World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:5, No:8, 2011

Study of Ageing Deterioration of Silicone Rubber Housing Material for Outdoor Polymer Insulators

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***Abstract*—** This paper presents the experimental results of salt fog ageing test of silicone rubber housing material for outdoor polymer insulator based on IEC 61109. Four types of HTV silicone rubber sheet with different amount of ATH were tested continuously 1000 hours in salt fog chamber. By visual observation after tested, slightly surface erosion was observed on tested specimen surface near the energized end. Furthermore, increasing in hardness and reduction in hydrophobicity were measured on tested specimen comparing with new specimen. In addition, chemical analysis by ATR-FTIR was conducted in order to elucidate the chemical change of tested specimens comparing with new specimen. Physical and chemical results confirmed the experimental results as well.

***Keywords*—** Accelerated ageing test, HTV silicone rubber, housing material, salt fog test, surface erosion, polymer insulator.

I. Introduction

Recently, silicone rubber (cross linked PDMS) has been widely used as housing material for outdoor polymer insulators. Polymer insulators have better performance over conventional porcelain and glass types, such as being light weight, having better contamination performance due to surface hydrophobicity, possessing high impact strength, etc. Furthermore, also, additives and fillers are included in the silicone rubber in order to enhance the physical and chemical properties for improve the long-term performance under environment stresses. Alumina trihydrate ($Al_2O_3 \cdot 3H_2O$: ATH) is commonly filled to enhance tracking- and erosion-resistance of polymer. ATH decomposes into aluminum oxide and water when heated to the temperature above 200 ºC. The liberation of water is endothermic and the surface is cooled, which may extinguish an electric arc. Furthermore, the resistance against tracking is improved. Which coupling agents are compounds added to a chemical reaction. This improves the ability to connect between the filler and polymer matrix links each well of the filler and the polymer matrix to make silicone rubber properties, electrical better reduce the modulus and tensile strength increases of the material [1-4].

Due to silicone rubber insulator made of polymeric housing material, so ageing deterioration is not avoidable. Artificial salt fog ageing tests are widely conducted for evaluating anti-tracking and/or anti-erosion performance of housing materials for polymer insulators. Salt fog ageing test have been conducted in order to evaluate anti-ageing performance of silicone rubber housing material. The deterioration of their surfaces in the salt fog ageing test depended on many effect such as filler content and their configuration [5]. Furthermore, surface tracking and weather shed puncture occurred on the polymer insulator surface resulting from many effect such as surface wetting, degree of contamination and dry-band arcing[6],[7].

This paper presents salt fog ageing test results of silicone rubber was conducted based on IEC 61109 specifications [8].

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II. Experimental

A. Specimens

Specimens made of high-temperature vulcanized silicone rubber (HTV SiR) with/without alumina trihydrate (ATH: $Al_2O_3 \cdot 3H_2O$) having content 0%, 50%, 100% and 150% by weight were used in this experimental, as shown in Table I and Fig. 1. Configuration of tested specimen illustrated in Fig. 2. All specimen having 2 mm in thickness, 30 mm in width and 200 mm in length attached with metal electrodes on the both ends of each specimen were hung vertically in test chamber during test.

TABLE I
CHARACTERISTICS OF HTV SPECIMENS

Type	With surface treatment	ATH (wt %)
A	✓	0
B	✓	50
C	✓	100
D	✓	150

Type-A Type-B Type-C Type-D

Fig. 1 specimens

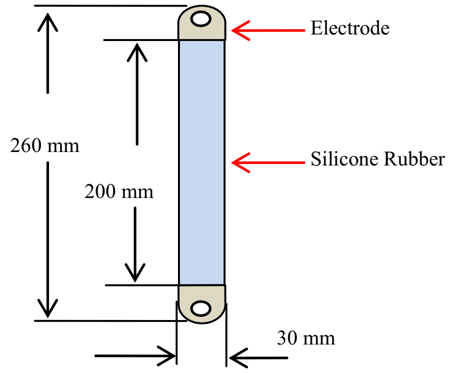


Fig. 2 Specimen configuration

B. Test Arrangement and Test Methods

A polyethylene tank having the volume 4.0 m^3 was used as the salt fog test chamber. During salt fog ageing tests, specimens were hung vertically in the test chamber. An ultrasonic humidifier was used as salt fog generation and salt fog was injected from the top of the test chamber. Fig. 3 shows the test arrangement and Fig. 4 shows the actual test chamber.

