Effects of the Filler Type and Quantity on the Flashover Voltage and Hydrophobicity of RTV Silicone Rubber Coatings

Faezeh Farhang[1], Morteza Ehsani[2*], and Seyed Hamid Jazayeri[1]

(1) Faculty of Chemical Engineering, Iran University of Science and Technology
P.O. Box: 16846/13114, Tehran, Iran
(2) Iran Polymer and Petrochemical Institute, P.O. Box: 14965/115, Tehran, Iran

A B S T R A C T

Room temperature vulcanizing (RTV) silicone rubber is widely used to coat glass and porcelain insulators to prevent surface flashover on the insulators that are heavily contaminated with industrial pollution and exposure to humidity in the coastal areas which may lead to outages of the power system. Fillers such as alumina trihydrate (ATH) and silica are also used in these coatings to provide tracking and erosion resistance. Therefore, a formulation of RTV coating system should be developed to optimize its performance and in particular to extend its lifetime. In this work, RTV coatings with different quantities of ATH and silica fillers were applied to porcelain suspension insulator. They were then artificially contaminated and exposed to dry and wet conditions. Moreover, contact angle measurements were performed to determine the state of the surface. To carry out surface characteristic studies of the coatings filled with ATH and silica, the samples were gold coated for SEM observation. In addition, TGA was utilized to investigate the role of ATH in RTV samples. The test results are reported on the basis of the role of ATH and silica fillers. The results showed that when ATH is used as filler the highest performance belongs to the sample with 70 pph ATH. Addition of 10 pph silica also improves the performance of coatings at ATH quantity between 35 to 70 pph, but replacement of 10 pph ATH with the same amount of silica was not productively efficient.

(∗) To whom correspondence to be addressed.
E-mail: M.Ehsani@ippi.ac.ir

INTRODUCTION

Insulator contamination has become a major problem in the operation of electrical power systems [1-3]. Porcelain and glass have been used in outdoor high voltage insulator construction for more than 100 years [4] but they contain high surface energy [5] due to their strong electrostatic bonds among the various atoms in the material [4-7]. Therefore, high humidity leads to formation of water films on the insulator surfaces and in the presence of contaminants leakage currents develop that can result in

flashover [3]. Insulator flashovers result in expensive and undesirable power outages [8]. It is known that in order to minimize contamination related problems and prevent flashover, it is important to reduce leakage current as much as possible [9,8].

The maintenance of outdoor insulator is an art learnt through life-long experience. In this art, many technologies have been employed with varying degrees of successes [10]. One of the recent practices is to use RTV silicone

rubber on high voltage ceramic/glass insulator to impart anti-pollution properties [11,8]. This maintenance practice imparts water repellence to the surface of porcelain insulator [12] thus it limits leakage current and suppresses flashover [13]. Today, there is a great interest to use RTV coatings as an effective counter-measure against insulator contamination problems. This method is attractive because it exempts existing insulators to be changed for new ones [9].

The coating can be applied by dipping, painting, and/or spraying. The liquid polymer layer vulcanizes inside a flexible rubber layer when exposed to moisture in the air [1-3]. Because pure silicone rubber shows little tracking and erosion resistance, fillers are used to reinforce the base elastomer of polymeric materials which can increase the physical properties or impart certain processing characteristics. ATH and silica are the two fillers that are mainly being used by manufacturers [14,15]. These fillers not only improve the tracking and erosion resistance but they also lower the cost of the materials [15].

As it is expected, the electrical, physical, and application properties of RTV coatings vary considerably depending on their formulation. These properties largely are dependent on the amount and type of fillers. Therefore, it is very important to find the best formulation for these coatings. In order to find out, we have studied the influence of surface contamination on flashover performance of RTV coated porcelain insulators and the effect of filler type and its quantity on their performance as well.

The aim of this study is to find out the effect of surface contamination and fillers on flashover performance of RTV coated porcelain insulators. Based on these findings, we have sought the best formulation for the coatings. In this context, the present work looks at the effect of ATH and silica on the performance of a one-part RTV silicone rubber. The electrical performance is measured by flashover voltages. In order to study the effect of different filler types and their quantity on hydrophobicity properties of the specimens, contact angles of distilled water droplets on the surface of the RTV silicone rubber were also measured. To examine surface characteristic and dispensability of silica particles in RTV matrix scanning electron microscope (SEM) technique was used.

Thermogravimetric analysis (TGA) is applied to study the thermal characteristics of filled silicone rubber and clarify the suppression mechanism of ATH on the heat erosion.

