Influence of Nano-ATH on Electrical Performance of LSR for HVDC Insulation

Ju-Na Hwang, Yong-Jun Park, Min-Hae Park, Kee-Joe Lim

Abstract—Many studies have been conducted on DC transmission. Of power apparatus for DC transmission, high voltage direct current (HVDC) cable systems are being evaluated because of the increase in power demand and transmission distance. Therefore, dc insulation characteristics of liquid silicone rubber (LSR), which has various advantages such as short curing time and the ease of maintenance, were investigated to assess its performance as a HVDC insulation material for cable joints. The electrical performance of LSR added to nano-aluminum trihydrate (ATH) were confirmed by measurements of the breakdown strength and electrical conductivity. In addition, field emission scanning electron microscope (FE-SEM) was used as a means of confirmation of nanofiller dispersion state. The LSR nanocomposite was prepared by compounding LSR filled nano-sized ATH filler. The dc insulation properties of LSR added to nano-sized ATH fillers were found to be superior to those of the LSR without a filler.

Keywords—Liquid silicone rubber, Nanocomposite, Nano-ATH, HVDC insulation, Cable joints.

I. INTRODUCTION

THE need for HVDC transmission for increased long distance transmission and to meet the demands for power is expanding. Around the world, many studies have been conducted on DC transmission. To transmit direct current power, the HVDC cable and joint are needed. The cable system is comprised of a cable and accessories, such as joints and terminations. Joints are connections between the cables [1]-[4]. When they are connected, several problems are encountered including the leakage current and heating. One of the major issues with the HVDC cable system is the accumulation of space charge and the consequent distortion of the electric field. These problems reduce the insulation performance, which is the breakdown strength, conductivity etc. [5]-[6]. To solve this problem, many studies have focused on HVDC cables, but the HVDC cable accessories have attracted less attention. Consequently, HVDC cable accessories currently do not meet the standard insulation property for insulation materials.

To enhance electrical performance of insulation materials, filler and additives are blended with the basic resin. The application of nano-scale fillers has been generally researched [15]. The addition of the appropriate nano-filler can reduce the accumulation of space charges and increase the dielectric strength and partial discharge resistance of composites. These fillers present that reaching the desired improvements in materials performance with comparatively low amounts (less than 10%wt) and avoiding the usual disadvantage of micro-filler. Also, the addition of nano-filler can reduce the total cost of the composites as well, because the price per unit polymer is typically higher than that of fillers [16].

This study examined the breakdown strength and volume resistivity of LSR, which has been used as an insulation material of HVAC cable joints to apply to the insulation material of the HVDC cable joint. In addition, field emission scanning electron microscope (FE-SEM) was used as a means of confirmation of nanofiller dispersion state, and the effects of addition of the nano-filler used LSR nanocomposite were considered.

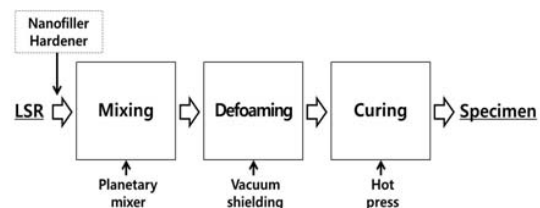## II. SAMPLE PREPARATION

Fig. 1 Fabrication scheme of the specimens

Silicone rubber is used mainly as insulation materials for outdoor insulators as well as cable joints. Among these, LSR is a good insulating material because of its short curing time and ease of maintenance [7]-[9]. LSR (Momentive Performance Materials Inc.) was used to prepare the specimens. The mixing ratio of LSR and hardener was 1:1. The ATH filler (US Research Nanomaterials, Inc.), 10~20nm size, was used to prepare the nanocomposites.