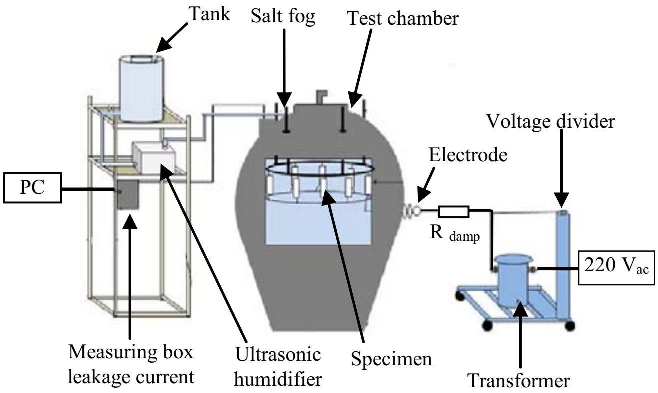


Fig.3 Test arrangement

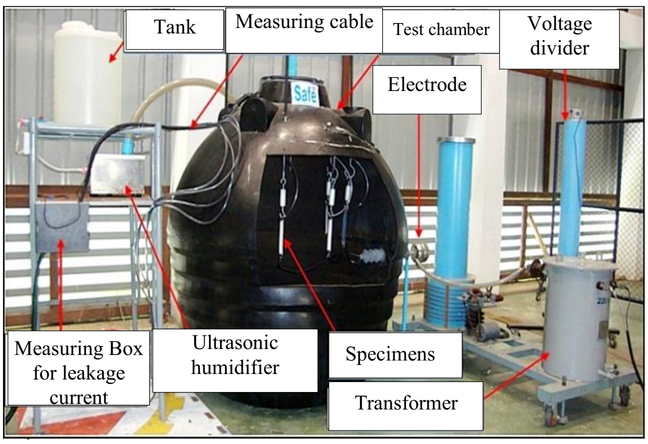


Fig. 4 Test chamber

C. Test Conditions

In this experimental, specimens were subjected to a constant voltage at voltage based on IEC 61109 specifications. The cyclic salt fog ageing test was conducted by injecting salt fog in to the test chamber for 8 hours and stopping it for 16 hours every day under ac high voltage 15 kV. The salt fog having injection 0.5 l/hr/m^3 was injected from the top of the chamber as test conditions shown in table II. All specimens were hung vertically in test chamber and were tested together. Leakage current measurement system is shown in Fig. 5. Individual specimens were connected to the leakage current measurement system via the shunt resistors of 100 Ω by means of coaxial cables. Leakage currents were continuously measured for individual specimens during the test. The leakage current was fed to an A/D board and converted to voltage. The leakage current data measured at the sampling rate of 10 kHz were recorded once every 60 s by postulating the data continuing for this period using the computer software developed via LabView.

TABLE II
TEST CONDITIONS [8].

