THE EFFECT OF ULTRAVIOLET (UV) RADIATION AND HUMIDITY STRESS ON SILICONE RUBBER INSULATOR BEHAVIOUR

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Abstract The performance of any electrical network depends largely on insulation. Today's use of polymeric insulator in transmission and distribution lines of electrical power system is widely improving. Silicone rubbers are one of the polymers that is used in producing of weather shed's insulator. Silicone Insulator service life can be affected by electrical, mechanical and environmental stresses. The greatest physical threats are generally mechanical loads and UV exposure. This destroyed energy consists of just about five percent of the whole radiation that reaches to the planet's surface. This effect is the most when the moisture is present on the polymer surface. Atmospheric contamination and moisture can form a conductive film leading to leakage current, dry bond arcing and eventually flashover. As this effect is illustrated in the above we should evaluate silicone rubber insulator behaviour under presence of UV radiation and high humidity. In this paper the effect of UV radiation and humidity stresses on surface and electrical properties of silicone insulator is simultaneously studied. The results of contact angle, SEM, electrical and mechanical tests show deduction of properties due to UV radiation and humidity stresses.

1. INTRODUCTION

Since the introduction of electricity in 19th century, there has been a growing demand for electrical energy. Higher voltages led the researchers to develop new types of insulators .In the early days, insulators were made of ceramic and glass material only. But in late 1960's polymeric insulator were developed and its improvements in design and manufacturing in the recent years have made them attractive to utilities [1]. At the beginning, non-ceramic insulators contained ethylene propylene rubbers (EPR) which were made by different companies such as Ceraver of France (1975), Ohio Brass of U.S.A. (1976), Sedivar of U.S.A (1977) and Lap of U.S.A (1980). At 1976, Rosenthal Co and Reliable Co of the U.S.A in 1983 presented silicone rubber (SIR) [2, 3]. Polymer Insulators, just like its porcelain counterparts have two basic purposes on transmission lines:

1. To support conductors and attach them to structures
2. To electrically isolate conductors from other components on a transmission line.

The second purpose is very important to operation since without some form of insulating material, electrical circuit cannot operate and any insulation deficiency oftentimes would result to trouble, say flashovers. Polymer insulator is an electrical insulation device made of three components, fibre glass reinforced resin rod system, metal end fittings, and polymeric weather sheds. The weather sheds are used for protecting the fibre glass rod from the environment and electrical surface discharges. polymeric weather sheds provide an extended creepage distance while also presenting a low surface energy for water repellency [4,5]. silicone insulators are widely as outdoor HV insulators, due to Stable behavior at extreme climate conditions, Long term surface hydrophobicity, Suitability for polluted environment and salty atmospheres, Resistance to breakage and vandalism, Practically unbreakable, Superior anti-tracking properties, High mechanical strength, Resistance to Seismic Shock [5]. Other advantages include light weight (25-30% less than ceramic insulator), easy maintenance, simply insulation (easier handling with lighter equipment and labor at the job site), cost, electrical properties [6]. Polymeric materials can be degraded by environmental stress like heat, moisture, UV radiation, contamination and this could lead to variety of dielectric and electrical properties [7, 8]. Electrical aging of insulators is associated with a wide variety of phenomena such as breakdown, discharges, surface tracking or erosion, treeing, electron interactions with charges, phonons, matters, etc.
The objective of this work is study of silicone insulator behaviour under simultaneous effect of UV radiation and humidity.

2. EXPERIMENTS

2.1 Material

The used HTV silicone rubber was obtained Wacker Company (Wacker Elastosil R401/60). The applied curing agent for sample was dicumyle proxide (DCP) with 99% purity. The used filler was Aluminium three Hydrate (ATH). Gray pigment was chosen for samples (wacker company product).

2.2 Mixing and molding

After material weighing based on selective formulation that is presented in table 2, initially for a period of two minutes, the silicone rubber was casted into internal Mixer. Rotor speed was 60 rpm. Then other formulation components except curing agent were mixed together, after accurately weighing according to formulation given in table 2. Finally curing agent on roller was added to system. Roll temperature was set so that curing agent was melt in this temperature (60 to 70 °c). After curing by using compression molding, samples were made as sheets with 10× 15× 0/2 cm dimensions.

Table 1: Formulation of prepared sample

	SR	ATH	DCP	pigment
phr	100	50	1	0.7
Kg	11.866	5.933	0.118	0.083

2.3 Aging process

The QUV test is an accelerated weathering test performed in conformance to ASTM G154. The QUV test alternates UV radiation exposure. Each cycle consists of 4 hours of saturation moisture condition in 50°c and 8 hours of UV exposure in 60°c. The QUV test simulates the effects of sunlight by means of fluorescent UV lamps (UVA-340) with intensity of 0.77 W/m^2/nm. A water reservoir at the bottom of the test chamber is heated to produce vapour. The hot vapour keeps the chamber at 100-percent relative humidity. During the condensation phase, water vapor condenses on the cooler surfaces of the specimens. The combination of humidity with high-intensity UV radiation results in an accelerated exposure test. The samples were aged for 24, 48, 96, 230, 600 and 800 hours.

