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Ageing Deterioration of Silicone Rubber Polymer Insulator under Salt Water Dip Wheel Test

J. Grasaesom, S. Thong-om, W. Payakcho and B. Marungsri*

***Abstract*—**This paper presents the experimental results of silicone rubber polymer insulators for 22 kV systems under salt water dip wheel test based on IEC 62217. Straight shed silicone rubber polymer insulators having leakage distance 685 mm were tested continuously 30,000 cycles. One test cycle includes 4 positions, energized, de-energized, salt water dip and de-energized, respectively. For one test cycle, each test specimen remains stationary for about 40 second in each position and takes 8 second for rotate to next position. By visual observation, sever surface erosion was observed on the trunk near the energized end of tested specimen. Puncture was observed on the upper shed near the energized end. In addition, decreasing in hydrophobicity and increasing in hardness were measured on tested specimen comparing with new specimen. Furthermore, chemical analysis by ATR-FTIR was conducted in order to elucidate the chemical change of tested specimens comparing with new specimen.

***Keywords*—**ageing of silicone rubber, salt water dip wheel test, silicone rubber polymer insulator

I. Introduction

RECENTLY, silicone rubber polymer insulator has been widely used in power transmission and distribution on over the world [1]. Polymer insulators have advantages of low cost, light weight, high mechanical strength, low surface tension energy and good electrical strength when comparing with the conventional type insulators [2]. Typical molecular structure of silicone rubber is polydimethylsiloxane (PDMS) which consists of an inorganic backbone of alternating silicone and oxygen atoms and methyl groups attached to the silicone rubber [3]. Filler are used to reinforce the silicone rubber and can improve tensile strength, modulus, tear strength and abrasion resistance of the silicone rubber. In addition, coupling agents provide a chemical bond between the filler and the polymer matrix which can greatly improve the electrical properties, modulus and tensile strengths [4].

Due to silicone rubber polymer insulators made from polymeric materials, the environment conditions are major problems to ageing for silicone rubber such as salt fog, humidity, dust, rain and UV etc.[5]. Dry band arcing and corona discharge due to surface contamination affect tracking, erosion and loss of hydrophobicity to surface silicone rubber polymer insulator [6], [7].

For study ageing of silicone rubber, many researchers have been studied the various services problems for polymer insulators. Tracking wheel test was adopted to use as the test method for ageing evaluation of silicone rubber insulator [8]. The measurement system and computer controls were incorporated with the tracking wheel test [5].

This paper reports salt water dip wheel test results of silicone rubber polymer insulator for 22 kV distribution systems.

II. Test Arrangements

A. Specimen

Straight shed polymer insulators made were of HTV silicone rubber with ATH (Alumina trihydrate) was used in this experimental. Four pieces of the specimen were tested together under test conditions based on IEC 62217 [9]. Configuration and dimension of the specimen are illustrated in Fig. 1.

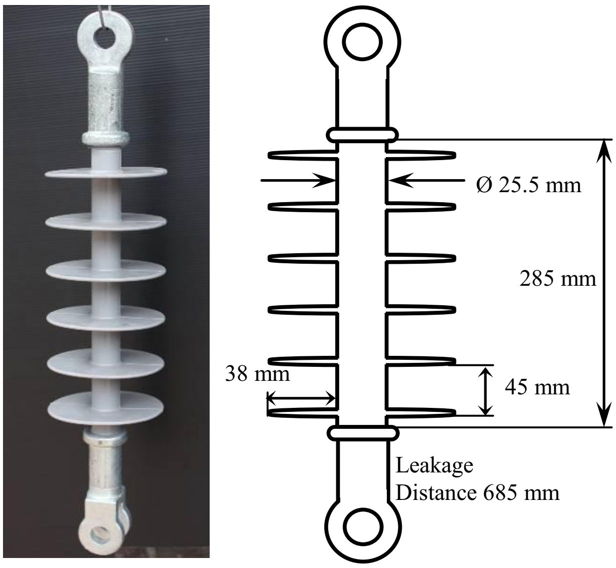


Fig. 1 Specimen.

B. Test Method

Test methods for salt water dip wheel test were based on IEC 62217 [9]. Test was conducted continuously for 30,000 cycles. One test cycle takes time 192 second and includes 4 test positions, energized, de-energized, salt water dip and

J. Grasaesom, S. Thong-om and W. Payakcho are graduate student in Suaranaree University of Technology, Nakhon Ratchasima, 30000, THAILAND.

