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Comparison Ageing Deterioration of Silicone Rubber Outdoor Polymer Insulators in Artificial Accelerated Salt Fog Ageing Test

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Abstract**—**This paper presents the experimental results of silicone rubber outdoor polymer insulators in salt fog ageing test based on IEC 61109. Specimens made ofHTV silicone rubber with ATH content having three different configurations, straight shedsalternated sheds, and incline and alternate sheds, were tested continuously 1000 hrs.in artificial salt fog chamber. Contamination level, reduction of hydrophobicity and hardness measurement were used as physical damaged inspection techniques to evaluate degree of surface deterioration. In addition, chemical changing of tested specimen surface was evaluated by ATR-FTIRto confirm physical damaged inspection. After 1000 hrs.of salt fog test, differences in degree of surface deterioration were observed on all tested specimens. Physical damaged inspection and chemical analysis results confirmed the experimental results as well.

Keywords**—**Ageing deterioration,Silicone rubber, Polymer Insulator, Salt fogageing test.

I. Introduction

POLYMER insulator for transmission line have significant advantages over porcelain and glass insulator, especially for ultra-high voltage (UHV) transmission line.The basic design of a polymer insulator is as follows; Afibre reinforced plastic (FRP) core, attached with two metal fittings, is used as the load bearing structure.Silicone rubber is mainly used for polymer insulators or composite insulators as housing material.Polymer insulators are quite different from the conventional porcelain and glass insulators. The advantages of silicone rubber polymer insulators are as follows[1,2].

Silicone rubbers have low surface tension energy and thereby maintain a hydrophobic surface property, resulting in better insulation performance under contaminated and wet conditions.Polymer insulators have higher mechanical strength to weight ratios compared with porcelain or glass insulators which enables the reduction of costs for construction and maintenance of transmission or distribution lines.Polymer insulators are less prone to serious damage from vandalism such as gunshots. However, the disadvantages of polymer insulators are as follows:Polymer insulators are made of organic materials and so subjected to chemical changes on the surface due to weathering and dry band arcing.Polymer insulators may suffer from erosion and tracking which may lead ultimately to failure of the insulators.Long term reliability is unknown and life expectancy of polymer insulators is difficult to estimate.Faulty insulators are difficult to detect.When a polymer insulator is employed and used in service for a long period and exposed under high voltage to weather, pollution and other environmental stresses, changes in the characteristics of the polymer insulator cannot be avoided because it is made of organic materials. These changes can be physical, chemical or phisico-chemical, and may lead to a serious electrically and mechanically failures. These long-term changes in characteristics are generally classified as ageing.

Marungsri et al.[3] studied the effect of surface treatment on ageing deterioration of silicone rubber housing material in salt fog ageing test. After tested, they found that erosion was observed only on the specimen without ATH and without surface treatment and slight erosion was observed on the specimen with ATH 50 and without surface treatment.

Sundararajan et al. [4] studied the modified IEC 5000-h multistress ageing test of 28 kV thermoplastic elastomeric insulators. This studied found that erosion and cracking or tracking were observed on the surface specimen.

Ageing deterioration is major problem of siliconerubber housing material for polymer insulator.The salt fog ageing test has been most widely conducted on insulators and arrester for evaluating the anti-tracking and anti-erosion performance of housing material for polymer insulators [5-10].

This paperpresents salt fog ageing test to examine the deterioration and erosion performance of silicone rubber housing material for polymer insulator. The test was based fundamentally on IEC 61109-1992 [10].

II. Test Arrangement

A. Specimen

Three-type specimens, having straight sheds,alternated sheds and incline alternated sheds, were used in this experimental. Insulator housing made of HTV silicone rubber with ATH (Alumina trihydrate). Dimensions and configurationsof tested specimen are illustrated in Fig. 1.

