PERFORMANCE OF SILICONE RUBBER POLYMERIC OUTDOOR INSULATOR MATERIAL UNDER AC AND DC CORONA

Joseph Vimal Vas and M. Joy Thomas*
High Voltage Engineering lab, Department of Electrical Engineering,
Indian Institute of Science, Bangalore, India
*Email: jtm@ee.iisc.ernet.in

Abstract: Degradation due to corona is one of the major problems of outdoor polymeric silicone rubber insulators. When exposed to corona, the surface hydrophobicity, which prevents the wetting of the surface leading to reduced leakage current, gets reduced. The effects of ac corona on silicone rubber insulators have been reported extensively, but studies on dc corona aging of silicone rubber are scarce. The present study deals with the corona aging of polymeric Room Temperature Vulcanized (RTV) silicone rubber (SR) insulators under ac, positive dc and negative dc voltages. A multi-needle-plane electrode system was used to generate the corona and the insulator was exposed to corona for two different time durations - 25 and 50 hours. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) analysis were conducted on the sample to understand the various changes occurring on the surface due to the exposure to corona. The contact angle was also measured before and after the test to understand the changes in hydrophobicity on the surface of the sample. Results show that the degradation is the highest in the case of ac corona tested samples for 50 hours of aging. Degradation was less for the 50 hour dc corona exposed samples. The contact angles measured for ac corona were the minimum which showed that hydrophobicity of the surface is lost during exposure to corona.

1 INTRODUCTION

Polymeric insulators are ideal for outdoor applications owing to their superior performance under wet and polluted conditions. Their surface hydrophobicity does not allow the formation of water film thereby reducing leakage current and hence the power loss. Also compared to porcelain, they are light in weight which makes them easier for erection and commissioning. This is especially advantageous for dc transmission where the contamination level is expected to be higher owing to unidirectional stress on the insulator. But the tendency to lose its hydrophobicity under exposure to electric stresses in polluted environment, especially under exposure to corona, and the lack of service experience is an issue of concern.

Corona generation on transmission line insulators occurs mainly due to improper design of hardware or due to the formation of water droplets on the surface of the insulators. The presence of water droplets on the surface of a charged insulator produces field enhancement at the water – insulator – air interface [1]. The enhancement factor varies from 3.9 to 4.8 and this again depends on the size and number of droplets. This enhanced electric field results in corona at the interface [2]. Hence the long term performance of the insulator can be affected by corona. Reports also suggest that humidity plays a major role on the degradation undergone by the Non Ceramic Insulators (NCI) housing material under ac corona [3].

Prolonged exposure to ac corona results in loss of surface hydrophobicity and also degradation of the polymeric insulators. Under the action of corona, the insulator is subjected to ions and reactive species as well as UV light and high temperature. The degradation occurs due to a variety of chemical reactions like (i) increase in oxygen content at the surface by formation of silanol and hydroxyl groups, (ii) oxidative crosslinking and (iii) degradation of the polymer structure forming lower molecular weight units [4].

Studies on ac corona exposed SR have shown that the surface hydrophobicity is lost on prolonged exposure to corona [5] [6]. This is due to the formation of hydroxyl groups on the surface. The SR recovers the hydrophobicity on exposure to dry air. The LMW species that are formed in situ during electrical discharges are sufficient to cause the hydrophobic recovery of oxidized PDMS elastomers [7]. Corona degradation under ac voltages has been reported. Cracks are observed on the surface of the SR insulator after exposure to ac corona [8] [9]. Adding nano sized fillers improves the corona performance of the insulator [8].

