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

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Abstract**—**This paper presents the comparison ageing deterioration of silicone rubber housing material for outdoor polymer insulators by using salt fog ageing test based on IEC 61109 and outdoor exposure test.Four types of high temperature silicone vulcanized silicone rubber sheet with different amount of ATH were used as testing specimen. For salt fog ageing test, the specimens were tested continuously 1000 hours with energized in test chamber. For outdoor exposure test, the specimens were hung continuously 18 months without energized. Physical and chemical analyses were conducted to evaluate degree of ageing deterioration of tested specimens. Slightly surface erosion was observed on specimen surface after salt fog ageing test and no erosion was observed on surface of outdoor exposure specimen. However, comparable degree of ageing deterioration can be seen from surface analysis results.

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

I. INTRODUCTION

SILICONE rubbers using in the area of high voltage insulation are mainly based on polydimethylsiloxane (PDMS). PDMS is the synthesis polymer commonly used in silicone rubber formulations for high voltage outdoor insulation applications. PDMS consists of an inorganic backbone of alternating silicon and oxygen atoms [1]. Methyl groups are attached to the silicon atoms forming the repeating unit in the polymer. The structural characteristics of PDMS are important for its properties. The hydrophobic character of PDMS is due to the close packing of the methyl groups, which under normal conditions point outward from the surface and provides the polymer with a hydrophobic skin. The molecular structure of siloxane chain is helical structure. Six Si–O bonds are included in one turn of the helix. Thus, the surface of silicone polymer is covered by a nearly hydrophobic methyl group, and the surface energy is low. Four structural characteristics of PDMS account for its surface properties: (1) the low intermolecular force between methyl groups, (2) the unique flexibility of the siloxane bond, (3) the high strength of the siloxane bonds and (4) the partial ionic nature of the siloxane bond.

These characteristics give PDMS a number of properties that make the material suitable for the production of high voltage outdoor polymer insulators[2].

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(a) Good dielectric properties.
(b) Excellent resistance to weathering.
(c) Hydrophobic surface properties.
(d) High thermal and oxidative stability.

Silicone rubber compounds retain hydrophobicity better than ceramic or glass, especially in coastal regions and contaminated areas. Polymer insulators are lightweight, and they can significantly reduce losses from breakage and vandalism.Furthermore, additives and fillers(Alumina trihydrate(ATH):$Al_2O_3{\cdot}3H_2O$) are included inthe silicone rubber for improve the long-term performance under environment stresses [1-5].

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. Polymers unlike ceramic and glass, are organic materials that can degrade under variety of stresses, so ageing deterioration is not avoidable [6].These long-term change in characteristics are generally classified as ageing.

The most concern in long-term performance of polymer insulators is the surface deterioration of housing material, which may reduce its ability to prevent water ingress to the FRP core. Loss of surface hydrophobicity on silicone rubber leads to surface deterioration. The loss of hydrophobicity during outdoor application by electrical and environmental stresses gradually enhances surface wetting and forms contaminated water films having high conductivity. This induces leakage current on the polymer insulator surface. Niemi and Orbeck [7] suggested that failure of polymer insulators is initiated by large leakage currents and dryband arcing. Gorur et al. [8] who also suggested that ageing deterioration of silicone rubber housing materials in outdoor high voltage insulation applications started with the loss of hydrophobicity due to the dry band arcing. Many researchers tried to investigate the correlation among leakage current, discharge activity, surface wetting and ageing deterioration of housing material[9-22]. Furthermore, effects of UV radiation [23,24], thermal [18,25], acids [26-28], corona discharges[17, 29-31] on ageing of housing material are investigated worldwide.

It is necessary to elucidate the ageing behavior of outdoor polymer insulators when they are applied to actual power systems. Salt fog ageing tests are widely conducted to evaluate the anti-tracking/anti-erosion performances of housing materials for outdoor polymer insulators.The deterioration of their surfaces in the salt fog ageing test depended on many effect such as filler content and their configuration [32]. 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 [33,34].

The 1000 hours duration salt fog ageing test is extensively applied. In this test, specimens are continuously under salt fog at constant voltage. The test is evaluating anti-tracking and/or anti-erosion performance of housing materials for polymer insulators. Outdoor exposuretest, specimens are hungvertically of the stainless steel. The test is subjected to a variety of environmental (e.g. thermal, UV-radiation, rain, winds etc.) area Suranaree University of Technology, located NakhonRatchasima, THAILAND.