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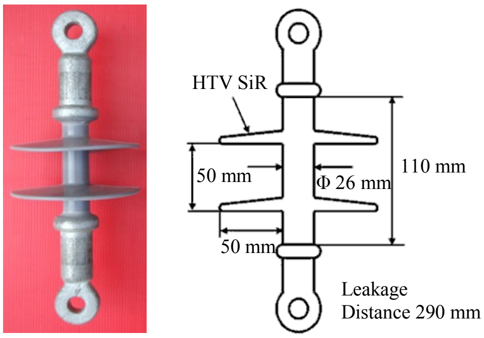
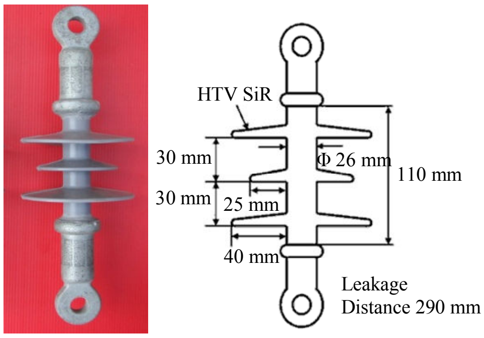
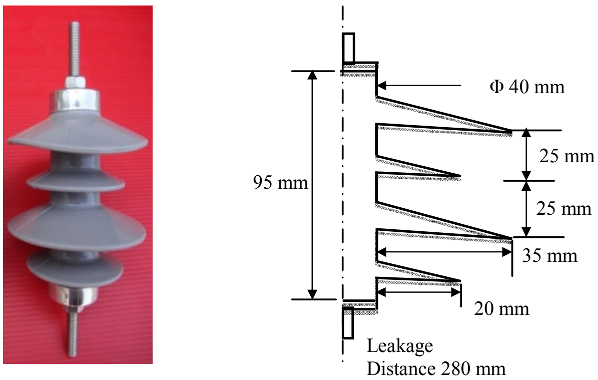


(a) Straight shed



(b) Alternateshed with small trunk



(c) Inclined and alternateshed with large trunk.

Fig. 1 Configuration and dimension of specimen

B. Test Method

A polyethylene tank having the volume 4.0 m^3 was used as the salt fog test chamber. During salt fog ageing tests, all specimens were hung vertically in the test chamber. Salt fog was generated by ultrasonic humidifier. Test arrangements are shown in Fig. 2 and test chamber is shown in Fig. 3 respectively.

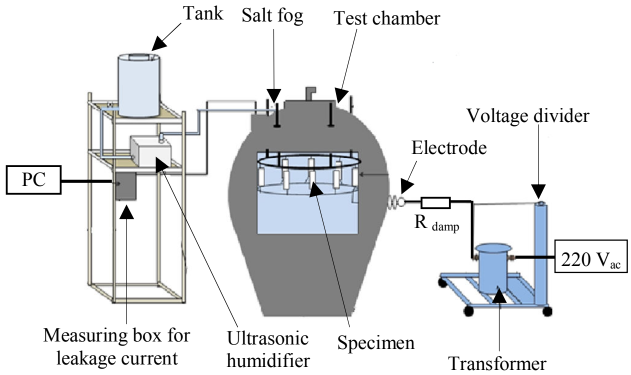


Fig. 2 Test arrangement for salt fog ageing test

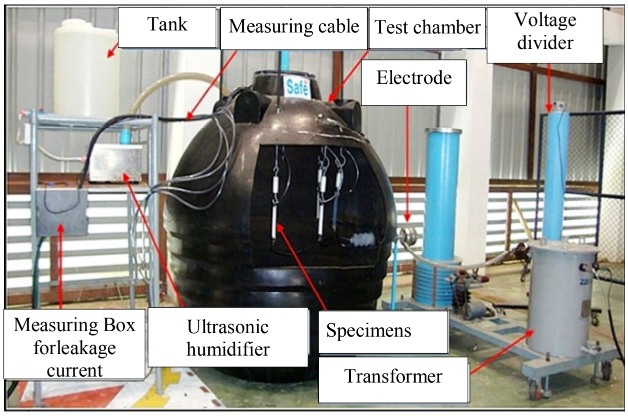


Fig. 3 Illustration of test chamber

C. Test Conditions

Test was conducted continuously for 1000 hrs based on IEC 61109-1992[11]. The cyclic salt fog ageing test was conducted by injecting salt fog for 8 hours and stopping it for 16 hours every day under AC 15 kV.All specimens were hung vertically in test chamber and weretested together under the conditions show in Table I and test cycle shown in Table II.Leakage current measuring system is shown in Fig. 4. Individual specimens were connected to the leakage current measurement system via the shunt resistors of 100 Ω by means of coaxial cables.

TABLE I
TEST CONDITIONS

Test Chamber	4 m^3
Test Voltage	AC 15 kV Continuously Applied
Voltage Stress	51.7 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 injectedfor 8 hoursand stopped for 16 hours.