Salt fog ageing test	Conditions
test chamber	4 m^3
test voltage	AC15 kV Continuously Applied
voltage stress	75 V/mm
salt fog generation	Ultrasonic Humidifier
salt fog injection rate	0.5 l/hr/m^3
salt fog salinity	10 kg/m^3 (16000 μS/cm)
test sequence in 24 hours	Salt fog injected for 8 hours and stopped for 16 hours

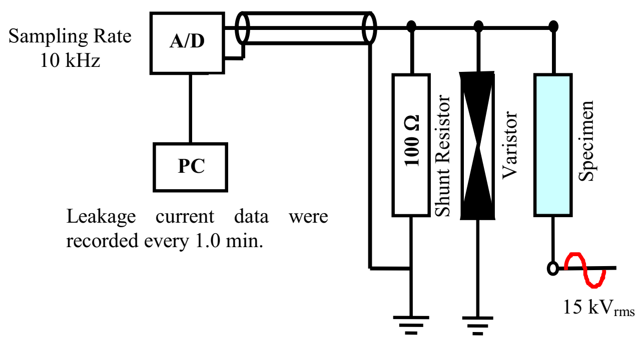


Fig. 5 Diagram of leakage current measuring system

III. Test Results and Discussion

A. Visual Observation

After 1000 hours salt fog ageing test, visual observation was conducted in order to inspect any change on tested specimen surface. Slightly surface erosion near the energized end, as shown in Fig. 5, was observed on specimens type A and type B. This may be caused by discharges on specimens surface during test due to higher electric field stress on such position. No surface erosion was observed on specimen type C and type D. The results confirm that the amount of ATH is effective to improve the anti-erosion performance of silicone rubber.

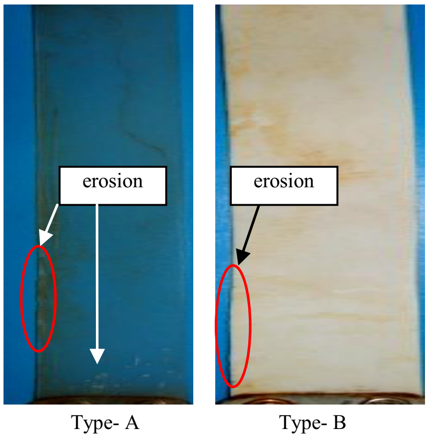


Fig.6 Specimens surface after 1000 hours.

B. Hydrophobicity

Surface discharges accompanying the contaminant deposit on the specimen surface led to a reduction in hydrophobicity. The occurrence of surface deterioration and contaminant deposition on the specimen surface may be related to the reduction in hydrophobicity and/or may be related to the amount of ATH. Reduction in hydrophobicity was evaluated by STRI criteria, as shown in Fig.7 [9,10]. Characteristics of hydrophobicity on tested specimen surface are shown in Fig.8. Hydrophobicity measurement results are shown in Table III.

Significant decreasing in hydrophobicity can be observed on thoroughly surface of the specimens. Extremely loss of hydrophobicity (HC 6) was observed on thoroughly surface of specimen type A. In the case of the specimen without ATH and without filler surface treatment, a larger reduction in hydrophobicity can be seen compared with the other specimens having ATH. Such results indicate that ATH filler and filler surface treatment can delay the reduction of hydrophobicity on silicone rubber surface. Also, extremely loss of hydrophobicity (HC 6) at energized end was observed on all specimen surfaces. Such results indicate that high electric field stress can accelerate the reduction of hydrophobicity on the specimen surface.