A direct mixing method was used to disperse the nanofillers. The ATH filler added at 1phr in the LSR for nanocomposite. The nano-sized filler improved properties of the pure material by forming a nanocomposite [11]. The planetary centrifugal mixer (ARV-310 from THINKY Co.), a high viscosity dispersion device, was used because of the very high viscosity of LSR [10]. The specimens were fabricated by curing for 5 min at 165°C in a hot press. Fig. 1 shows the preparation process of the LSR nanocomposite. Table I lists the classification for the specimens.

J. Hwang is with Department of Electrical Engineering, Chungbuk National University, Republic of Korea (phone: +82-10-7530-5721; fax: +82-43-263-2419; e-mail: hjn1435@naver.com).

M. Park and K. Lim* are with Department of Electrical Engineering, Chungbuk National University, Republic of Korea (e-mail: falli@naver.com, kjlimg@gmail.com).

TABLE I
CLASSIFICATION OF THE SPECIMENS OF THE LSR NANOCOMPOSITES

	LSR_NF	LSR_A1	LSR_A3
Resin [phr*]	100	100	100
Hardener [phr]	100	100	100
Nano-ATH [phr]	0	1	3

phr* : Part per hundred parts of LSR resin

III. EXPERIMENTAL

A. Unipolar DC Breakdown Strength Test

Fig. 2 (a) shows the experimental setup for the unipolar dc Breakdown Test. The set up consisted of a DC power apply, electrode system, and temperature controller. A sphere-sphere electrode system was used and the diameter of the electrode was 8mm. The electrode was immersed in insulation oil to prevent surface flashover. This study examined the DC breakdown strength of a sheet specimen of the LSR nanocomposite material, approximately 120~150μm in thickness. The measurement temperatures were 30 and 90°C. The applied voltage was increased at a rate of 1kV/sec.

B. DC Conductivity Test

Fig. 2 (b) shows experimental setup for the dc conductivity test. A three-terminal electrode system was used. The volume resistivity of a sheet specimen the LSR nanocomposite material, approximately 80~100μm in thickness, was examined. The applied electric field was 10, 20 and 30kV/mm, and the measurement temperatures were 30 and 90°C. The volume resistivity was evaluated from the leakage current 1 hour after commencing the measurements.

C. FE-SEM Imaging

For the image analysis to evaluate the dispersion state of fillers, pictures of surface of LSR specimens were taken using the FE-SEM. The SEM image was separated into filler and basic resin. Following platinic coating, the FE-SEM imaging was conducted. X-rays used FE-SEM was applied to the acceleration voltage of 3kV, and the FE-SEM image of the specimens has a magnification of 500.
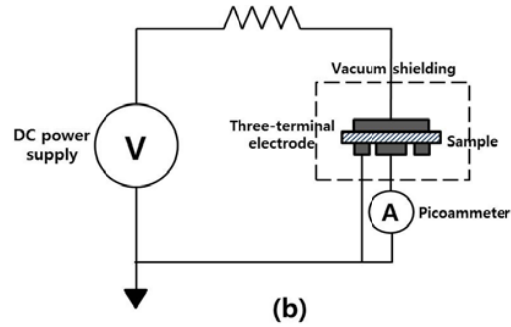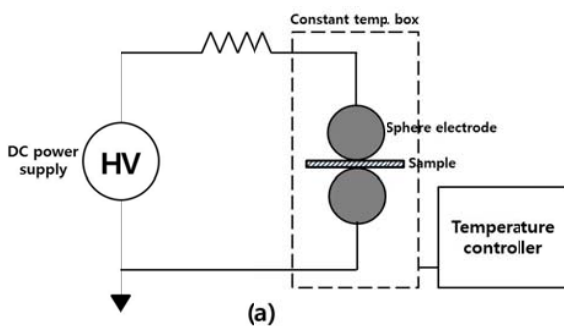

Fig. 2 Experimental setup used for the dc insulation property test: (a) unipolar dc breakdown test, (b) dc conductivity test