TABLE II
TEST CYCLE

Aging period (hr)	0-8	8-24
Voltage		
Salt fog		

Leakage currents were continuously measured for individual specimens during the test [12]. Leakage current was fed to an A/D board at the sampling rate of 10 kSampling/secand was recorded once every 60 sec by postulating the data continuing for this period using the computer software developed via LabView®.

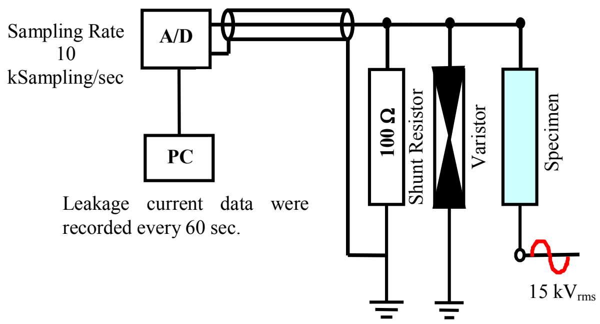


Fig. 4 Diagram of leakage current measuring system

III. TEST RESULTS AND DISCUSSIONS

Silicone rubber polymer insulators having different configurations were tested together based on IEC 61109-1992in order to elucidate degree of surface ageing. Physical inspection and chemical analysis such as visual observation, contamination degree measurement, hydrophobicity evaluation,hardness measurement andATR-FTIR analysis were conducted on tested specimen after 1000 hrs salt fog ageing test.

A. Visual Observation

During salt fog ageing test,many discharge activities along surface of tested specimen during salt fog injection were observed. As shown in Fig.5, many discharge activity were observed. Mainly discharge activities were observed on the trunk between sheds of all testing specimens. However, large discharge was also observed on upper shed surface of incline and alternate shed specimen. Yellow light for dry band arcing was observed. Such discharge indicated that large dry band arc discharge occurred on the trunk surface between sheds.Small discharge activity or corona discharge was also observed on trunk surface between sheds.

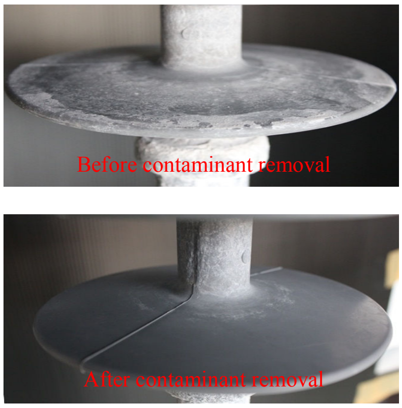
In case of straight sheds specimen, more contaminant was observed on trunk surface than on shed surface, as shown in Fig. 6 (a). Obviously surface erosion was observed on trunk surface when comparing with shed surface. Parting line tracking was only observed on trunk portion. Also, severely tracking was observed on trunk surface at energized end, as shown in Fig. 6 (c).

In case of alternate sheds specimen, more contamination was observed on trunk surface comparing with shed surface same as straight shed specimen. Obviously surface erosion was observed on trunk surface. Slightly tracking of parting line was observed on trunk portion. No severely tracking and erosion were observed when comparing with straight shed specimen.

(a) Straight Shed. (b) Alternate Shed with small trunk. (c) Inclined and Alternate Shed with large trunk.