Reports on the effect of exposure to dc corona on polymeric insulators are scarce. However the behaviour of water droplets on the surface of an energised SR sample have been reported. The behaviour of water droplet on the surface of the insulator is different for ac and dc voltages [10]. Water droplets are deformed under both ac and dc voltages. However under ac voltages, it is seen that the water droplets undergo vibrations but not under dc voltage. Higashiyama et al [11] have reported that water droplets placed on the surface of SR samples elongate and discharges occur under the application of positive and negative dc. Reports on studies conducted by charging polymeric insulators with ac and dc show that there are significant differences in the surface charging phenomenon [12]. It was observed that the decay of corona implanted positive dc charge took longer than the decay of charges due to ac and negative dc. Lan Lei et al. [13] have studied the effect of dc corona on unfilled and nano filled Silicone rubber (SR) and showed that performance under dc corona improved by adding fillers.

The literature revels that corona influences the state of polymeric insulators. The surface hydrophobicity of polymeric insulator is lost when exposed to corona. Also, the surface of the polymer degrades under the influence of ac corona. Reports on the effect of dc corona on polymeric insulators are scarce. Hence the present study aims to evaluate the performance of polymeric SR insulator under positive and negative dc corona and compare it with the performance under ac corona. Polymeric silicone rubber insulators are used for this study as they are the most attractive options among polymeric insulators. For evaluating the performance of polymeric insulators to corona, the different methods used are the water droplet corona and the corona generated by the needle-plane electrode geometry. Though water droplet corona is similar to those seen in the field, it is difficult to control. Hence a needle-plane electrode system was used in the present work to generate and study the effect of corona on SR insulators.

2 EXPERIMENTAL TECHNIQUES

2.1 Materials

Test samples were prepared using RTV SR material supplied by Wacker Chemie, Germany. A two component (namely 'A' and 'B') system was used for making RTV Silicone Rubber samples. 'A' component was a cross linker and 'B' component was a Pt based catalyst (both of density 0.97g/cc).

2.2 Sample preparation

The ‘A’ and ‘B’ components were kept under vacuum (10^{-2} Torr) for at least 24 hours to remove the moisture and air bubbles from the material. Ratio of the RTV components A: B, for the material studied was 3:1, which was found to be appropriate for getting samples of very low tackiness, appropriate hardness and good curing. The processing methodology is as follows; The required quantity of RTV ‘A’ and RTV ‘B’ components were added in a beaker and mixed well. The mix was evacuated to remove the air bubbles. The mix was poured into a circular mould of 72 mm diameter and 5 mm thickness and cured in a high temperature oven for 24 hours.

2.3 Corona aging of SR under ac and dc

Figure 1 shows the experimental set up used for aging studies under positive and negative dc. For the ac corona studies, the rectifier and the filter capacitor were not included in the circuit. A needle-plane electrode system was used to expose the SR sample to coronating conditions. 12 needles of ~ 32 µm tip radius were used to age multiple locations on the sample surface simultaneously. The arrangement of needles is as shown in figure 2a.

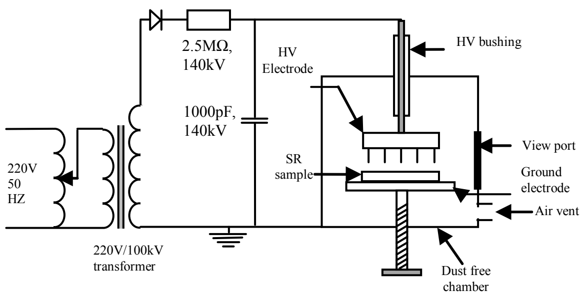
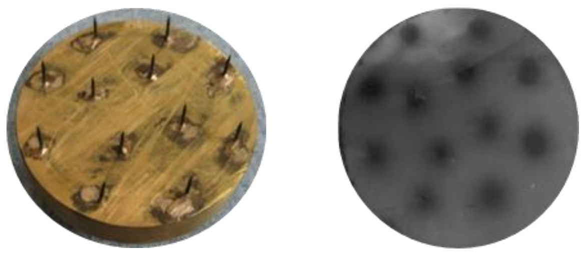


Figure 1: Experimental setup used for DC corona aging studies on SR samples.