EXPERIMENTAL

Materials
The specimens include 3 groups of RTV with different filler types and levels, labeled as Series 1, 2, and 3. The concentration and type of the filler used in each specimen are given in Table 1. Moreover, the unfilled RTV silicone rubber (RTV-SR) sample labeled A0S0. Materials used in this work include one component RTV-SIR 5411 made by Wacker Co., ATH made by Martinswerck Co. and amorphous precipitated silica made by Degussa Co., all from Germany. Figure 1 shows the result of particle size analysis of ATH and silica used in this work.

In order to weigh accurately, a digital weighing balance (FEJ-200 model) with 0.01 g accuracy was used. To mix the entire components, a laboratory mixer was used with the speed of 230 rpm for 90 min.

Preparation of Insulators
RTV coatings were applied to porcelain suspension insulators made by Iran Insulator Co. (255 mm in

Table 1. The quantity and type of filler in each specimen.

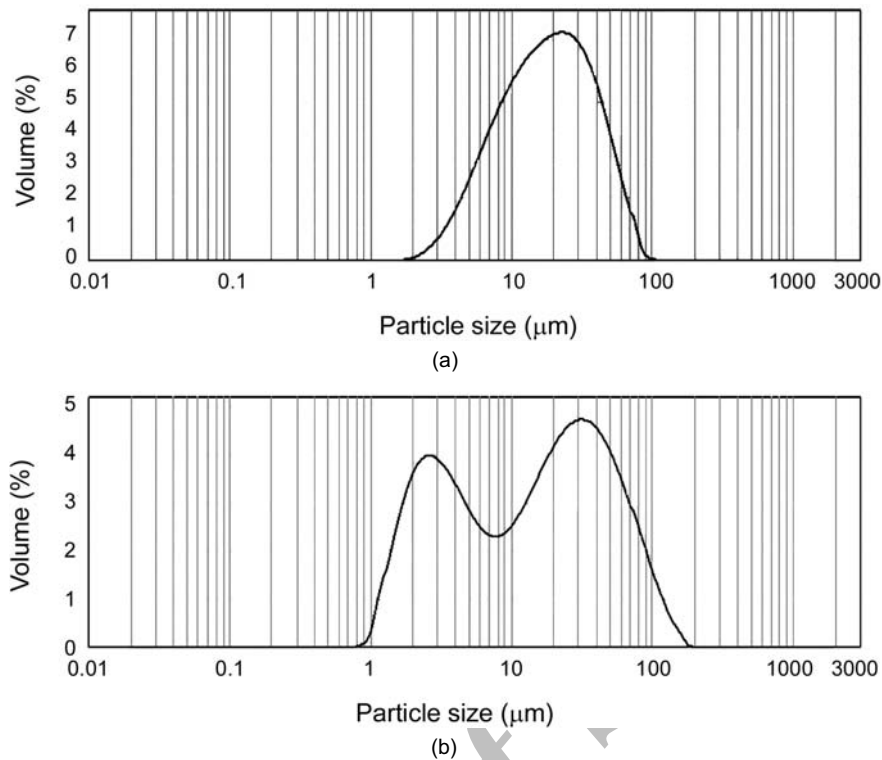| Sample name	ATH (pph)	Silica (pph)
A35S0	35	0
A50S0	50	0
A70S0	70	0
A90S0	90	0
A100S0	100	0
A35S10	35	10
A50S10	50	10
A70S10	70	10
A90S10	90	10
A100S10	100	10
A25S10	25	10
A40S10	40	10
A60S10	60	10
A80S10	80	10
A90S10	90	10

Figure 1. Particle size analysis of: (a) ATH and (b) silica fillers.

diameter and 295 mm creepage distance) by spray method. They were then dried at room temperature for one week. The recommended nominal thickness was between 0.3 and 0.5 mm [3]. Therefore, in this work the coatings were applied within 0.35 to 0.41 mm thicknesses.

Preparation of Contamination Slurry
The contamination slurry was prepared by mixing 50 g of kaolin and 15 g of sodium chloride salt (NaCl)

Figure 2. Applying the contamination slurry on insulator.

in one litre of distilled water, and then 200 mL of this slurry was applied on the coated insulators in two steps, which each included 100 mL of slurry (Figure 2).

Measurements
Flashover Voltage
Flashover voltage measurements were in the range 0-350 kV, made by MSL in Germany. The input signal was in voltage range 0-500 kV on 2 phases and the output signal was in voltage range 0-350 kV on 1 phase.

Dry condition: The coated insulator was suspended at the centre of the test chamber and then it was energized. Voltage increased from 0 kV until flashover occurred and the voltage value was recorded.

Dew condition: Samples from previous test were slightly sprayed with distilled water and the test was repeated similar to the previous section.