Fig. 5 Discharge Activities

(a) Straight shed



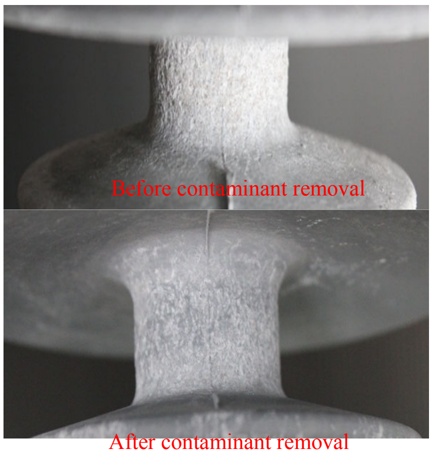
(b) Upper surface of near energized

(c) Energized end trunk

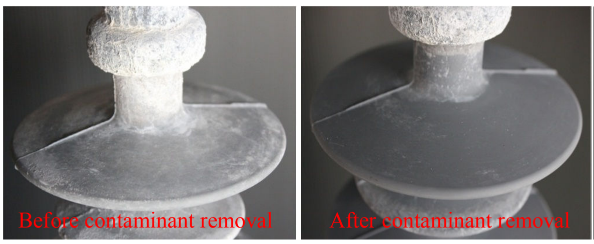
(d) Ground end trunk

Fig. 6 Surface damagedstraight shed specimen

(a) Alternate shed



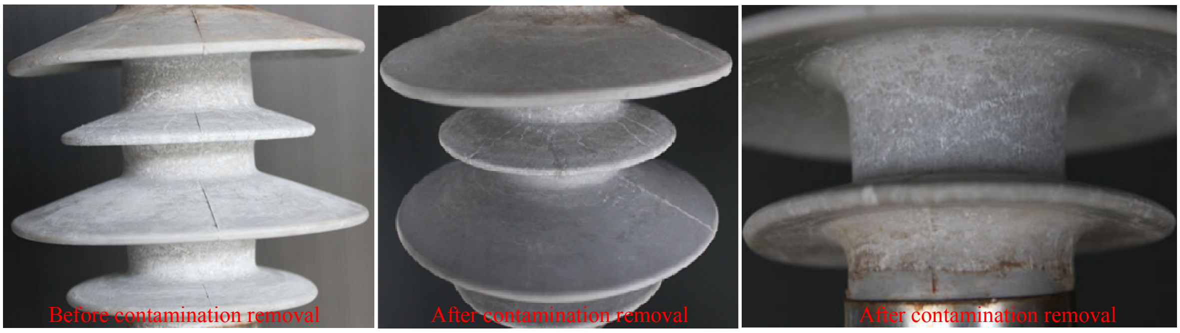
(b) Erosion on trunk



(c) Upper surface of near ground end shed

(d) Tracking on trunk parting line near energized end

Fig. 7 Surface damaged of alternate shed specimen



(a) Incline and alternate shed (b) Tracking on trunk near energized end

(c) Salt layer on shed surface. (c) Erosion on shed surface.

Fig. 8 Surface damage of tested specimens

In case of incline and alternate sheds specimen, as shown in Fig. 8, contaminant was observed on the whole surface. No different in amount of contaminant on shed surface and trunk surface was observed. Such occurrence may be explained by the specimen having smaller shed diameter and larger trunk diameter when comparing with those two type specimens. Slightly surface erosion and tracking was observed on all shed and trunk surfaces.

B. Contamination Degree

Contamination degree was determined by measuring salt deposit density (SDD). The measurement procedures were based on IEC 60507 [13]. After 1000hrs test, contaminants were observed on the trunk surfacemore than on the shed surface of all tested specimen. More contaminants were also observed on the eroded portion surface. Table III shows the SDD measurement results on the whole surface of each specimen after 1000hrs salt fog ageing test. The formulas for SDD calculation are as follows.

$$SDD = \frac{S_a}{A} \quad (1)$$

$$S_a = (5.7 \times 10^{-4} \sigma_{20})^{1.03} \quad (2)$$

$$\sigma_{20} = \sigma_\theta [1 - b(\theta - 20)] \quad (3)$$

where
θ is solution temperature (^{0}C),
σ_θ is the volume conductivity at temperature of θ ^{0}C (S/m),
σ_{20} is the volume conductivity at temperature of 20 ^{0}C (S/m),
b is the factor depending on temperature of θ ^{0}C,
Sais Salinity (mg/cm^3),
SDD is salt deposit density (mg/cm^2),
V is Volume of distilled water (cm^3),
A is Area of the specimen surface for collecting contaminations (cm^2).

Significant different in contamination degree was notmeasured.

TABLE III
CONTAMINATION DEGREE

Specimen type	Sa (mg/cm^3)	SDD (mg/cm^2)
Straight sheds	0.1209	0.0652
Alternate sheds	0.1825	0.1088
Incline and alternate sheds	0.2008	0.0997

C. Hydrophobicity

Loss of silicone rubber surface hydrophobicity by electrical and environmental stresses could accelerate the surface deterioration. The loss of hydrophobicity gradually enhances surface wetting and forms water films having high conductivity. This induces leakage current and dry band arc

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discharges on the polymer insulator surface. Reduction in hydrophobicity of tested specimen surface comparing with new specimen surface indicates degree of surface deterioration.