* B. Marungsri is with Suaranaree University of Technology, Nakhon Ratchasima, 30000, THAILAND. (Corresponding author, phone: +66 4422 4366; fax: +66 4422 4601; email: bmshvee@sut.ac.th).

de-energized, respectively. For each position, test specimen remains stationary for about 40 second and takes 8 second for rotate to the next position. Salt water was re-newed every week and re-newing time must less than 1 hour. Test arrangement for dip wheel test is shown in Fig. 2 and the specimen arrangement during test is shown in Fig. 3.

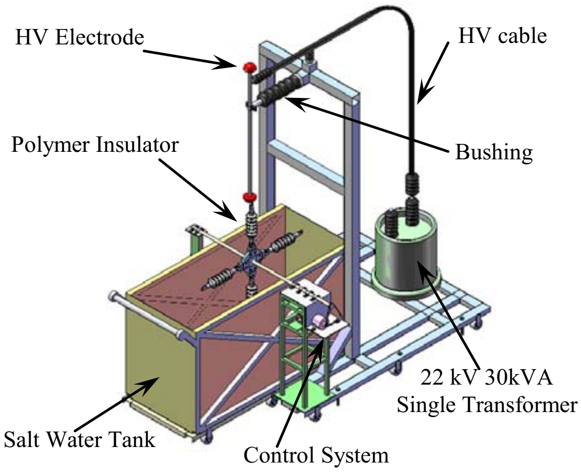


Fig. 2 Test arrangement for dip wheel test.

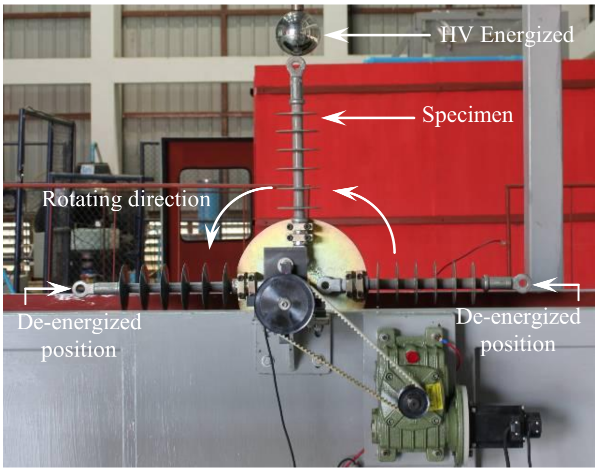


Fig. 3 Specimen arrangement during dip wheel test.

C. Test Condition

Test conditions were based on IEC 62217 and condition were illustrated in Table I. Test voltage was generated from 22 kV, 30 kVA distribution transformer.

TABLE I
TEST CONDITION

Voltage stress	35 V/mm (AC voltage)
NaCl content of de-ionized water	1.4 kg/m^3 ± 0.06 kg/m^3
Test duration (1 cycle = 192 second)	30,000 cycles

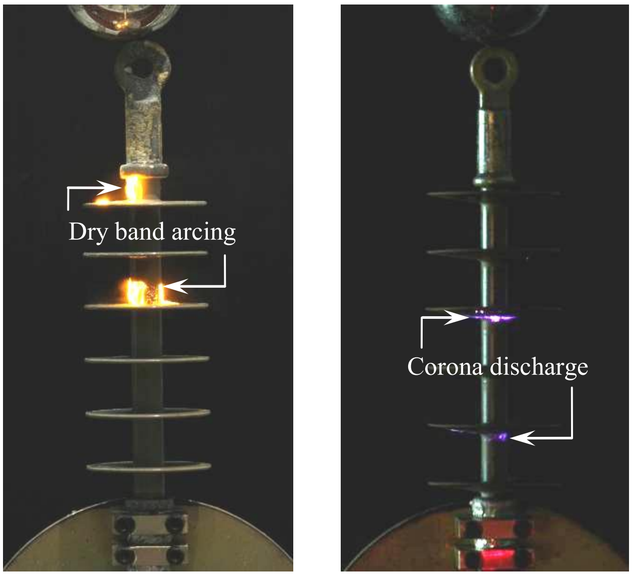
III. EXPERIMENTAL RESULT AND DISCUSSION

The insulators were tested continuously for 30,000 cycles. Then, tested specimens were analyzed by physical and chemical methods such as visual observation, loss of hydrophobicity, surface contamination degree, hardness measurement and ATR-FTIR in order to evaluate degree of surface erosion.

A. Visual observation

Visual observation was conducted in order to inspect any ageing on the surface of tested specimen. During the test, dry band arc and corona discharge occurred and were obviously observed on the trunk surface during energized position. Visible discharge activities during test are shown in Fig. 4.