Artificial rain: Samples were placed in a room equipped with an artificial rain producer. The conductivity of the saline water was 220 µS/cm and its flow rate was 1.2 mm/min. Samples were exposed to rain for 15 min and then they were energized until

flashover occurred. For the next step the flow of water (rain) was stopped and 5 min later the insulator was energized again and the flashover voltage value was recorded.

It is necessary to say that all tests were repeated three times for each sample and the normal average of flashover voltages was reported as the test result.

Contact Angle
An angle formed between a water droplet in contact with a solid surface is called the "contact angle. The shape of water droplet depends on the material of the sample and the physical and chemical states of its surface. Solids with low surface energy repel water such that the droplets stand separately and form contact angles larger than 90º. This surface is said to be hydrophobic [13]. Hydrophobicity of a surface is closely related to contact angle. Consider an ideal axisymmetric drop of water resting on an ideal flat homogeneous horizontal solid surface. The contact angle is the angle θ which is formed by the air-water interface of the drop and the solid surface at the three-phase line of contact. The most commonly used method for contact angle measurements of surface hydrophobicity is the Sessile drop technique. A droplet of a purified liquid (distilled water) is placed on a surface using a syringe. The resulting angle between the droplet and solid surface is measured, generally using a goniometer. The schematic of this method is shown in Figure 3. A drop shape analysis was used for hydrophobicity studies [16]. In order to measure the contact angle, approximately 30 μL drop sizes were used. The angles were determined at five locations on the specimen within ~2 s. After placing the water drop, the normal average of these measured angles was reported as the contact angle value [13]. The angle θ was estimated using eqn (1) in which h is height and d is diameter of water droplet.

$$\theta = 2\tan^{-1} 2h/d \qquad (1)$$

Thermogravimetric Analysis
The method simply measures the variation of weight vs. temperature as a sample is heated in an oxygen or nitrogen atmosphere [17]. TGA is a very effective technique to study the chemical and physical phenomena as a function of temperature as well [14]. It
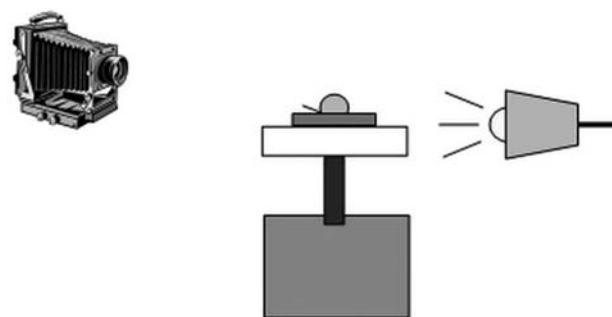

Figure 3. Schematic set-up of the contact angle measurement [16].

provides definitive data for materials and product designing and aging stability information with short test duration times (<60 min) [16]. For TGA measurement, two samples of RTV-SIR (~10 mg) filled with either 0 pph or 35 pph ATH (A0S0 and A35S0, respectively) were set in a platinum pan, separately and were heated from 30°C to 700°C at a fixed rate of 20°C/min in nitrogen atmosphere.

Scanning Electron Microscopy
The morphological features and characteristics of the samples with ATH and silica fillers in the silicone rubber matrix were studied using scanning electron microscopy (SEM) technique. A Philips electron microscope with an accelerating voltage of 20 kV was used. The samples were coated with gold using a vacuum sputter coater.

RESULTS AND DISSCUSSION

Flashover Voltage Study
Figure 4 shows the results of the dry test for all samples. As can be seen, due to the dry test conditions there are not any significant differences among flashover voltages of the samples. This implies that dry contamination on insulator surface does not act as a conductive material and therefore does not cause leakage current.

Figure 5 shows the dependence of the flashover voltage on the silica and ATH filler levels under dew condition. Figure 5 also illustrates that the coating with 70 pph ATH (A50S0) shows the best performance in series 1 and as the ATH level increases above
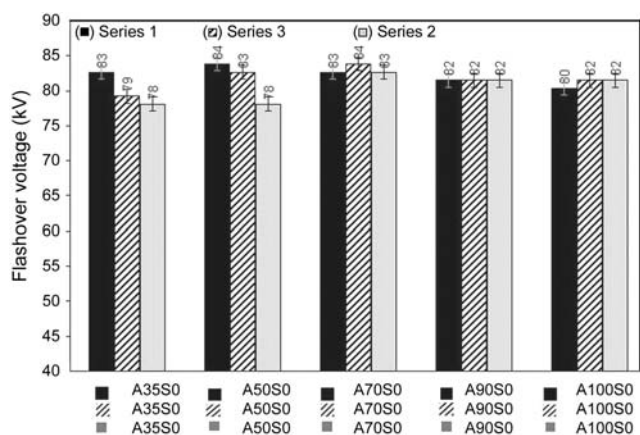
Figure 4. Flashover voltage (FOV) changes as a function of ATH and silica content in dry condition. (Note: All samples labeled as AXSY, X indicates the amount of ATH filler in ppm and Y indicates silica filler in ppm).