In this study, hydrophobicity classification guide by Swedish Transmission Research Institute (STRI), as illustrated in Fig. 9, was used to evaluate hydrophobicity level on the tested specimen surfaces. Hydrophobicity measurement results are shown in Table IV. Reduction in hydrophobicity on all tested specimen surfacewas measured. More reduction in hydrophobicity was measured on trunk surface comparing with shed surface of all tested specimens.

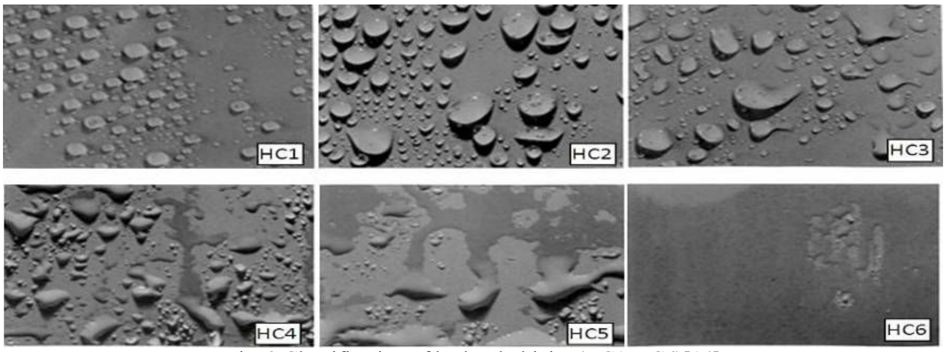
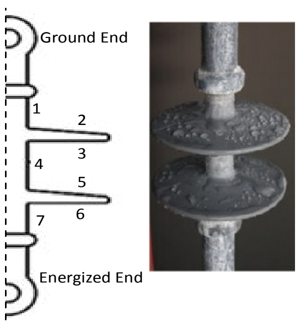
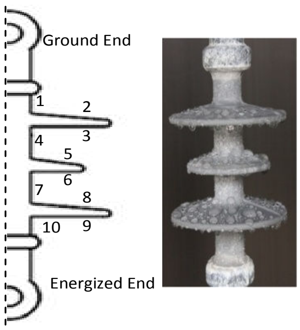
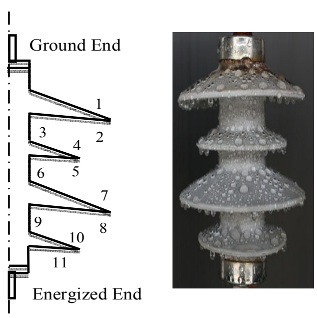


Fig. 9 Classification of hydrophobicity (HC1-HC6)[14]

TABLE IV
HYDROPHOBICITY BY STRI CRITERIA

Position	HC	Straight Shed Position	Position	HC	Alternated Shed Position	Position	HC	Incline and alternate shed Position
1	HC 5		1	HC 4		1	HC 2	
2	HC 5		2	HC 5		2	HC 1	
3	HC 2		3	HC 2		3	HC 3	
4	HC 4		4	HC 4		4	HC 2	
5	HC 5		5	HC 5		5	HC 1	
6	HC 2		6	HC 3		6	HC 3	
7	HC 5		7	HC 4		7	HC 2	
			8	HC 4		8	HC 2	
			9	HC 2		9	HC 3	
			10	HC 4		10	HC 4	
						11	HC 4	

D. ATR – FTIR Analysis

It is well known that possible chemical reactions by leakage current and dry band arc discharges on polymer insulator surface which lead to surface deterioration are as follows[15]:

1. Scission and/or interchange of side chains (CH_3 groups) or backbones (Si–O groups) of PDMS.
2. Hydrolysis of side chains or backbones of PDMS.
3. Oxidation of side chains or crosslinking of backbones of PDMS.

Attenuated total reflection fourier transform infrared spectroscopy (ATR – FTIR)is a surface chemical analysis technique that provides information about the chemical bonding or molecular structure of materials. The wave numbers showing noticeable change along with their functional groups found in the specimen are shown in Table V. Reduction in magnitude of chemical bonding spectra at wavenumber 1270-1255 cm^{-1} indicates scission of side chainsof PDMS. Reduction in magnitude of chemical bonding spectra at wavenumber 1100-1000 cm^{-1} indicates scission of backbones of PDMS.