IV. RESULTS AND DISCUSSION

A. DC Breakdown Strength

The test of the dc breakdown and dc conductivity under the maximum allowable temperature and operating field of the HVDC cable system was carried out to examine the electrical performance of the LSR nanocomposite.
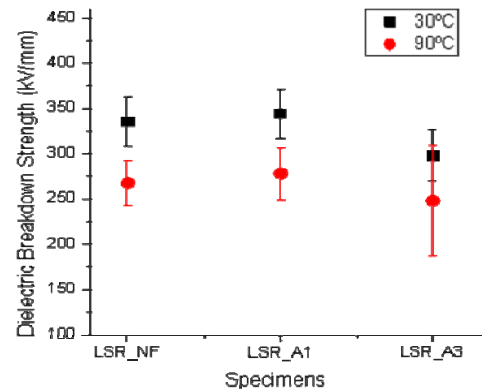

Fig. 3 DC Breakdown Strength of LSR spcimens as a temperature

Fig. 3 shows the value of the dc breakdown strength. The results are listed in Table II. The TDC (temperature dependence coefficient) is the dependence of the evaluated dc breakdown strength on temperature. This index can be observed in the amount of degradation for the breakdown strength for each 1°C increase in temperature at room temperature. The TDC is defined as follows:

$$-\text{TDC } [\%] = \frac{1}{E_{b,(30)}} \cdot \frac{\partial E_b}{\partial T} \times 100 \qquad (1)$$

As shown in Table III, the TDC was calculated using (1). All the specimens were not affected substantially by temperature because of the excellent heat resistance of LSR.

LSR_A1 showed the best electrical dielectric characteristic and the dielectric strength of LSR added to the nanofiller were superior to those of the LSR unfilled nanofiller. However, LSR_A3 showed the lowest dielectric characteristic. It seems that LSR added ATH 3phr act as impurities. The breakdown strength decreased with increasing temperature due to the

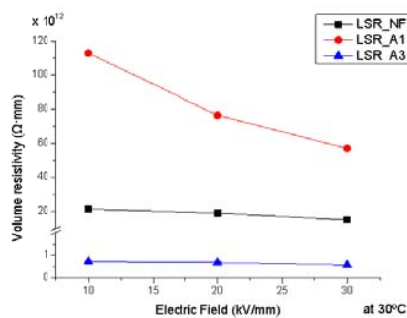thermal breakdown mechanism ($\frac{\partial E_b}{\partial T} < 0$).

TABLE II
DC BREAKDOWN STRENGTH IN LSR NANOCOMPOSITES AT 30,90°C

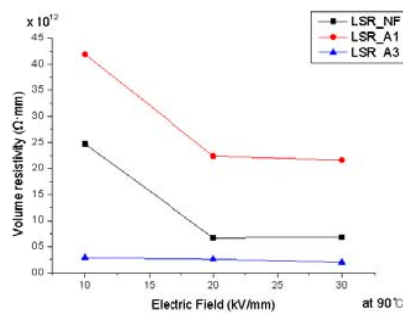| Specimen	BDS(30°C) [kV/mm]	BDS(90°C) [kV/mm]
LSR_NF	335.5	268.3
LSR_A1	343.9	277.7
LSR_A3	297.4	247.4

TABLE III
TEMPERATURE DEPENDENCE COEFFICIENT

Specimen	TDC
LSR_NF	0.33
LSR_A1	0.32
LSR_A3	0.28

B. Volume Resistivity

(a)

(b)

Fig. 4 Volume resistivity of the LSR nanocomposite specimens as a function of the electrical field: (a) at 30°C, (b) at 90°C

Fig. 4 shows the volume resistivity of the specimens as a function of the electrical field strength. The volume resistivity decreased with increasing electrical field strength and temperature. It can be seen from all the figures that the dc resistivity value for LSR filled ATH 1phr is marginally higher than the values obtained in the LSR nanocomposites with different fillers. It introduces free ions into the system which can increase the dc conductivity of the composite.