or decreases below this value, the flashover occurs at lower voltages. Because at lower ATH level there is not enough resistance to tracking and erosion and the coating cannot withstand the heat of arcing, thus it fails. With increasing ATH concentration, the surface roughness increases and the amount of LMW fluid decreases [18]. The flashover phenomenon is highly influenced by surface roughness and it occurs faster on the rougher surfaces. Furthermore, it can be concluded from S shape curve in Figure 5 that at lower ATH levels the addition of silica to the samples acts as a positive parameter and these samples show better performance compared to samples in Series 1 because silica has good bonding affinity for silicone matrix and decreases the overall void volume of the samples
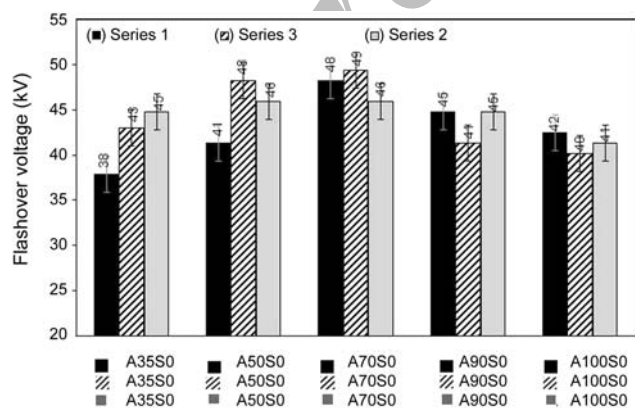

Figure 5. Flashover voltage changes as a function of ATH and silica content under dew conditions.
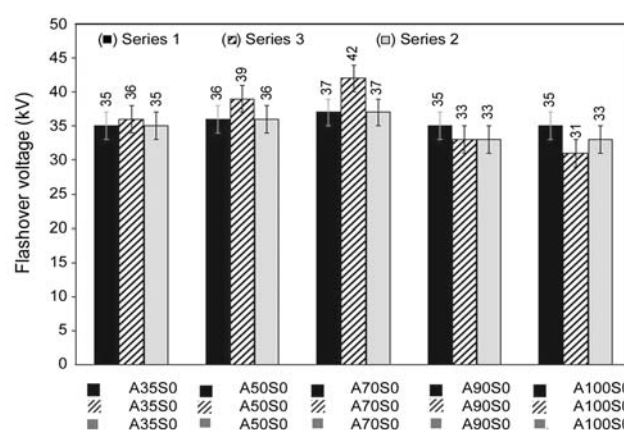

Figure 6. Flashover voltage changes as a function of ATH and silica content under artificial raining.

[15]. However, at higher ATH level, because there is not enough silicone, it is difficult for silica to disperse in elastomer phase so it migrates to the surface and creates a rough surface. The results of SEM tests can prove this claim and it will be explained subsequently. In this condition the results of Series 2 show that again the best performance in this series belongs to A60S10, though in general it is not suitable to replace 10 pph ATH with the same amount of silica.

Figures 6 and 7 demonstrate the results of the rain tests. They both show the flashover voltages with a rising-falling trend when the filler level is increased. ATH can increase the entire thermal conductivity of the mixture; thereby it improves the heat durability of the material [14]. However, at high filler quantity the roughness of the surface prevents it to be cleaned by rain and the water accumulated on the contaminated
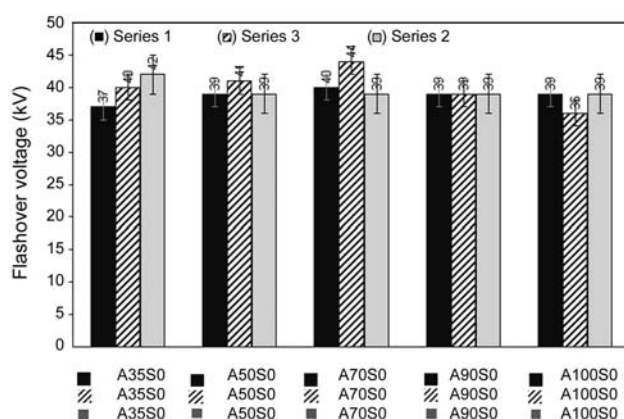