The SR sample was placed on the lower grounded electrode directly below the upper HV electrode. A gap of 5 mm was maintained between the needle tip and the sample surface. A voltage of 7.5 kV rms was used to generate corona under ac voltages, and for the dc studies 11 kV was used to generate the corona. The above dc voltage was selected so as to match the peak of the ac voltage of 7.5 kV rms and also a stable corona was obtained during the studies.



(a) (b)

Figure 2: Photograph showing (a) the needle arrangement on the HV electrode and (b) scanned image of the photographic film after exposure to corona.

For the results to be comparable it is important to keep the corona intensity around each needle identical. To quantify the corona intensity around the needles, a photographic sheet was kept under the HV needle electrode just on top of the sample on the lower ground plate and voltage was applied for 10 sec. Figure 2b shows the scanned image of the photographic film after exposure to the corona. The black marks on the film correspond to the light produced during corona. It can be seen that the corona intensity under all the points are comparable.

2.4 Measurement of Hydrophobicity

The hydrophobicity was assessed using contact angle measurements. The contact angles were measured using a Rame-hart CA Goniometer (model 190). Sessile drop method was used to measure the contact angle. The drops used were of 8 µl volume. For all the samples, the hydrophobicity was measured before and after the corona aging tests. The measurement was done directly at the area affected by corona.

2.5 Surface studies using SEM

To study the changes happening on the surface of the samples, SEM (model: ESEM Quanta, of FEI make, USA) was used. Energy dispersive X-ray analysis (EDX) was done using the same machine. The point on the sample directly below the needle tip is termed as ground 0. Crack width was measured at ground 0 and at 6 different locations moving away radially for every 100µm from the ground 0 as shown in figure 3. The crack width was measured at each of these points and the average crack width was calculated.

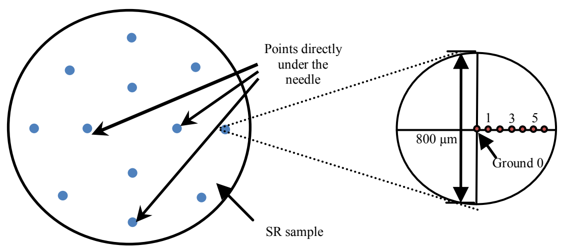


Figure 3: Locations on the SR sample at which the surface profile was measured.

3 RESULTS

Visible damage could be seen on the surface of the SR samples after exposure to ac and negative dc corona. Spots directly below the needles showed circular patches where erosion took place. The samples tested under ac showed more visible damages than negative dc corona after 50 hours of aging. Compared to ac and negative dc corona tested samples, positive dc corona tested samples showed no visible damage. All the samples became hydrophilic after the exposure to corona except the positive dc samples tested for 50 hours.

3.1 Hydrophobicity studies

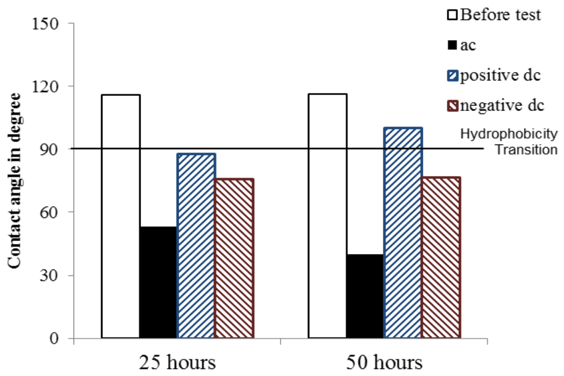
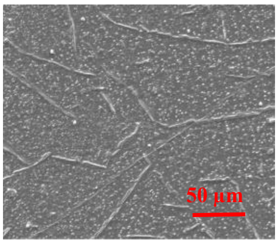


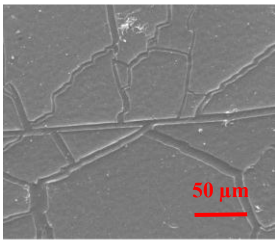
Figure 4: Contact angle of the SR sample before and after exposure to corona under ac, positive and negative dc voltages for 25 and 50 hours.