This paper presents salt fog ageing test results was conducted based on IEC 61109 specifications andoutdoor exposuretest results of silicone rubber [35].

II. Experimental

A. Specimens

Rubber sheets 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 as specimens in this experimental. Specimens were classified into 4 types according to ATH content, as shown in Table I and Fig. 1.

For salt fog ageing test, specimens having 2 mm in thickness, 30 mm in width and200 mm in length attached with metal electrodes on the both ends were used while specimens having 200 mm in length were used for outdoor exposure test. Configuration of tested specimen illustrated in Fig. 2(a) and 2(b).

TABLE I
Characteristics Of Htv Specimens

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

Fig. 1 Types of specimens

B. Test Arrangement and Test Methods

In this study, ageing deterioration of tested specimens using salt fog ageing test was considered comparing with specimens from outdoor exposure. A polyethylene tank having the volume 4.0 m^3 was used as the salt fog test chamber. During salt fog ageing test, specimens were hung vertically in the test chamber. An ultrasonic humidifier was used as salt fog generating source and salt fog was injected from the top of the test chamber. Test arrangement is illustrated in Fig. 3 and actual test chamber is illustrated in Fig 4.

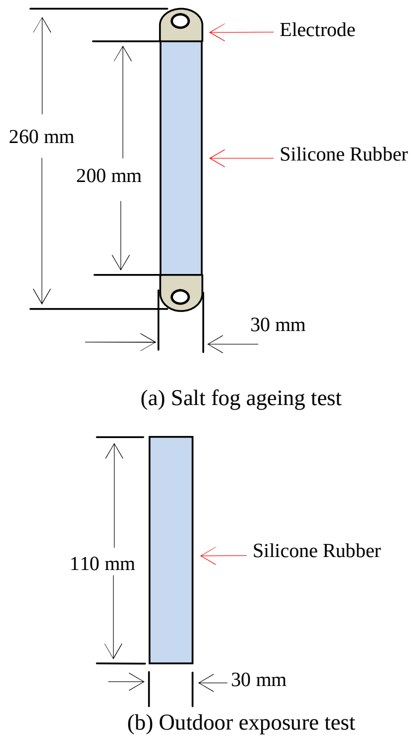


Fig. 2 Specimen configuration

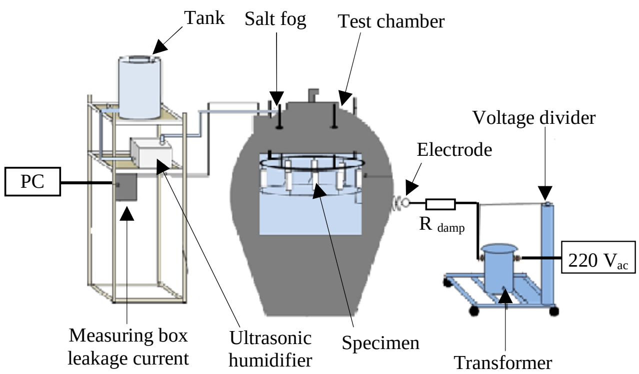


Fig. 3 Test arrangement

All specimens were hung vertically in open environments for outdoor exposure test, as shown in Fig. 5. Only, effect of environmental, i.e. UV, rain, dust, etc., was considered. All specimens were hung in parallel with the north and the south.For every day, specimen surface was exposed to morning and afternoon sunlight.Ageing deterioration of specimen surface due to morning and afternoon sunlight is aim.