Figure 7. Flashover voltage changes as a function of ATH and silica content at 5 min after rain stopped.
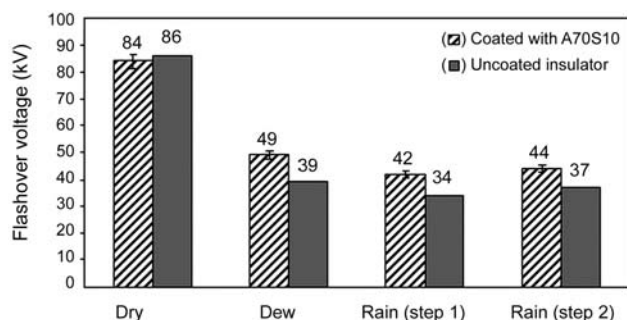
Figure 8. Comparison between flashover voltages of the insulators uncoated and coated with A70S10.

surface leads to flashovers at lower voltages. As water droplets run on the contaminated surface with difficulty, when the rain stops, the rougher surfaces remain wet and they flash at lower voltages. It is noticed that in all samples when the amount of filler is more than 70 pph the contamination slurry cannot be removed completely, and hence, it increases the conductivity and reduces the flashover voltages.

Figure 8 shows the comparison between the performance of uncoated insulator and the coated insulator with A70S10 (70 pph ATH and 10 pph silica fillers) in all tests. It can be seen that coated insulator shows much better performance than uncoated one except in dry condition. This is due to the surface roughness that plays a rather important role compared to other parameters in dry condition and just in this case the coated insulator flashes faster than the uncoated one.

Contact Angle Study
The extent of hydrophobicity can be estimated using the contact angle variation. If the contact angle of the material increases above 90°, it indicates that the material is hydrophobic [16]. In order to study the behaviour of virgin RTV coatings with different filler types and quantities the specimens containing various amounts of ATH and silica fillers were used [13]. The static contact angle of a sessile droplet of water was measured on a stable horizontal surface of the coating. The measurements of contact angle showed that θ is almost independent of filler quantity and it is about 98°±3° for Series 1, 95°±3° for Series 3 and 96°±3° for Series 2 in the range 25-100 pph. This can be explained by the filler particles that were almost unexposed to the surface of the virgin coatings. The
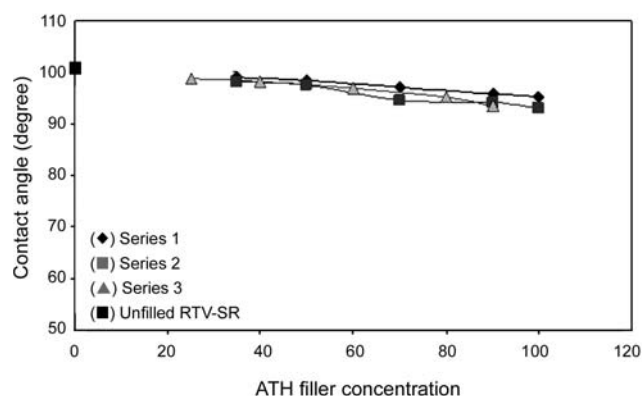

Figure 9. Contact angle changes as a function of ATH content on the unfilled RTV-SR coatings

fillers were covered by the silicone rubber at all concentrations of ATH with or without silica [18]. Figure 9 shows the results of this test for all series.

Morphological Study
SEM micrographs at magnification ×1000 are shown in Figure 10. They show the difference in the morphologies between the two samples. The silica filled samples (Figures 10b and 10d) have a higher packing density with very few voids. This could be, in part due to the affinity of silica (SiO_2) for the main polymer base (polydimethylsiloxane) [15]. In both cases, by comparing Figures 10a and 10b with 10c and 10d, clearly as mentioned before when silica was added to ATH, the surface became rougher.