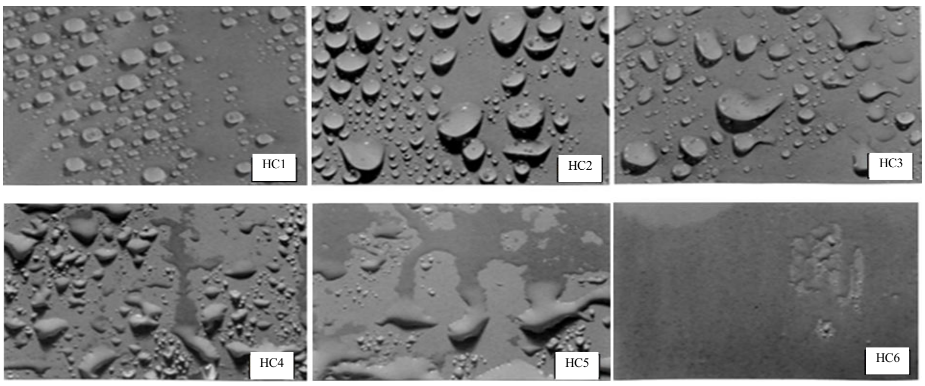


Fig. 7 Characteristics of the sample surface HC1-HC6

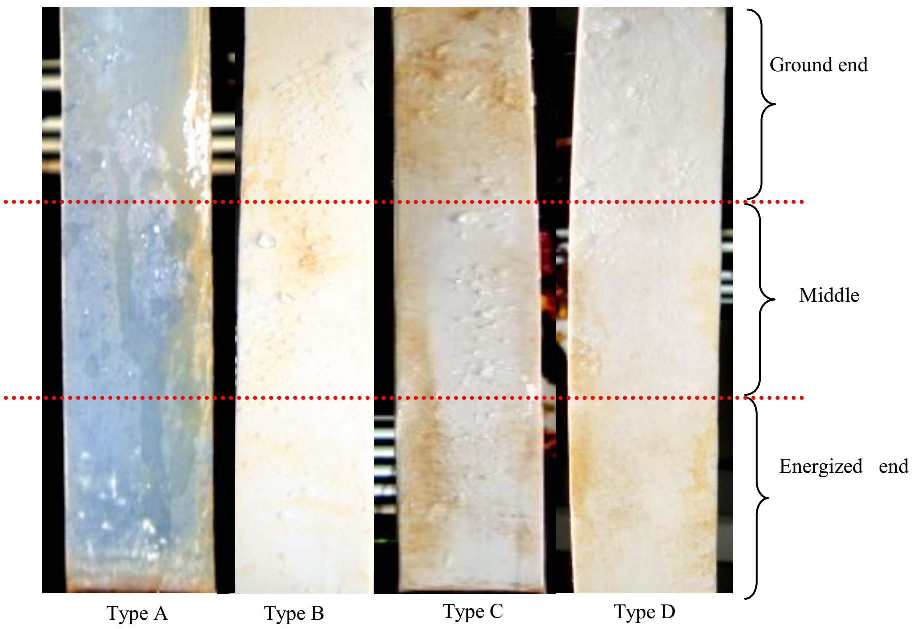


Fig. 8 Characteristics of hydrophobicity on surface

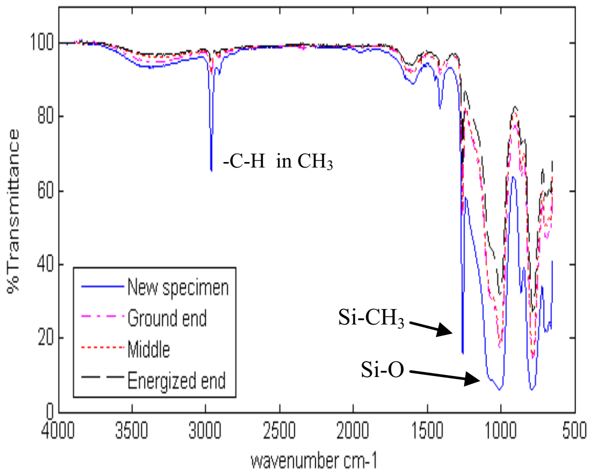
TABLE III
REDUCTION OF HYDROPHOBICITY

Position	Specimen			
	Type-A	Type-B	Type-C	Type-D
Ground end	HC6	HC4	HC4	HC4
Middle	HC6	HC4	HC4	HC5
Energized end	HC6	HC6	HC6	HC6