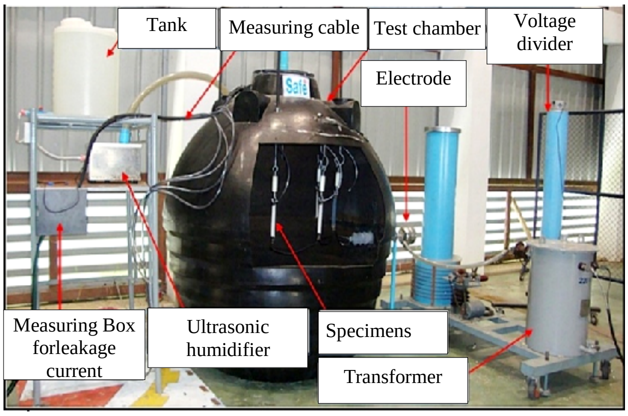


Fig. 4 Salt Fog Test chamber

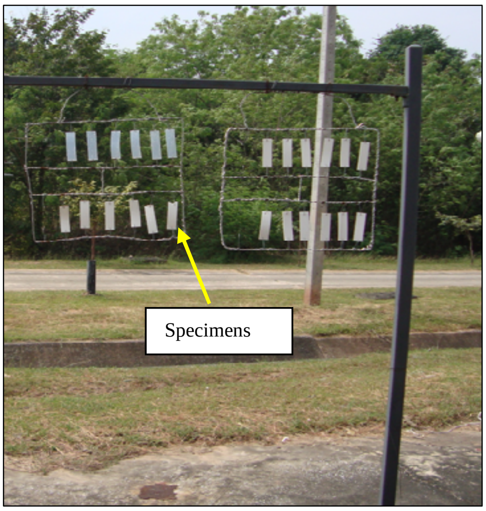


Fig. 5 Outdoor exposuretest

C. Test Conditions

Specimens were subjected to a constant voltage based on IEC 61109 for salt fog ageing test.Test conditions illustrated in Table II. 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 rate 0.5 l/hr/m^3 was injected from the top of the chamber.All specimens were hung vertically in test chamber and were tested together.

TABLE II
TEST CONDITIONS [36]

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 injectedfor 8 hoursand stopped for 16 hours

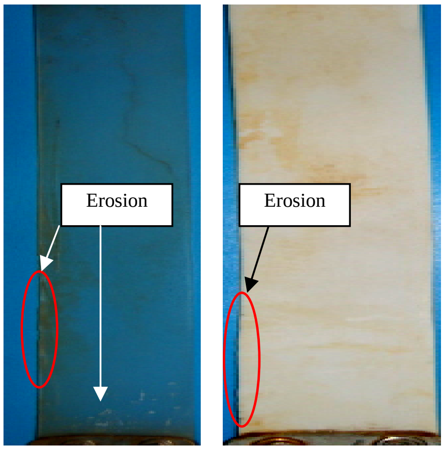
In case of outdoor exposure test, 4 type specimens were hung continuously without energized.Both sides of specimen surface were analyzed degree of ageing deterioration every three months.

III. Test Results and Discussion

For evaluation ageing deterioration degree, many physical and chemical analyses were conducted. Firstly, visual observation by naked eyes was conducted to observe any discernible change of specimen surface.Also, hydrophobicity, contamination degree and hardness measurements were conducted.Thesetechniques were defined as physical analysis.Fourier transform infrared ray spectroscopic (FTIR) analysis is a surface chemical analysis technique that provides information about the chemical bonding or molecular structure of materials.In this study, any chemical changes on specimen surface were analyzed by ATR-FITR.

A. Visual Observation

During salt fog ageing test, many electrical discharge activities were occurred. Such electrical discharge may lead to surface deterioration.After 1000 hours salt fog ageing test, visual observation was conducted in order to inspect any change on tested specimen surface.Any severe surface damage was not observed on all tested specimen surface.But contaminant and dirtwere observed on specimen surface.However, slight surface erosion close to the energized end portion was observed on type A and type B tested specimens.This occurrence may be caused by discharges on specimens'surface during test due to higher electric field stress on such position. Under the same test conditions, 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 siliconerubber.



Type- A Type- B

Fig. 6 Specimens surface after 1000h of salt fog ageing test

After 18 months of outdoor exposure, any visible damage of specimen surface was not observed. Only, dust particles were observed on the both sides of specimen surface as shown in Fig.7.