The basic properties of the nanocomposite were examined to understand the effects of nanofiller addition. The erosion resistance of the silicone rubber (SR) nanocomposite with low wt% silica fillers was improved as compared to the microcomposite [12]-[14]. The epoxy nanocomposite also showed improved dc dielectric performance, such as breakdown strength and volume resistivity [17]. Therefore, the properties of the nanocomposite will be helpful in improving the insulation properties [18]

These results show that the nanofiller acts as a deep trap site in LSR. Therefore, the volume resistivity and breakdown strength were increased due to the nano-sized filler addition. As shown in Fig. 5, the nanofiller trap effect is explicated. The LSR added to nanofiller has a deeper trap site than the LSR unfilled nanofiller [19]. However, a specimen of LSR_A3 is excluded from this trend
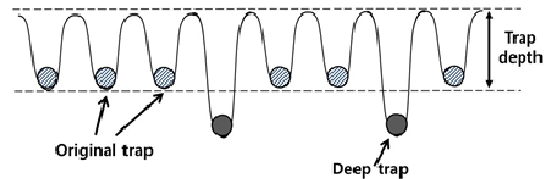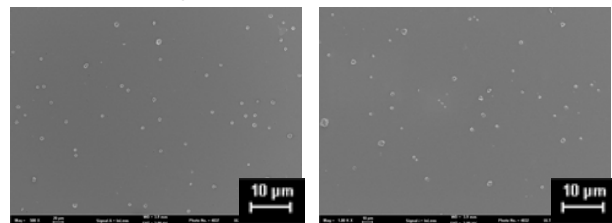

Fig. 5 Model of the nanosize filler trap effect.

C. FE-SEM Image

| (a) LSR_A1 | (b) LSR_A3 |

Fig. 6 SEM images of fillers for nanocomposite

Fig. 6 shows images of each specimen. Fig. 6 (a) indicates the dispersion state of ATH 1phr, Fig. 6 (b) signify that a specimen filled ATH 3Phr is dispersed in the nano scale. Also, the primary particle diameter is approximately 100nm or less. As the result, ATH nano-filler are well dispersed generally.

V. CONCLUSION

ATH/LSR nanocomposites were prepared with nano-ATH. The specimens were tested using dc breakdown strength and dc conductivity for an understanding influence of nano-ATH on electrical dielectric performance of the composites. Dielectric property of nano composite was investigated.

Summaries of the experimental results are as follows:

(1) DC breakdown strength of LSR_A1 specimen has the highst, and increased by 0.3~3.5% more than different specimens. But, LSR_A3 specimen has bad characteristic in the dielectric material.

(2) Nano-ATH/LSR nanocomposite (1phr) has higher volume resistivity than other composites at 30 and 90°C. Therefore, there are optimistic combination and ratios.

(3) It is that LSR added ATH 3phr act as impurities

(4) In the comprehensive this study, he temperature dependence coefficient of ATH_A1 had lower value. So

that properly growing content of nano composite can be used for a stable insulation structure.

(5) The dispersion state of fillers using FE-SEM image was fairly uniform to the specimen filled nano-ATH.

Investigation results are that the opinion that there are effects from the nano filler that make the electrical performance good but the degree of this effect is unpredictable. The nano filler content is not proportional or inversely proportional. Therefore, the study regarding the consecutive study of the thermal, mechanical and chemical properties as well as electrical dielectric should be conducted.