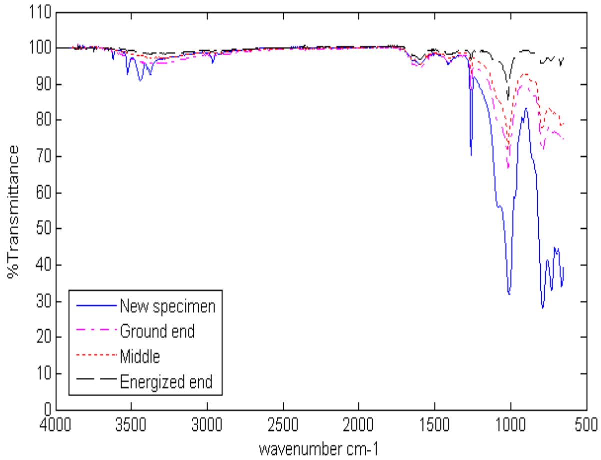
C. *ATR-FTIR*

Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR) technique was used to investigate the molecular structural changes at the specimen surface. All tested specimen were cleaned by ethyl alcohol to remove deposition of salt layer. Then, each tested specimen was cut in to three small pieces, energized end, middle and ground end portions. The absorption takes place at different frequencies, which is displayed by the IR spectra. IR spectra are expressed in wave numbers versus their intensities [11].

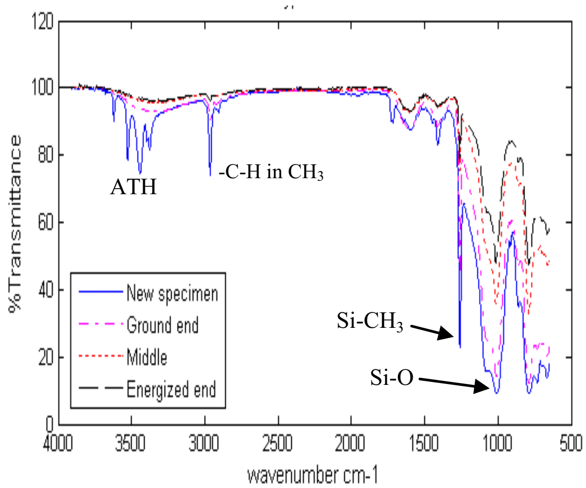
The chemical bonds of interested chemical structure are bonding side chain (Si-CH_3) with wave number 1261 cm^{-1}, backbone (Si-O) with wave number 1041 cm^{-1}. Decreasing of Si-CH_3 means separation of side chain and decreasing of Si-O refers to the separation of the back bone of polydimethylsiloxane bonding changes. The changes in the absorption peak of Si-CH_3 and Si-O bonds show degree of specimen surface deterioration. FTIR spectra of specimens and %Transmittance of specimens after 1000 hrs salt fog test are shown in Fig.9 and Table IV.