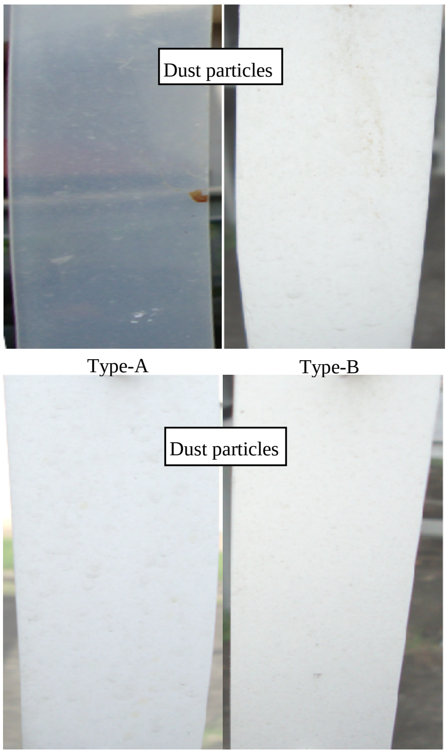


Fig. 7 Specimens surface after 18 months of outdoor exposure

B. Hydrophobicity

Surface discharges, i.e. dry band arc and corona discharges, accompanying the contaminant deposit on the specimen surface led to a reduction in hydrophobicity. Reduction of silicone rubber surface hydrophobicity by electrical and environmental stresses could accelerate the surface deterioration. The occurrence of surface deterioration and contaminant deposition on the specimen surface may be related to the reduction in hydrophobicity.This induces leakage current and dry band arc discharges on the polymer insulator surface. Uncontrolled leakage current promotes intense dry band arcing or surface discharges,can ultimately lead to material degradation and may be tothe reduction in hydrophobicity[37,38].Reduction in hydrophobicity was evaluated by STRI criteria [39], as shown in Fig.8.Thecharacteristics of hydrophobicity on tested specimen surface are shown in Fig.9(a) for salt fog ageing test, and as shownin Fig.9(b) for outdoor exposure test. Hydrophobicity measurement results are shown in Table III.

Significant decreasing in hydrophobicity can be observed on thoroughly surface of the salt fog ageing test 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 with surface treatment, a larger reduction in hydrophobicity can be seen compared with the other specimens having ATH. Such results indicate that ATH filler and 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.

After 18 months of outdoor exposure, all specimens remain their good property of hydrophobicity surface, as shown in Fig. 9 (b). Any discernible difference in reduction of hydrophobicity on specimen surface exposure to morning and afternoon sunlight was not observed.This result shows that mild environment and sunlight without energized in short time exposure may not affect to loss of hydrophobicity. By using STRI hydrophobic classification guide,all specimen surface remained high level of hydrophobicity (HC:1-2) on both sides,exposure to morning and afternoon sunlight.

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
MT	6*	HC1	HC1	HC1	HC1
	9*	HC1	HC1	HC1	HC1
	12*	HC1	HC1	HC1	HC1
	15*	HC2	HC1	HC1	HC1
	18*	HC2	HC1	HC1	HC1
AT	6*	HC1	HC1	HC1	HC1
	9*	HC1	HC1	HC1	HC1
	12*	HC1	HC1	HC1	HC1
	15*	HC2	HC1	HC1	HC1
	18*	HC2	HC1	HC1	HC1

New specimens: HC1, * Months

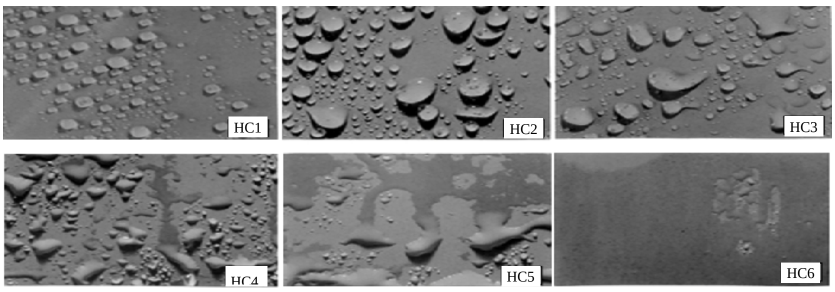
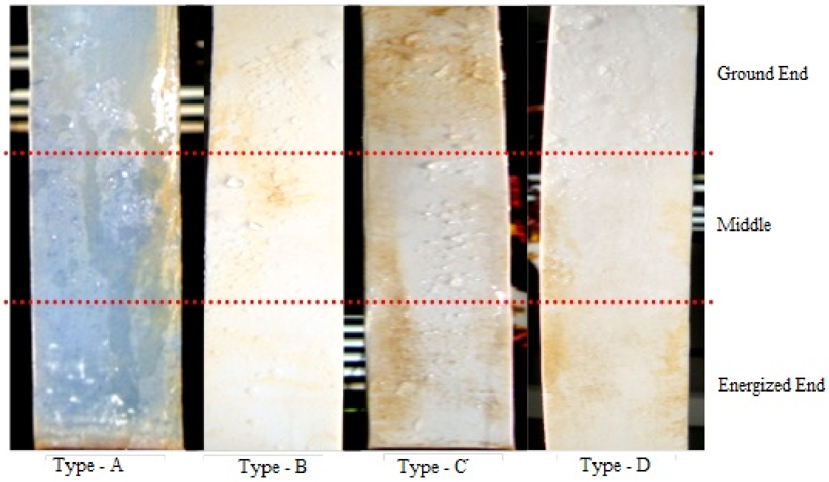
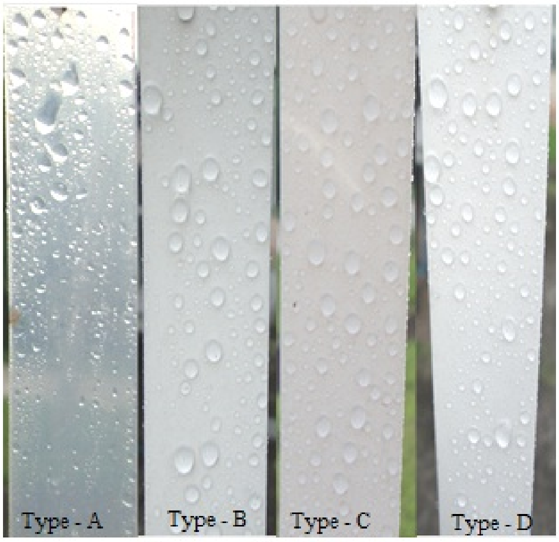