It can also be seen from this picture that silica particles are not dispersed perfectly. Samples which only filled with ATH showed a greater number of voids compared to those samples that had silica in addition to ATH filler. The number of found voids and loose particles indicates that ATH particles do not strongly bond to main polymer base. The differences observed with silica and ATH filled samples are mainly due to the way in which the filler particles are adsorbed onto the base polymer. The differences in the behaviour of samples filled with ATH and those filled with both ATH and silica can be better understood when considering two different mechanisms by which the filler imparts tracking and erosion resistance. ATH being a flame-retardant, when heated to about 220°C, releases water of hydration, helping to cool the spot under attack by dry-band arcing. Silica, on the other hand, having a better bonding affinity for the silicone
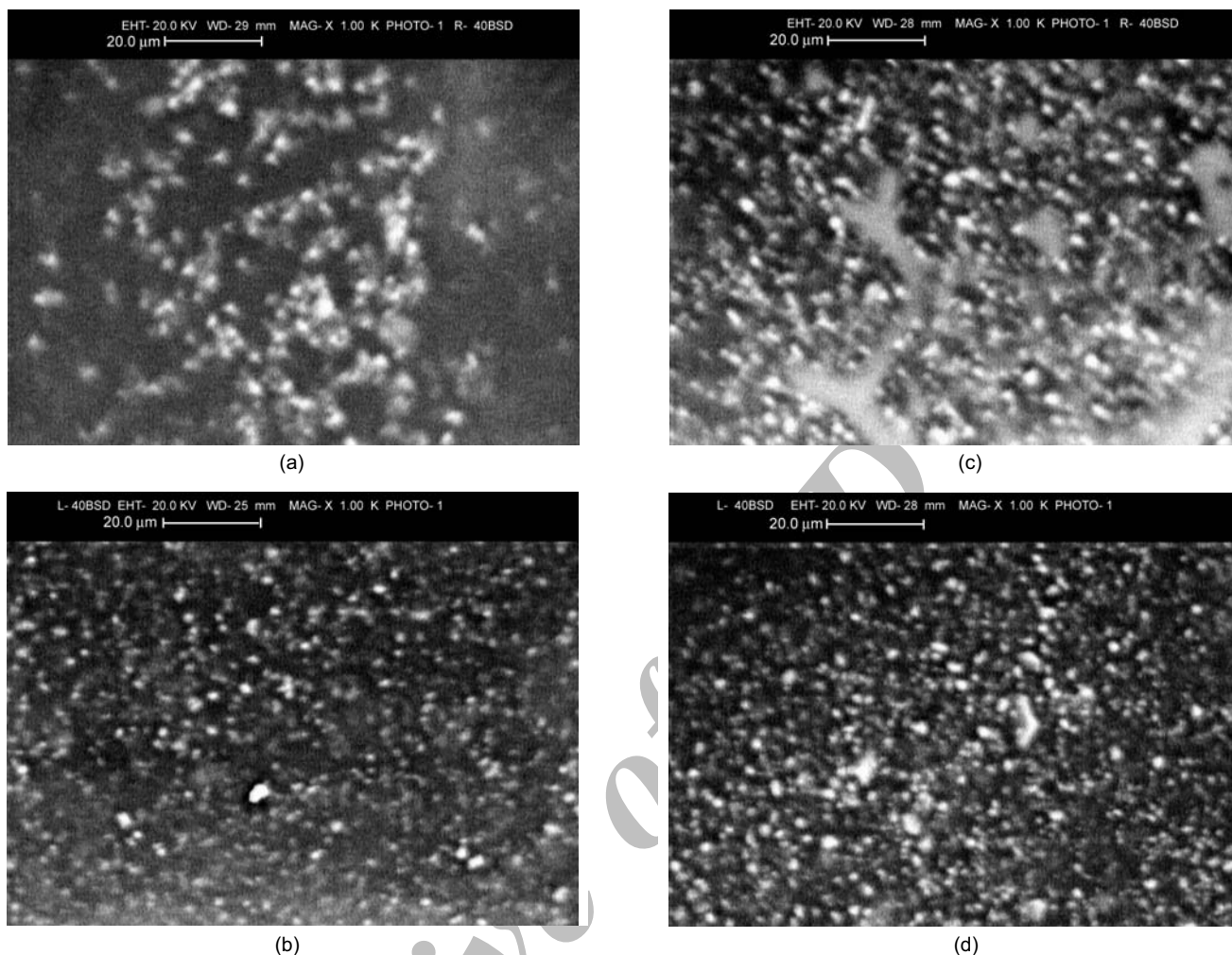
Figure 10. SEM micrographs of fractured surfaces of: (a) 70 pph ATH [A50S0], (b) 70 pph ATH and 10 pph silica [A70S10], (c) 100 pph ATH [A100S0], (d) 100 pph ATH and 10 pph silica [A100S10] (magnification ×1000).

matrix, decreases the overall void volume of the samples. These bonds can also defer the evaporation of LMW silicone fluid [15]. Hence, although the addition of silica to ATH improves the performance of sample A50S0, as it was stated before and it is noticed in Figures 4 and 5, in the case of A100S10, the addition of silica to ATH causes the surface to be rougher than A100S0 and the flashover phenomenon was depressed as well.

TGA Study

Tracking and erosion of polymeric materials occur with thermal degradation as a result of high temperatures caused by dry band arcing. Thermal degradation behaviour under elevated temperature may be closely related to the resistance to tracking and erosion [16].