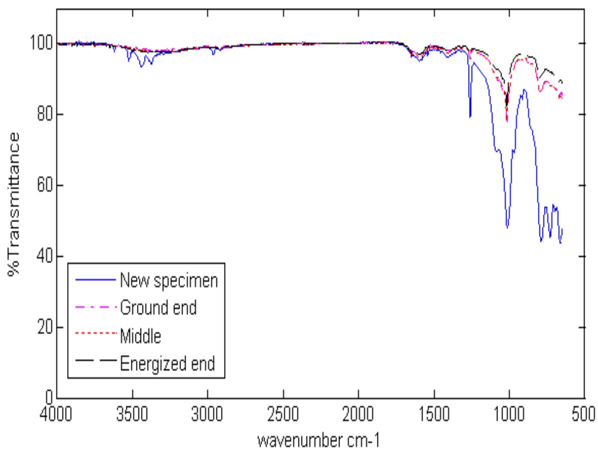
(a) Type-A



(c) Type-C



(b) Type-B



(d) Type-D

Fig. 9 FTIR spectra of test specimens

TABLE IV
SPECIMEN SURFACE ANALYSIS RESULTS BY ATR-FTIR

Type	Vibration	Wave No. cm^{-1}	%Transmittance			
			New specimens	Ground end	Middle	Energized end
A	$Si\text{-}CH_3$	1261	81.79 (100%)	45.31(55.4%)	43.37(53.23%)	31.74(38.81%)
	Si-O	1041	92.00 (100%)	72.09(78.36%)	70.26(76.37%)	58.27(63.34%)
B	$Si\text{-}CH_3$	1261	75.52 (100%)	53.60(70.97%)	24.28(25.42%)	20.70(21.67%)
	Si-O	1041	85.79 (100%)	77.43(90.25%)	54.07(63.02%)	40.41(47.10%)
C	$Si\text{-}CH_3$	1261	11.93 (100%)	11.91(99.83%)	6.82(57.17%)	2.92(24.48%)
	Si-O	1041	28.28 (100%)	24.16(85.43%)	18.3(64.71%)	6.34(22.42%)
D	$Si\text{-}CH_3$	1261	20.53 (100%)	3.96(19.29%)	4.14(20.17%)	2.96(14.42%)
	Si-O	1041	36.56 (100%)	13.33(36.46%)	12.80(35.01%)	9.77(26.72%)

D. SEM

A scanning electron microscope (SEM) was used for inspecting topographies of the specimen surface at high magnifications. Although visual observation by naked eyes was conducted to find out any deterioration on the specimen surface, but microstructural changes or invisible deterioration could not be found out by naked eyes. SEM can produce photo-micrographs of fracture surfaces of a specimen surface. A comparison of the photo-micrographs between the aged and new specimen can provide a comparative indication of the surface conditions. Specimens were gold coated prior to examination [11]. Severe micro-erosion was observed on the energized end of tested specimen type-A comparing with the other type, as shown in Fig. 10.