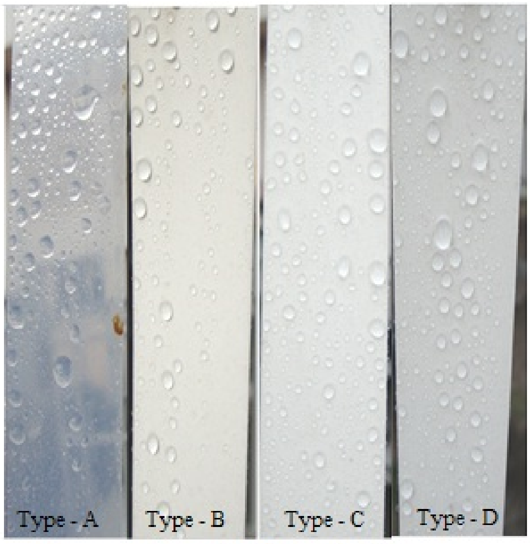
Fig. 8 Characteristics of the sample surfaceHC1-HC6



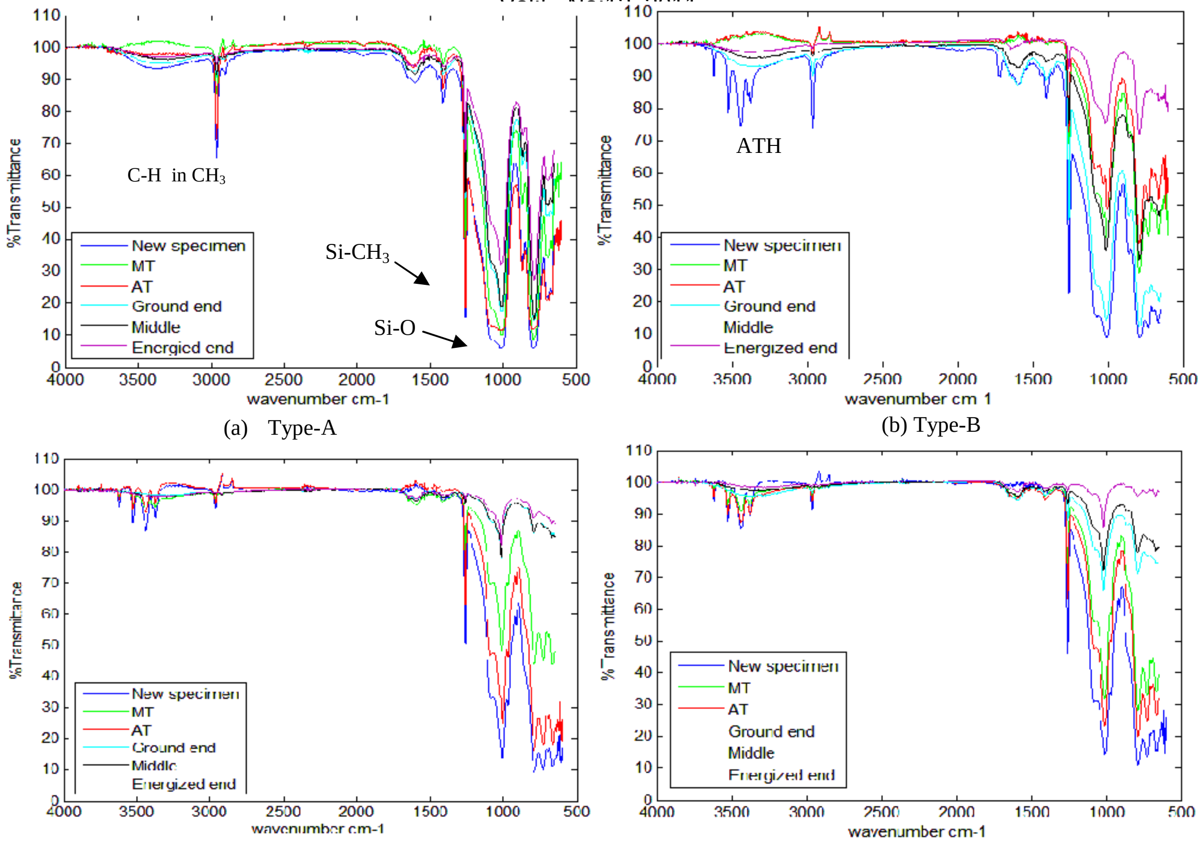
(a) After 1000 hours salt fog ageing test



