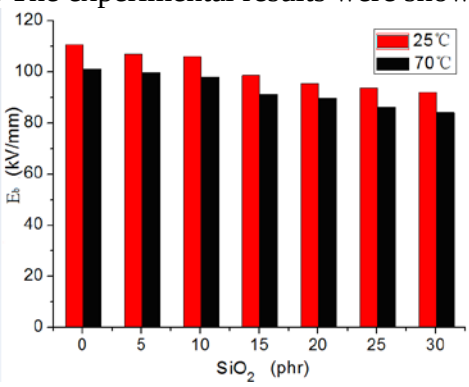


Fig.7 The DC breakdown strength of EPDM matrix composites filled with nano-SiO2

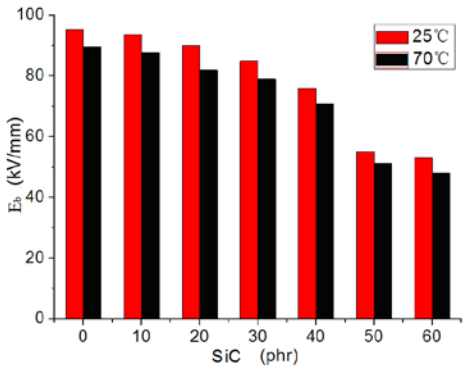
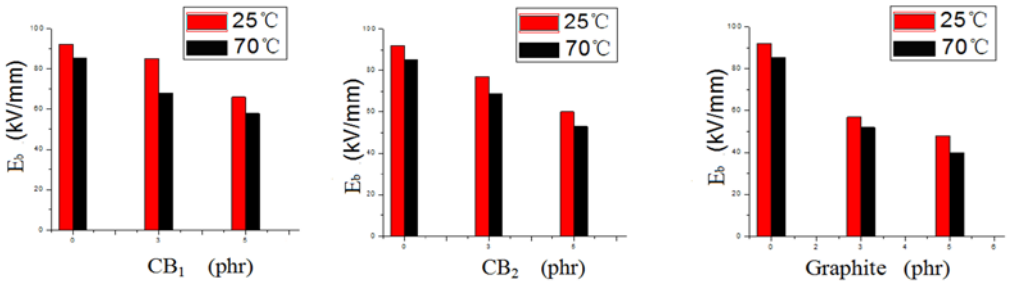


Fig.8 DC breakdown strength of EPDM matrix composites filled with nano SiO2 and nano SiC

From Fig.7, the breakdown strength of EPDM matrix composites at 25 ^{o}C was higher than the results tested at 70 oC. When the content of nano SiO_2 increased from 0 phr to 30 phr, the DC breakdown strength of EPDM matrix composites fell by 16.8% at 25 ^{o}C and 16.7% at 70 ^{o}C. In general, the addition of nano SiO_2 had little impact on the DC breakdown strength of EPDM matrix composites. From Fig.8, when the content of nano SiC was greater than 20 phr, the DC breakdown strength of EPDM matrix composites obviously decreases with the increase of nano SiC content, and the breakdown strength fell more rapidly when nano SiC content exceeded 40 phr.

2) The influence of carbon black and graphite on DC breakdown strength of EPDM matrix composites

The DC breakdown strength of EPDM matrix composites filled with carbon black and graphite were shown in Fig.9.



a) carbon black 1 b) carbon black 2 c) nano graphite

Fig.9 DC breakdown strength of EPDM matrix composites filled with nano conductive materials

As shown in Fig.9, the breakdown strength of each material at 25 ^{o}C was higher than the results tested at 70°C. With the increase of carbon black and graphite content, the DC breakdown strength of EPDM matrix composites decreased. When the content of carbon black and graphite was the same, the composite filled with nano graphite had the lowest DC breakdown strength and the material filled with nano carbon black 2 was secondary.

4. Conclusion

(1) With the increase of nano SiO2 content, the tensile strength and elongation increased firstly and then decreased in tendency, and the conductivity decreased firstly and then increased.

(2) The conductivity of EPDM matrix composites decreased firstly and then increased with the increase of SiC content. When the content was larger than 40 phr, the nonlinear conductivity of EPDM matrix composites grew rapidly under the electric field strength exceeding 17 kV/mm.

(3) With the increase of carbon black content, the conductivity of EPDM matrix composites filled with the same kind of carbon black increased. The improvement of the conductivity properties introduced by carbon black 2 was better than that of carbon black 1.

(4) With the increase of nano SiO_2, SiC, carbon black and graphite content, the breakdown strength of EPDM matrix composites decreased. The impact of nano SiO_2 was minimal, the impact of nano SiC was little larger and the impact of nano conductive materials was the largest.

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