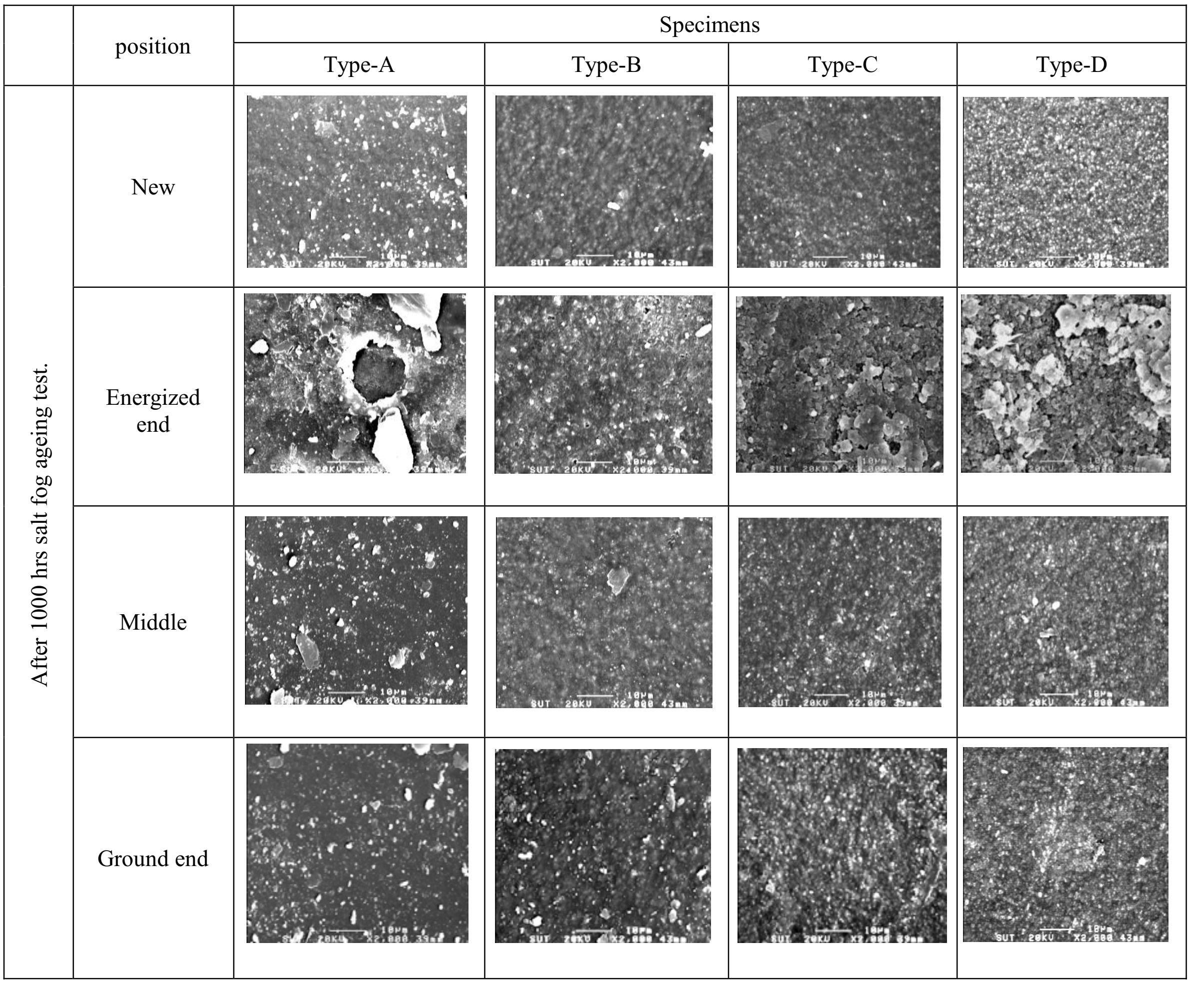


Fig. 10 SEM analyzes of the specimens surface.

E. Hardness

Hardness was measured to examine the chemical reactions, e.g. depolymerization and oxidative crosslinking, of the specimen surface. It is known that depolymerization of the backbone by thermal scission of siloxane bond causes softening of the silicone rubber whereas oxidative crosslinking causes hardening of the silicone rubber. The specimen surfaces were cut into small pieces at three portions, ground end, center and energized end, of individual specimens and surface hardness was measured. Hardness of tested specimens after 1000 hours salt fog ageing test, was measured with a shore A scale durometer system based on the ISO 868- Shore hardness[12]. Slightly increasing in hardness was obtained from the measurement result as shown in Table V. However, no significant different incessantly hardness was observed.

TABLE V
HARDNESS OF THE SPECIMEN BY SHORE A SCALE

Type	Shore A			
	Ground end	Middle	Energized end	New
A	67.04	65.68	67.2	66
B	77.6	77.28	80	76.64
C	84.64	84.24	83.92	82.88
D	90.96	89.76	90.24	89.36

F. Leakage Current

Leakage current flowing along the specimen surface was continuously measured and was recorded every 1 minute by leakage measuring software via LabView. Typical leakage current waveforms in each test cycle during salt fog injection are shown in Fig.11. The magnitudes of the leakage current increased gradually as the number of test cycles increased. The degree of the surface deterioration correlated with magnitudes of the leakage current.