REFERENCES

[1] Y. Maekawa, A. Yamaguchi, C. Ikeda, Y. Sekii and M. Hara, Proceeding of Jicable91, B.9.3, pp.562-569 (1991)
[2] K. Terashima, H. Suzuki, M. Hara and K. Watanabe, IEEE Trans. Pow. Delive., Vol.13, No.1, pp.7-16 (1998)
[3] Y. Maekawa, C. Watanabe, M. Asano, Y. Murata, S. Katakai and M. Shimada, Trans. IEE of Japan, Vol.121-B, No.3, pp.390-398 (2001)
[4] Y. Maekawa, T. Yamanaka, T. Kimura, Y. Murata, S. Katakai and O. Matsunaga, The Hitachi Densen, No.21, pp.65-72 (2002)
[5] L. J. Hiivala, IEEE press, pp. 208-240 (2000)
[6] R. Bodega, G. Perego, P. H. F. Morshuis, U. H. Nilsso and J. J. Smit, IEEE Int'l. Conf. Electr. Insu. Dielectr.(CEIDP), pp.507 (2005)
[7] Ch. C. Reddy and T. S. Ramu, IEEE Trans. Dielectr. Electr. Insul., Vol. 17, pp. 221 -227 (2008)
[8] D. Fabiani, G. C. Montanari and L. A. Dissado, IEEE Int'l. Conf. Properties Appl. Dielectr. Materials (ICPADM), No. D-2, pp.337-340 (2009)
[9] L. Meyer, E.A. Cherney and S.H. Jayaram, IEEE Electr.Insul. Mag., Vol. 20, No. 4, pp. 13-21 (2004)
[10] M. Kozako, M. Higashikoji, T. Tominaga, M. Hikita, G. Ueta, S. Okabe and T. Tanaka, IEEE Trans. Dielectr. Electr. Insul., Vol. 19, No. 5, pp.1760-1764 (2012)
[11] I. B. Jeong, J. S. Kim, J. Y. Lee, J. Y. Shin and J. W. Hong, Trans. Electr. Electro. Materials, Vol. 11, No. 6, pp. 261-265 (2010)
[12] L. Lei, W. Xishan and C. Dengke, IEEE Intern. Conf. Solid Dielectr.(ICSD), pp.804-807 (2004)
[13] B. Venkatesulu and M. Joy Thomas, IEEE Trans. Dielectr. Electr. Insu., Vol. 17, No. 2 (2010)
[14] S. Fang, Z. Jia, H. Gao and Z. Guan, IEEE Int'l. Conf. Electr. Insu. Dielectr.(CEIDP), pp.300-303 (2007)
[15] Han, C. Diao, L. Dong and X. Zhang, IEEE Int'l. Conf. Solid Dielectr.(ICSD), pp.330 (2007)
[16] S. Singha and M. J. Thomas, IEEE Trans. Dielectr. Electr. Insu.,Vol. 15, No. 1 (2008)
[17] T. Tanaka, G.C. Montanari and R. Mulhapt, IEEE Trans. Dielectr. Electr. Insul., Vol. 11, pp. 763-784 (2004)
[18] M.L. Frechette, M.L. Trudeau, H.D. Alamdari and S. Boily, IEEE Trans. Dielectr. Electr. Insul., Vol. 11, pp. 808-818 (2004)
[19] Y. Murata, Y. Sekiguchi, Y. lnoue and M. Kanaoka, Proceedings of 2005 Int'l. Symp. Electr. Insu. Materials, pp.650-653 (2005)T. W. Dakin, "Application of Epoxy Resins in Electrical Apparatus", IEEE Trans. Dielectr. Electr. Insul., Vol.EI-9, No.4, pp.121-128,

Kee-Joe Lim received B.S. M.S. and Ph.D. degrees from HanYang University, Seoul, Republic of Korea, in 1973, 1979 and 1986. He is currently a full professor with dept. of electrical engineering at Chungbuk National University, Korea. His research interests include electrical materials, high voltage techniques, piezoelectric ceramics and so on.

Ju-Na Hwang (B.S'13) She received B.S. degrees from Chungbuk National University, Cheongju, Republic of Korea, in 2013. She is currently pursuing M.S. degree in Electrical Engineering at Chungbuk National University. Her research interests include electrical insulation materials and high voltage techniques.

Min-Hae Park (B.S'11) She was born on October 12, 1988. She received the B.S. degree in 2011 in Electrical Engineering from ChungBuk National University. Currently she is a student in the Master` course of the Department of Electrical Engineering, ChungBuk National University.