In this study,chemical boding spectra of new and tested specimen was analyzed.Typical ATR –FTIR analysis results of tested specimen at position 2 comparing with new specimen are shown in Fig. 10,Fig. 11 and Fig. 12, respectively. ATR – FTIR analysis results for all portion of tested specimen are shown in Table VI.

TABLE V
FUNCTIONAL GROUPS FOUND IN THE SPECIMEN BY ATR-FTIR

Functional Groups	Wave numbers (cm^{-1}), SiR	comments
OH	3600-3200	Stretching, hydrogen bonding from ATH
CH in Methyl	3300-2850	Stretching, present in most organic molecules
$Si-CH_3$	1270-1255	Asymmetric C_3 deformation
Si-O-Si	1110-1000	Asymmetric stretching

International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:5, No:12, 2011

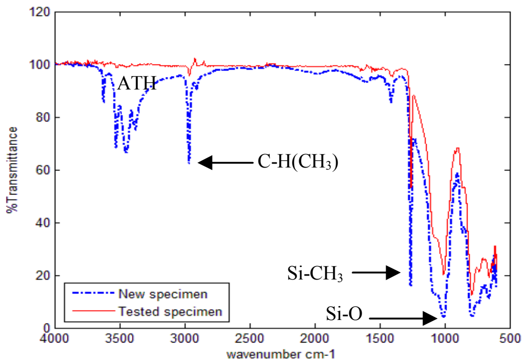


Fig. 10 ATR – FTIR Analysis Result of Straight shed Specimen (Position 2).

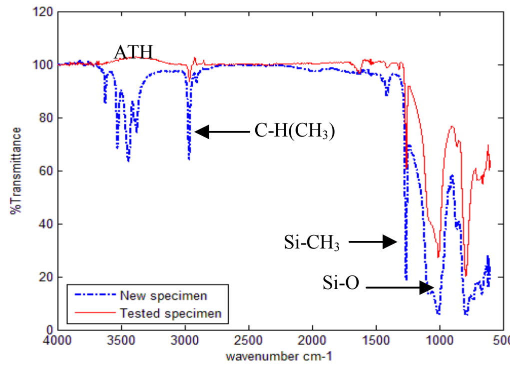


Fig. 12 ATR – FTIR Analysis Result of Straight shed Specimen (Position 2)

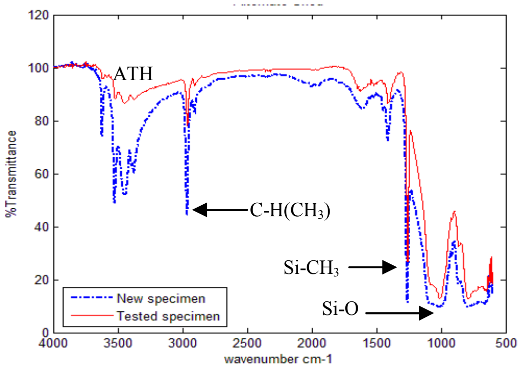
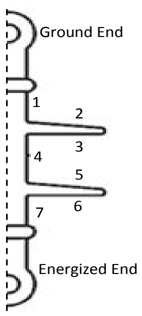
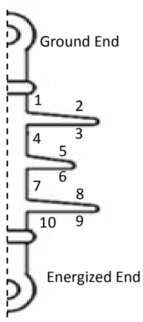
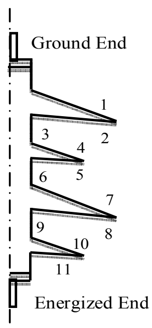


Fig. 11 ATR – FTIR Analysis Result of Alternated shed Specimen (Position 2)

TABLE VI
SURFACE ANALYSIS RESULTS BY ATR-FTIR

Position	Straight Shed %T ($Si-CH_3$)	Straight Shed %T (Si-O)	Straight Shed Position	Position	Alternate Sheds %T ($Si-CH_3$)	Alternate Sheds %T (Si-O)	Alternate Sheds Position	Position	Incline and Alternate Sheds %T ($Si-CH_3$)	Incline and Alternate Sheds %T (Si-O)	Incline and Alternate Sheds Position
1	20.186	38.898		1	47.889	57.452		1	26.066	42.799	
2	53.544	73.334		2	14.169	15.598			28.297	43.613	
3	47.059	74.128		3	24.483	43.643			18880	28.753	
4	11.914	19.588		4	16.702	23.474			19.765	29.146	
5	67.244	83.151		5	12.832	18.301			22.473	22.698	
6	29.316	45.675		6	11.478	9.224			18.964	28.598	
7	21.139	35.196		7	20.331	32.177			25.580	41.673	
				8	11.575	15.616			33.006	47.020	
				9	10.379	8.159			21.212	29.724	
				10	46.513	72.793		10	19.591	24.533	
								11	22.907	21.194	