TGA thermograms of two virgin samples are shown in Figure 11. The TGA curve of unfilled RTV-SR shows gradual weight loss at 75-200°C, considerable weight loss at 200-510°C, and slight weight loss above 510°C. It is clear that the unfilled RTV-SR loses weight because of oxidation and combustion of narrow molecular weight fractions of the siloxane matrix at 75-510°C, and the slight weight loss above 510°C could result from thermal decomposition [14, 17]. In addition, some inorganic materials such as amorphous carbon must remain at temperature higher than 700°C [17]. ATH is used in polymeric materials to impart high resistance to electrical tracking, erosion, and inflammability. Crystalline water in ATH can reduce internal oxidation to polyolefins and therefore, this should suppress carbonization and erosion. It has been reported already that the crystallization water of ATH can be liberated twice,
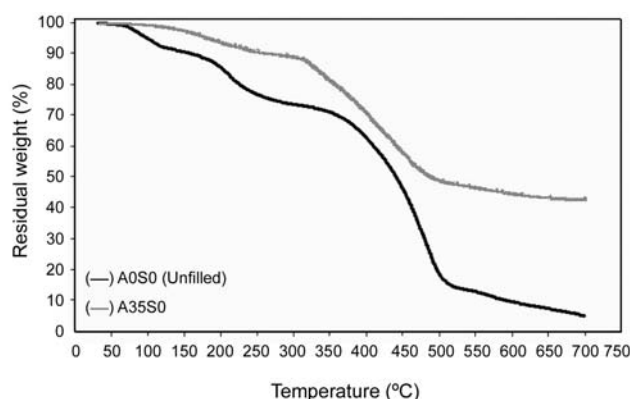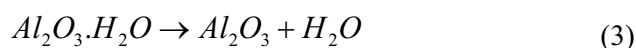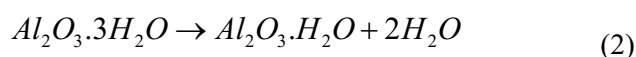
Figure 11. TGA curves of unfilled (A0S0) and ATH filled (A35S0) SR.

respectively around 300ºC and 500°C, as shown in eqns (2) and (3) [14,19]:

$$Al_2O_3 . 3H_2O \rightarrow Al_2O_3 . H_2O + 2H_2O \tag{2}$$

$$Al_2O_3 . H_2O \rightarrow Al_2O_3 + H_2O \tag{3}$$

For RTV-SR filled with 35 pph ATH, there is a gradual weight loss at 130-310°C and a considerable weight loss at 310-500°C, and a slight weight loss above 500°C, as can be seen in the TGA curve. By comparing the TGA curves for unfilled coating and the one filled with 35 pph ATH, it is observed that the thermal-oxidation of RTV-SR can be deferred by dehydration of ATH filler during the heat treatment.

The initial degradation temperature corresponding to 1% decomposition for neat materials is shown in Figure 12. It can be seen in this figure that the initial degradation temperatures corresponding to the
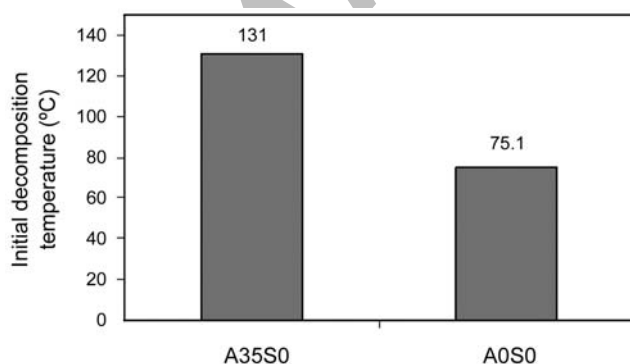

Figure 12. Histogram of initial decomposition temperature for unfilled (A0S0) and ATH filled (ATH35S0) SR.

silicone rubber filled with 35 pph ATH (A35S0) and the unfilled silicone rubber (A0S0) are found to be 131°C and 75.1°C, respectively. It is also noticed that with the addition of filler the initial degradation temperature increases. The upper initial degradation of filled silicone rubber compared to unfilled sample is due to the water of crystallization in ATH filler and its subsequent exothermic reaction.

Conclusion

The RTV-SIR coatings on the surface of porcelain insulator increase the flashover voltage of the contaminated insulator. At a fixed size of filler particle, the coating containing higher filler concentration has rougher surface. Furthermore, dispersion of silica in RTV liquid is not complete and the coating surfaces with silica in high quantity show distinct areas where large protruding roughness and discontinuities exist. The aggregation of the silica particles in RTV coating may occur due to the poor dispersion in the liquid or during vulcanization, after coating the substrate. The hydrophobicity of the virgin specimens of RTV-SIR coating as determined by the contact angle is independent of the ATH filler level (from 25 to 100 pph). The weight loss of unfilled specimen increases rapidly and, in contrast, the heat erosion of filled specimens can be suppressed as well. It is also confirmed that the depression effect of ATH filler on erosion can be improved by filler amount increasing until saturation. The best performance belongs to the sample filled with 70 pph ATH and 10 pph silica.