Exposure to Morning Sunlight



Exposure to Afternoon Sunlight



(a) Type-A (b) Type-B

(c) Type-C (d) Type-D

Fig. 10 FTIR spectra of test specimens (MT and AT of 18 months)

Vibration		%Transmittance							
		Type-A		Type-B		Type-C		Type-D	
		Si-O	Si-CH_3	Si-O	Si-CH_3	Si-O	Si-CH_3	Si-O	Si-CH_3
New		100	100	100	100	100	100	100	100
Ground end		78.36	55.4	90.25	70.97	85.43	99.83	36.46	19.29
Middle		53.23	76.37	63.02	25.42	64.71	57.17	35.01	20.17
Energized end		63.34	38.81	47.10	21.67	22.42	24.48	26.72	14.42
MT	6*	84.37	68.63	65.00	45.50	79.58	68.06	31.23	23.46
	9*	51.76	36.43	51.01	33.68	10.43	6.14	2.05	4.09
	12*	9.88	6.94	25.55	17.61	19.82	16.28	15.55	11.57
	15*	83.51	82.58	88.93	95.18	90.89	94.48	66.39	48.52
	18*	91.38	78.19	58.43	40.68	68.29	54.91	49.73	41.76
AT	6*	90.81	73.44	65.47	45.17	68.30	54.91	35.43	25.42
	9*	72.05	51.9	18.78	12.78	15.03	8.48	7.29	4.97
	12*	49.49	33.49	70.61	50.98	94.66	88.15	21.65	20.53
	15*	83.06	83.00	93.94	69.11	95.42	98.03	83.29	76.71
	18*	95.21	97.19	47.41	35.62	79.58	68.06	80.25	74.65

TABLE V
HARDNESS OF THE SPECIMEN BY SHORE A SCALE

Position		Specimen			
		Type-A	Type-B	Type-C	Type-D
New		66	76.64	82.88	89.36
Ground end		67.04	77.6	84.64	90.96
Middle		65.68	77.28	84.24	89.76
Energized end		67.2	76.64	82.88	89.36
MT	6*	66.16	75.92	83.12	88.64
	9*	69.12	79.52	86	92.4
	12*	68.96	80.24	86.72	92.8
	15*	68.16	80.48	87.2	93.52
	18*	68.8	80.8	87.36	93.68
AT	6*	66.23	76.56	83.68	90.48
	9*	69.2	78.16	86.08	92.4
	12*	68.48	80.4	86.8	93.36
	15*	68.64	80.32	87.2	93.52
	18*	69.04	80.96	86.32	93.76

IV. CONCLUSION

Comparisons of ageing deterioration of silicone rubber housing material for outdoor polymer insulator based on IEC 61109 (salt fog ageing test 1000 hrs.) and outdoor exposure test were conducted. The following conclusions were given.

1.) Electrical stress, electric discharges and pollutants deposited on the surface of specimens caused ageing deterioration of specimens' surface.
2.) For salt fog ageing test, slightly erosion was observed on the specimens type-A (ATH 0 pph) and Type-B (ATH 50 pph). Onlydust particleswere observed on surface ofoutdoor exposure specimens.
3.) For salt fog ageing test, extremelyreduction of hydrophobicity (HC6) was observed on the 4 type's specimens near the energized end.Foroutdoor exposure test, specimens retained high hydrophobicity (HC:1-2) of sidesboth (MT and AT).
4.) The chemical analysis by ATR – FTIR also confirmed surface deterioration of silicone rubber housing material for polymer insulator in these tests.
5.) For outdoor exposure test,slightly increasing in hardness was measured for all specimen surfaces compared with salt fog ageing test specimens.

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