Figure 4 shows the contact angles measured before and after exposure to ac, positive and negative dc corona for 25 and 50 hours. The contact angles reported are the values measured directly under the needle points. Ac corona tested samples, showed the least contact angle after exposure for 25 hours followed by negative dc and positive dc. The contact angles measured after 25 hours of exposure to ac corona was 53°. Comparing the samples tested for 25 and 50 hours, the contact angles reduced with exposure time for ac and negative dc corona. But for positive dc corona tested samples, the trend was opposite. The contact angle was higher after 50 hours as compared to 25 hours of aging under positive dc. The samples were still hydrophobic after 50 hours of exposure to positive dc corona. Hence it can be concluded that under ac corona, the hydrophobicity loss is higher as compared to dc corona.

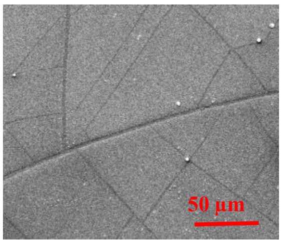
3.2 SEM analysis

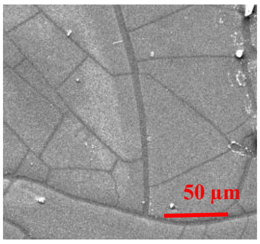
The SEM analysis was conducted on the surface of the samples after exposure to ac, positive and negative dc corona for 25 and 50 hours. Figure 5 shows the photographs of the samples tested under ac, positive and negative dc for 25 and 50 hours. It can be seen that the degradation was maximum in the case of ac. The crack width is highest after exposure to 50 hours of ac corona. Negative dc corona exposed samples showed the next largest crack width whereas the damage was minimal under positive dc. This can also be seen in figure 6 which gives the crack width measured in the samples after 25 and 50 hours of exposure to ac, positive and negative dc corona.



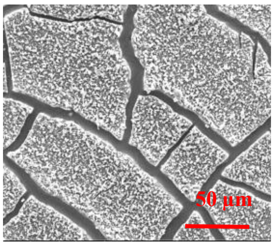


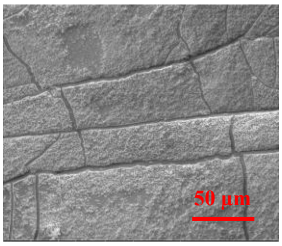
(a) ac, 25 hours (d) ac, 50 hours





(b) +dc, 25 hours (e) +dc, 50 hours





(c) –dc, 25 hours (f) –dc, 50 hours

Figure 5: SEM images of samples exposed to ac, positive and negative dc corona for 25 hours (a, b, c) and 50 hours (d, e, f).

The ac and negative dc corona exposed samples showed an interesting phenomenon. It was seen that there was attachment and growth of the polymeric material, which was eroded from the SR sample under exposure to corona, from the tip of the HV needle electrode. This was also reported by Venkatesulu and Joy Thomas for the ac corona test [8]. The pattern seen for the polymer growth under ac and negative dc corona was different. Figures 7a and 7b show the SEM images of the material deposited on the tip of the HV electrode after the corona exposure under ac and negative dc respectively after 50 hours of aging. It can be seen that the structures are different for both the kinds of voltages.

Negative dc corona tested samples also showed deposition of white powder on the surface of the sample. This can be seen as the white coloured powder in figure 7c and 7d. With increase in exposure time, the area of deposition of these white coloured powder increased which can also be seen in figure 7d. The polymer that got attached and grew at the tip of needles fell off from the needle electrodes. Similar deposition could be seen in the case of samples tested under ac corona also, though the amount of deposition was much lesser in the case of ac corona.