REFERENCES

1. Ehsani M, Zeynali M, Abtahi M, Harati A, LDPE/EPDM blends as electrical insulators with unique surface, electrical and mechanical properties, *Iran Polym J*, **18**, 37-47, 2009.
2. Ehsani M, Bakhshandeh GR, Morshedian J, Borsi H, Gockenbach E, The dielectric behavior of outdoor high voltage polymeric insulation due to environmental aging, *J Eur Trans Elect Power*, **1**, 47-59, 2007.
3. Cherney EA, Hackam H, Kim SH, Porcelain insulator maintenance with RTV silicone rubber coatings, *IEEE Trans Power Deliv*, **3**, 1177-1181,

1991.

4. Gorur RS, Chernry EA, Burnham JT, *Outdoor Insulators*, 1st ed, Gorur Inc, Phoenix, Arizona, USA, 16-245, 1999.

5. Deng H, Hackam R, Cherney EA , Influence of thickness, substrate type, amount of silicone fluid and solvent type on the electrical performance of RTV silicone rubber coatings, *IEEE Trans Power Deliv*, **1**, 431-443, 1996.

6. Ehsani M, Borsi H, Gockenbach E, Morshedian J, Bakhshandeh GR, An investigation of dynamic mechanical, thermal, and electrical properties of housing materials for outdoor polymeric Insulators, *Eur Polym J*, **11**, 2495-2503, 2004.

7. Ehsani M, Borsi H, Gockenbach E, Bakhshandeh GR, Morshedian J, Modified silicone rubber for use as high voltage outdoor insulators, *J Adv Polym Technol*, **1**, 51-61, 2005.

8. Grour RS, Cherney E.A, Tourreil C, Dumora D, Harmon R, Hervig H, Kingsbury B, Kise J, Orbeck T, Tanaka K, Tay R, Toskey G, Wiitanen D, Protective coatings for improving contamination performance of outdoor high voltage ceramic insulators, *IEEE Trans Power Deliv*, **2**, 924-933, 1995.

9. Gorur RS, Karady G, Jagota A, Shah M, Furumasu BC, Comparison of RTV silicone rubber coatings under artificial contamination in a fog chamber, *IEEE Trans Power Deliv*, **2**, 713-719, 1992.

10. Chernry EA, RTV silicone- A high tech solution for a dirty insulator problem, *IEEE Elect Insul Magazin*, **6**, 8-14, 1995.

11. Devendranath D, Channakeshava, Rajkumar AD, Leakage current and charge in RTV coated insulators under pollution conditions, *IEEE Trans Dielect Elect Insul*, **2**, 294-299, 2002.

12. Kim S, Cherney EA, Hydrophobic behaviour of insulators coated with RTV silicone rubber, *IEEE Elect Insul Magazin*, **3**, 610-622, 1992.

13. Kim S, Cherney EA, Hydrophobic behaviour of insulators coated with RTV silicone rubber, *3rd Intl Conf on Properties and Applications of Dielectric Materials*, Tokyo, Japan, 972-976, 8th-12th July 1991.

14. Zhu Y, Otsubo M, Honda C, Ohno A, Suppression effect of ATH filler on the erosion of filled silicone rubber exposed to dry band arc discharge, *Polym Test J*, **24**, 893-899, 2005.

15. Meyer L, Omranipour R, Jayaram S, Cherney EA, The effect of ATH and silica on tracking and erosion resistance of silicone rubber compounds for outdoor insulation, *IEEE Int Symp*, USA, 271-274, 2002.

16. Ehsani M, Multi-component polymeric alloys as outdoor high voltage insulator, PhD thesis, Department of Polymer Processing, Iran Polymer and Petrochemical Institute, Apr 2003.

17. Homma H, Kuroyagi T, Izumi K, Mirley CL, Evaluation on surface degradation of silicone rubber using thermogravimetric analysis, *Int Symp Elect Insul Mater*, Japan, 631-634, 27th-30th Sep 1998.

18. Deng H, Hackam R, Low-molecular weight silicone fluid in RTV silicone rubber coatings, *IEEE Trans Dielect Elect Insul*, **1**, 84-94, 2005.

19. Katz HS, Milewski JV, *Handbook of Fillers for Plastics*, Van Nostrand Reinhold, New York, 166-169, 1987.