2.4 Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM) was used for study of morphological behaviour of silicone rubber. Surface of specimens was inspected by Cambridge 360, SEM, in magnifications of 2kx for virgin sample and 5kx for aged samples using a voltage of 15 kV.

2.5 Contact angle

Hydrophobicity is defined as a surface which is not readily wet able. Water on the surface doesn't form continues film, but forms individual droplet. To study surface hydrophobicity of silicone rubber, contact angle was used. Contact angle is defined as the angle formed between the tangent to the water droplet and the horizontal surface. In this work contact angle was measured for virgin and aged samples with goniometer.

2.6 Electrical properties

2.6.1 Measurement of insulation losses coefficient and dielectric number

In this test, the Shrink Bridge (2809A Model) and Standard capacitor 10000 pF, (320 / 10000 Model) and solid insulators test chamber (2914 Model, Tettex Company) were used for Measurement of insulation losses Coefficient, and dielectric number.

2.6.2 Measurement of volume specific resistivity

Solid insulators test chamber (2809a model,Tettex company) and M.ohm meter (Chouvin Arnoux Company) were used for This test.

2.6.3 Measurement of dielectric resistance

For this test, Semiautomatic dielectric test set machine (DTS90 model, BAUR Company) was used. Samples were placed within the insulation oil and voltage was applied on both sides. Voltage from zero with rate of 2 kV / s increased and Punch voltage was recorded. This test was performed five times for each sample.

2.7 Mechanical properties

For Mechanical properties, tensile strength and weight loss were studied. For study weight loss, samples were weighted after aging. Then weight difference between virgin and aged samples was calculated. According to ASTM D412, dumbbells shaped samples for measurement of tensile strength put in tension instrument (Tinius Olsen H25KS). Tension speed was 500 ± 50 mm/min.

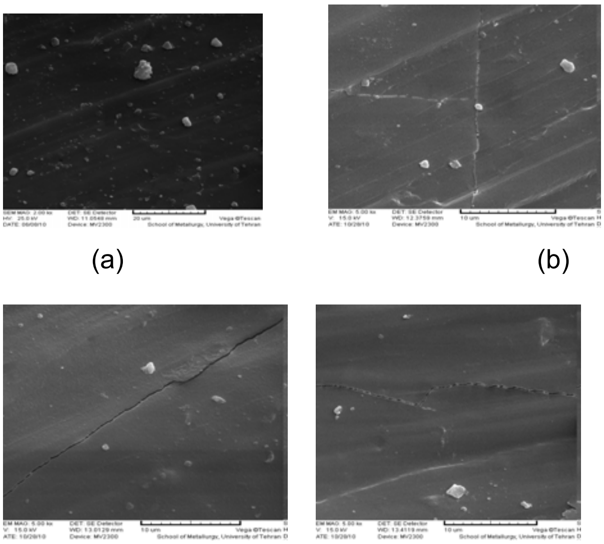
3. RESULT AND DISCUSSION

3.1 Scanning electron microscopy

Surface topography of silicone rubber was studied by Scanning electron microscopy (SEM). The SEM images of the specimens are shown in Figure 1. Figure 1a shows image of virgin sample. It is clear from Figure 1 (b, c and d) that cracks are formed on the surface due to breakdown of Si-C bond (lower bond energy) and decomposition of cyclic silicone oligomers in silicone rubber with increasing exposure time [2, 5].

3.2 Hydrophobicity

Hydrophobcity is the property that prevents water from forming a sheet on the surface of polymer. And idealized surface with prefect hydrophobicity will have a contact angle of 180 degrees. A sample that is completely hydrophilic will have contact angle of 0 degrees. To be considered hydrophobic, the contact angle must be at least 90 degrees; to be considered super hydrophobic; the contact angle must be more than 150 degrees. Figure 2 shows the curves of deduction of contact angle vs. exposure time in QUV. It can be seen that contact angle is going to be reduced over time. It means if silicone rubber insulator is exposed under UV radiation for a long time, hydrophobicity will be reduced because of decreasing methyl groups on the surface.



(a) (b)

(c) (d)

Fig 1: SEM images of the virgin and aged samples: a: virgin, b: 300 hrs aged, c: 600 hr aged, d:800 hr aged

It was observed that C-H and Si-CH3 bonds in PDMS were broken, due to UV irradiation. Because of availability of oxygen in the provided environment OH bonds were formed at broken chain sites in the form of silanol (Si-OH) groups [2, 5].