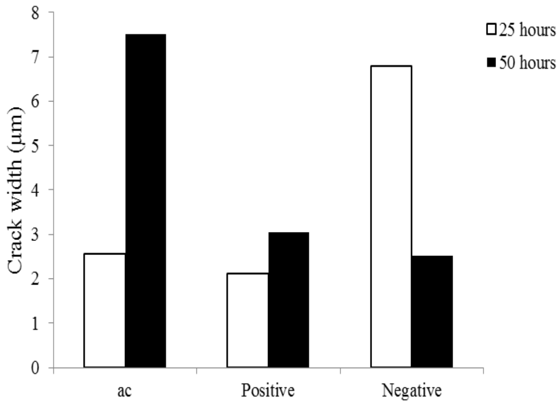
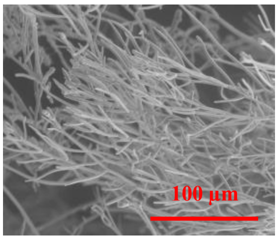
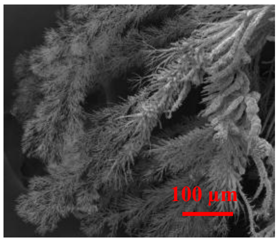
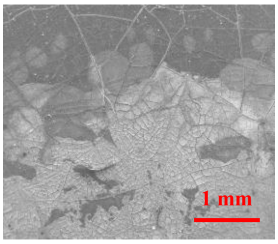


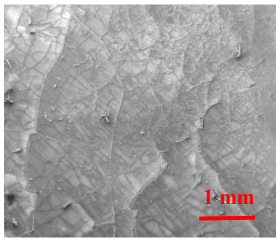
Figure 6: Crack width measured after 25 and 50 hours of exposure to ac, positive and negative dc corona.





(a) (b)





(c) (d)

Figure 7: SEM image showing (a) the polymer deposited on the needle tip after exposure to 50 hours of ac corona [8] and (b) the polymer deposited on the needle tip after exposure to 50 hours of negative dc corona, (c) surface of sample after 25 hours of aging and (d) after 50 hours of aging under negative dc corona.

4 DISCUSSION

4.1 Effect of voltage type

The hydrophobicity studies have shown that the loss of hydrophobicity was the highest in the case of samples exposed to ac corona as compared to the positive and negative dc. It was also seen that with exposure time the contact angle decreased for ac and negative dc corona exposed samples. The reduction in contact angle with exposure to corona is because of the scission of the methyl groups residing on the surface of the SR and formation of the hydrophilic –OH group which in turn increases with time [6]. Contrary to expectations, it is seen that with exposure time the hydrophobicity of the samples increased for the samples tested under positive dc.

From the crack width analysis, it was seen that the least crack width was observed for samples exposed to positive dc corona. The samples aged under negative dc corona showed the largest cracks.

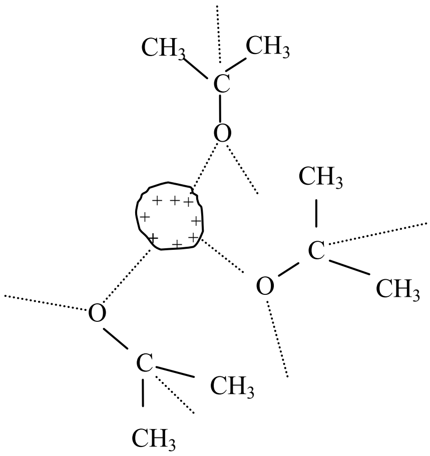


Figure 9: Model showing the effect of induced positive charges inside the polymer matrix forming ionic bonds with the oxygen due to positive dc corona.

The reason for the better performance of SR samples under positive dc corona can be explained as follows; Gorur et al. [12] have reported that the decay of the surface charging of samples tested under positive dc was the slowest compared to ac and negative dc. Such a charging phenomenon results in formation of charge centres on the surface and in the bulk of the polymer as shown in figure 9. The oxygen in the backbone of the SR chain is highly electronegative and gets attracted towards these charge centres. Hence the presence of charges on the surface and in the bulk not only repels more charges hitting the surface but also holds the material together thereby reducing the erosion of the material when exposed to positive dc corona.