E. Hardness

It is well known that depolymerization of silicone rubber by thermal scission of the siloxane bond caused softening of silicone rubber. Butincreasing in hardness of silicone rubber indicated the oxidation crosslink ofPDMSchains.After 1000 hrs salt fog test, hardness was measured on tested specimen surface comparing with new specimen surface. Measure results method base on the ISO 868 – ShoreHardness [16]. The measurement results are shown in Table VII. Significant increasing in hardness was measured on all tested specimen surface near energized end portion. From measurement results, more oxidation crosslink may be occurred on such portion.

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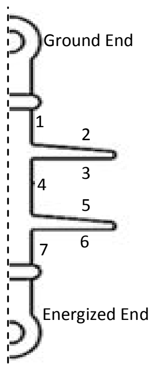
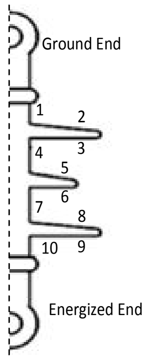
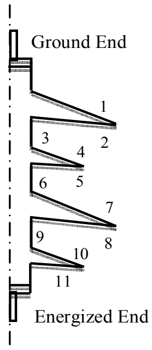
Vol:5, No:12, 2011

TABLE VII
HARDNESS MEASUREMENT RESULTS

Position	Straight Sheds		Position	Alternated Sheds		Position	Incline and Alternate Sheds	
	Hardness	Position		Hardness	Position		Hardness	Position
New	59.60		New	52.88		New	42.48	
1	66.16		1	63.04		1	53.36	
2	68.00		2	58.48		2	49.44	
3	68.40		3	58.00		3	55.84	
4	70.56		4	67.44		4	56.16	
5	74.56		5	72.08		5	56.96	
6	75.84		6	66.56		6	48.08	
7	66.40		7	71.36		7	59.04	
			8	74.00		8	57.60	
			9	74.32		9	56.88	
			10	69.84		10	58.00	
						11	58.64	

F. Leakage Current and Cumulative Charge.

Leakage current flowing along the specimen surface was continuously measured and was recorded every 60sec. by leakage current measuring software via LabView. Typical leakage current waveforms in each test cycle during salt fog injection are shown in Fig.13. 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.

Surface cumulative charge was calculated from leakage current measurement results. The cumulative charges are shown in Fig. 14. The highest cumulative charge was obtained from the alternate sheds specimen. The lowest cumulative charge was obtained from the straight sheds

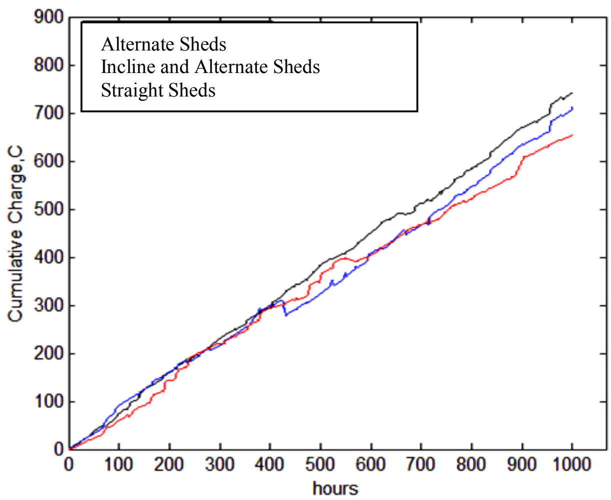


Fig. 14 Cumulative Charges

IV. CONCLUSION

Salt fog ageing test have been conducted on silicone rubber polymer insulators based on IEC 61109. The following conclusions are given.