Table 2: Contact angle of aged samples

800	600	230	96	48	24	Time(hr)
110.4	113.5	115.1	116	118	126.8	Contact angle

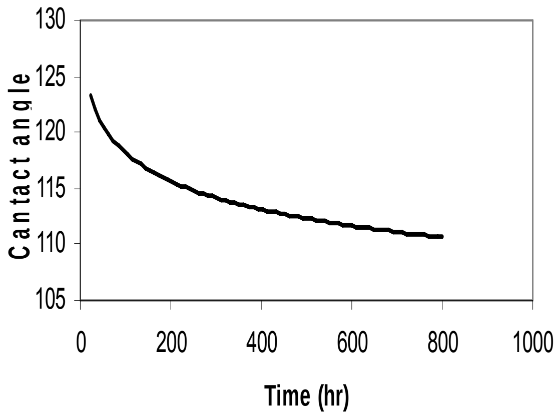


Figure 2: Contact angle of aged samples over the time

3.3 Electrical properties

The results of electrical tests for virgin and aging (800 hr) samples are shown in tables 3, 4 and 5. It can be seen that with increasing exposure time, low increase was observed in breakdown voltage and dielectric number. It is seen that capacitance and insulation losses coefficient were increased with increasing exposure time.

Table 3: Volume Specific resistivity for virgin and aged samples

Volume resistivity(TΩ.m)	Thickness(mm)	Applied DC voltage (V)	Sample
3.8	2.1	1000	virgin
3.8	2.1	1000	800 hr

It is taken from Tables 3 and 4 that volume resistivity and dielectric number isn't changed during exposure time.

Table 4: Electrical properties of virgin and 800 (hr) samples

dielectric number(ε r)	insulation losses Coefficient	Capacitance (PF)	applied voltage (V)	sample
3.4	2.6×10^{-2}	28.85	1000	virgin
3.52	3.2×10^{-2}	29.756	1000	800 hr

Table 5: Breakdown voltage for virgin and 800 (hr) samples

breakdown voltage(KV)	Thickness (mm)	Rate of increasing voltage (KV/S)	sample
41.28	2.1	2	virgin
41.5	2.1	2	800 hr

3.4 Mechanical properties

According to figure 3, Weight loss increased with increasing exposure time and number of cycles, due to the formation of degraded layer on the surface. Figure 4 shows reduction of tensile strength with the exposure time due to breakdown of chains in silicone rubber [2, 5].

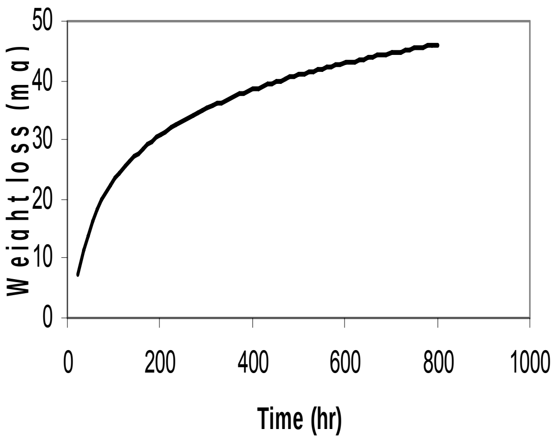


Figure 3: Weight loss vs. time exposure

CONCLUSION

- Hydrophobicity property of silicone rubber insulator is reduced because of decreasing methyl groups on the surface.
- Mechanical properties of silicone rubber insulator such as tensile strength decrease due to breakdown of chains in silicone rubber.
- Images of SEM show cracks on surface silicone rubber because of breakdown of Si-C bond (lower bond energy Si-C) and decomposition of cyclic silicone oligomers in silicone rubber.
- Volume resistivity and dielectric number remain stable during aging process.

Table 6: Mechanical properties of samples

800	600	230	96	48	24	T (hr)
53	52	59	62	63	64	TS(Mpa)
336.1	337.6	369	355.1	390	388.4	E %
46.92	42.5	34.93	17.85	13.43	10.68	WL(mg)

T: Exposure time
TS: Tensile strength for aged samples
E: Percentage of elongation at break for aged Samples
WL: Weight loss for aged samples

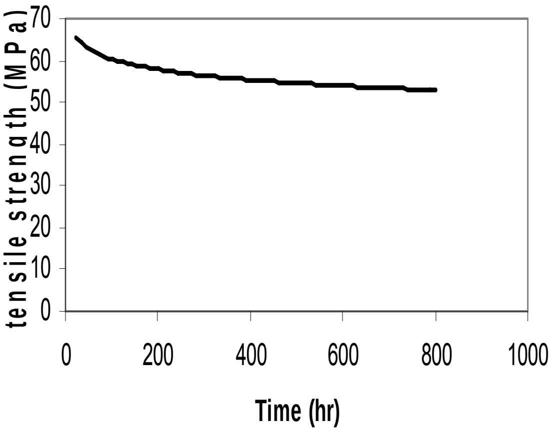


Figure 4: Tensile strength vs. time

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