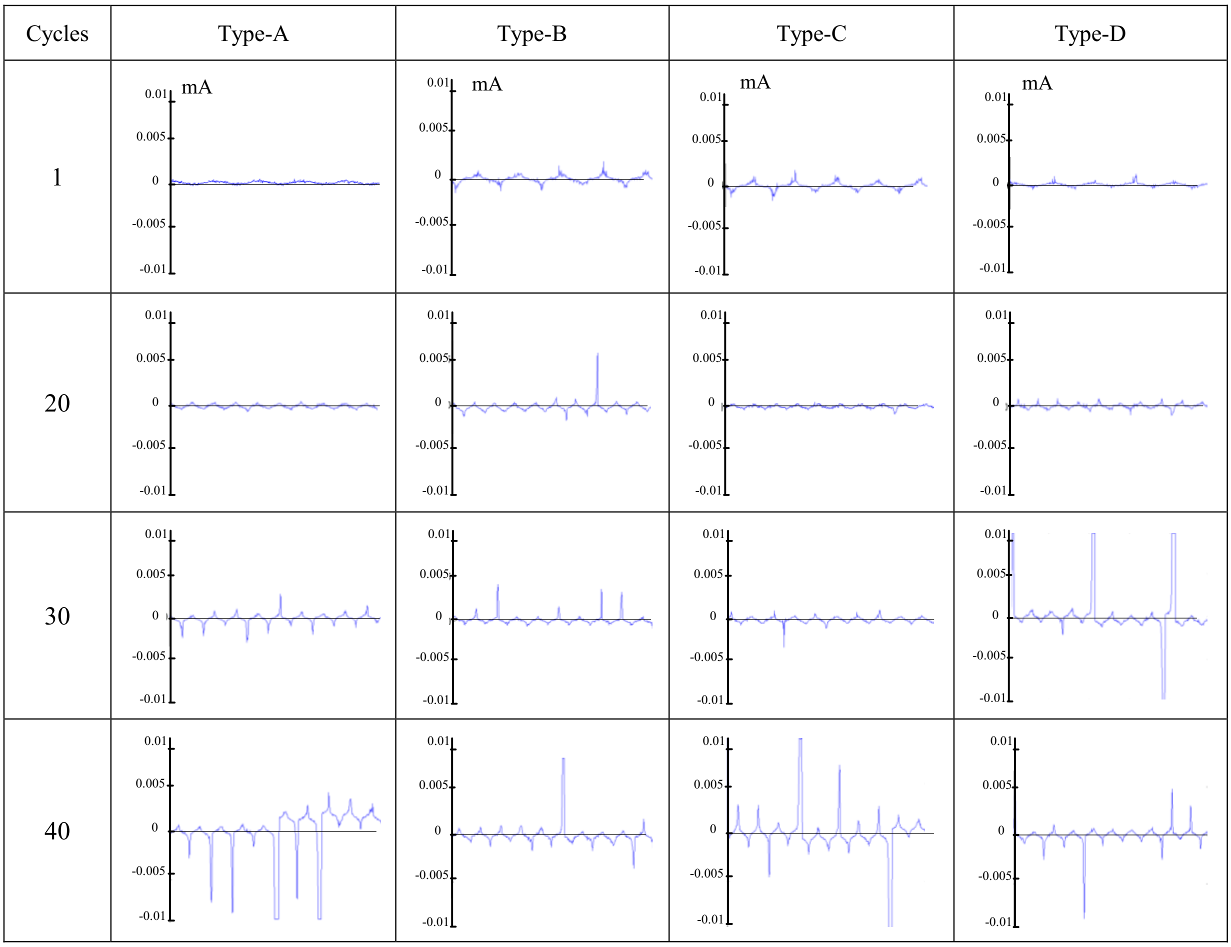


Fig. 11 Leakage current waveform (1 cycle is 24 hrs).

IV. CONCLUSION

Study of ageing deterioration of silicone rubber housing material for outdoor polymer insulator based on IEC 61109. The following conclusions were given.

1.) Electrical stress and pollutants deposited on the surface of specimens caused ageing deterioration of specimens surface.
2.) Slightly erosion was observed on the specimens type-A (ATH 0 pph) and Type-B (ATH 50 pph).
3.) Extremely reduction of hydrophobicity (HC6) was observed on the 4 types specimens near the energized end.
4.) The chemical analysis by ATR – FTIR also confirmed surface deterioration of silicone rubber housing material for insulator in the salt fog ageing test.

ACKNOWLEDGMENT

The Author would like to thank you Suranaree University of Technology and National Research Council of Thailand for kind financial support.

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