1.) Obviously, surface erosion and surface tracking were observed on the trunk surface of all type specimens. However, severest surface erosion was observed on specimen having straight sheds comparing with other two type specimens.
2.) Larger reduction in hydrophobicity was measured on trunk surface comparing with shed surface of all type specimens. But no significant difference in reduction of surface hydrophobicity was observed when comparing three type specimens.
3.) Surface hardness, ATR-FTIR analysis results, and leakage current measurement results confirmed the difference in degree of surface deterioration of silicone rubber polymer insulator in the salt fog ageing test.

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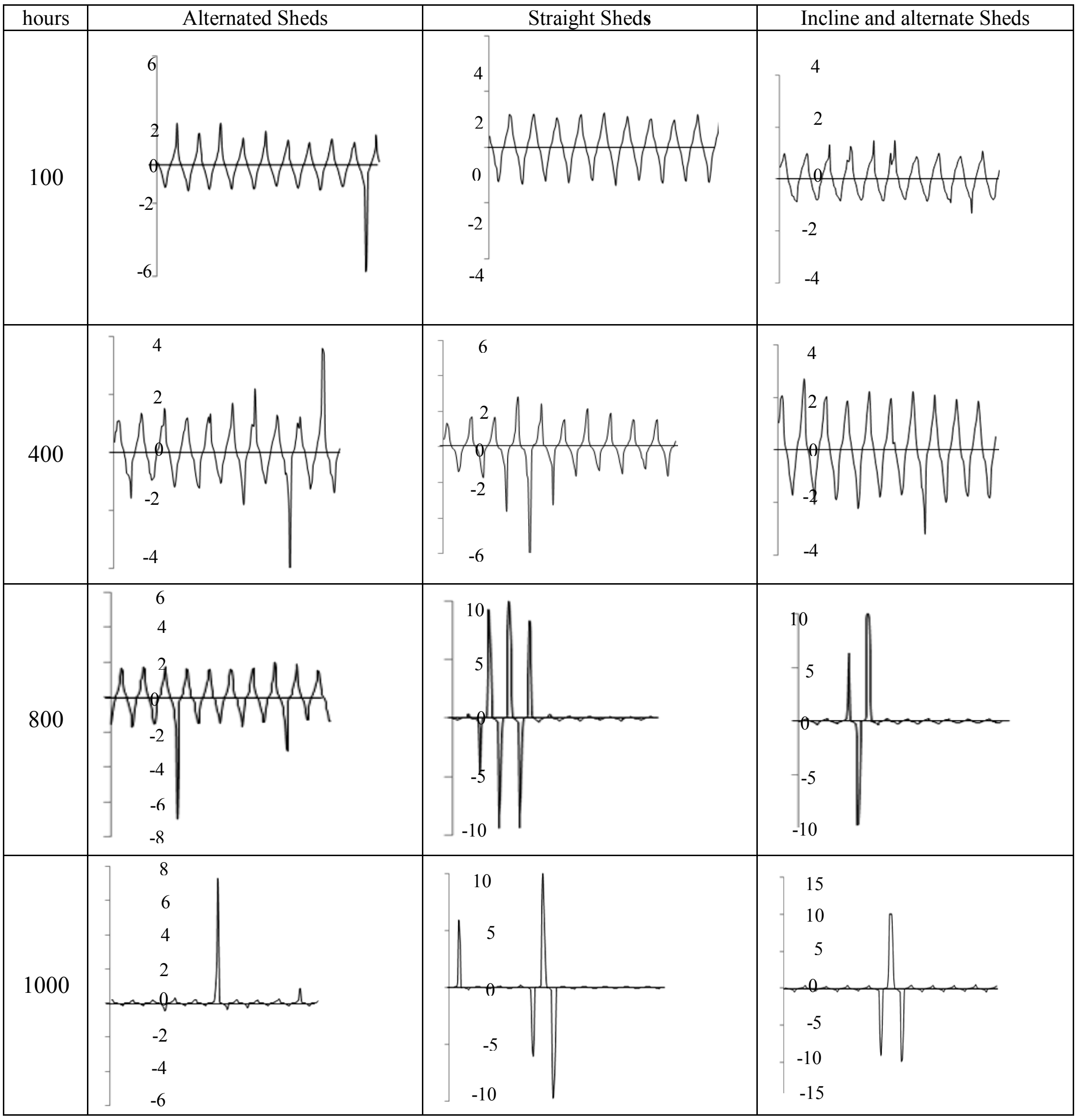

Fig. 13 Leakage Current (mA)

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