In the case of the samples exposed to ac and negative corona, the charge decay occurs much faster. Hence there is no charge build up on the surface of negatively charged samples and hence more charges hit the surface. This leads to higher erosion in the case of negative dc corona exposed samples.

4.2 Effect of exposure time

Hydrophobicity studies show that the loss of hydrophobicity was more after 50 hours of exposure to ac and negative dc corona. The positive dc corona tested samples showed an increase in contact angle values or an improvement in hydrophobicity. This can be explained as follows; As discussed in section 4.1, when the sample is exposed to corona, the surface gets charged. The rate of discharge varies with the kind of voltage used. For the positive dc corona charged samples, the charge decay takes longer than those charged with ac and negative dc corona [12]. Such a charge build up, leads to repelling of more charges moving towards the surface. Hence after the charge build up at the surface, no more corona generated charges hit the sample surface. After the initial degradation, the movement of lower molecular weight units to the surface makes the surface non polar. This results in a higher surface tension of the water molecules depositing on the surface and hence the surface is more hydrophobic after 50 hours of aging under positive dc.

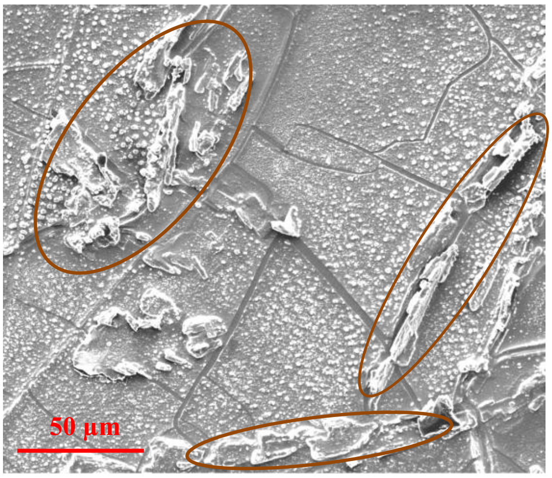


Figure 10: SEM image showing the deposition of polymer from the needle in the cracks.

Another interesting phenomenon which occurred during the corona testing experiments was that after 50 hours of aging under negative dc the samples showed less cracks when compared to the 25 hour tested samples. As seen in the section 3.2, the polymer which got detached from the SR sample surface and got attached to the HV needle electrodes in the case of negative dc, got deposited again on the SR surface. These deposits filled up certain regions where cracks are seen on the surface as shown in figure 10. Hence the effective crack width in the case of negative dc corona exposed samples reduced with time of exposure.

5 CONCLUSIONS

Corona aging studies on polymeric SR insulators showed that the samples performed best under positive dc followed by negative dc and ac corona. The contact angles of the samples were least for the samples tested under ac corona for both 25 and 50 hours. Negative dc corona tested samples also showed a similar trend. But the samples tested under positive dc corona showed improvement in contact angle after 50 hours of exposure. This was because of the charge deposition on the surface and in the bulk in the case of positive dc corona.

The crack width of samples tested under positive dc corona was the least. Negative dc corona tested samples showed more crack width after 25 hours of exposure, followed by ac corona tested samples. The crack width of ac and positive dc corona tested samples increased with exposure time. But the samples tested under negative dc corona showed the opposite trend with exposure time. The material deposited in the cracks effectively reduced the crack width after 50 hours of corona aging under negative dc.

6 ACKNOWLEDGMENT

The authors would like to thank Mr. Riaz Ahmed for the support in setting up the experimental facility, Wacker Chemie AG for supplying the silicone rubber material and Mr. Sankar, Huber Corporation for providing the ATH powder for the studies The authors would also like to thank the Nanocentre at the Indian Institute of Science for the permission to use the SEM facility. The assistance provided by Dr. B. Venkatesulu, Dr. Midhun Ben Thomas, Mr. Alex Joseph and Dr S Ananthalakshmy are greatly acknowledged.

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