As illustrated in Fig. 4 (a), yellow color of light for dry band arcing was observed. The evaporating of water caused dry band arcing on the surface of the polymer insulators. Occurring of such arcing caused tracking on the surface [10]-[12]. Corona discharge was also observed on under surface of shed. Occurring of corona discharges may be generated by high electric field stress on the tip of water droplet.



(a) Dry band arcing (b) Corona discharge
Fig. 4 Visible discharge activities during dip wheel test.

After 30,000 test cycles, significant changing on the specimen surface was observed on tested specimen. Many types of surface ageing, such as erosion and tracking etc., were observed.

As show in Fig. 5 (a) and Fig. 5 (b), dirt was observed on both shed and trunk surfaces of tested specimens.

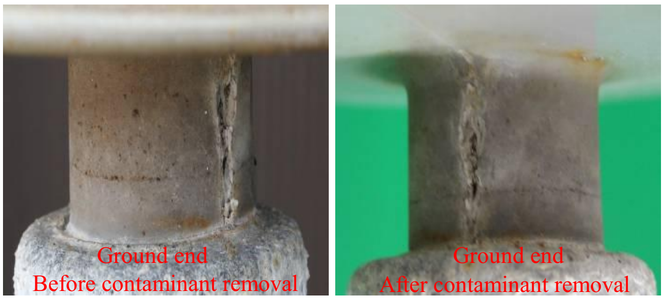
As shown in Fig. 5 (c) and Fig. 5 (d), severe surface tracking was observed on parting line of trunk surface near both energized and ground ends. The occurring of surface tracking on such portion may caused by high electric field stress.

As shown in Fig. 5 (e), surface tracking, also, was observed on parting line of shed surface near energized end

(a) Dirt on trunk surface.

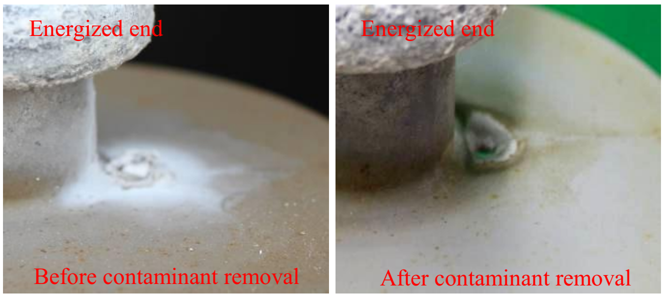
(b) Dirt on shed surface.

(c) Tracking on trunk parting line.



(d) Tracking on trunk parting line.

(e) Tracking on shed parting line.



(f) Shed puncture.

Fig. 5 Surface damage of tested specimens.

comparing with other shed surface portion. This occurring may caused by higher electric field stress.

Surface tracking along parting line in high electric field stress portion may caused by remaining water droplet during high voltage energized

As shown in Fig. 5 (f), punched of shed near energized end was observed. The puncture was observed on the parting line of shed. Occurring of such surface damage may caused by high power electric discharge [13]. The results show that imperfect of parting line can caused seriously surface damage of polymer insulator under contamination condition.

B. Contamination Degree

Contamination degree is an indicator for contamination level on the tested insulators. Contamination degree is determined by measuring the salt deposit density (SDD) based on IEC 60507. The formulas for SDD calculation are as follows.

$$S_a = (5.7\sigma_{20})^{1.03} \quad (1)$$

$$SDD = \frac{S_a \times V}{A} \quad (2)$$

where:

σ_{20} is the volume conductivity at temperature of 20°C (S/m)

S_a is salinity (kg/m^3)

SDD is the salt deposit density (kg/m^2)

V is the volume of the suspension (m^3)

A is the area of the cleaned surface (m^2) [14].

SDD measurement results are illustrated in Table II. No significant different in SDD was obtained.

TABLE II
SDD AFTER 30,000 TEST CYCLES

SDD, mg/cm^2			
No. 1	No. 2	No. 3	No. 4
0.076	0.044	0.079	0.050

C. Hydrophobicity

In study, hydrophobicity is evaluated by water spray method based on STRI guide, as shown in Fig. 6 [15]. In order to comparisons hydrophobicity of the tested specimens with the new specimen, HC level for hydrophobicity was evaluated, as shown in Fig. 7 and the results of HC level are shown in Table III.

After 30,000 test cycles, decreasing in hydrophobicity for tested specimens was evaluated comparing with the new specimen. Significant HC level can be seen. HC3 is almost hydrophobic level for all tested specimens. The loss of hydrophobicity may be caused by electrical and environmental stresses during test cycle such as UV radiation and heat etc. [11].

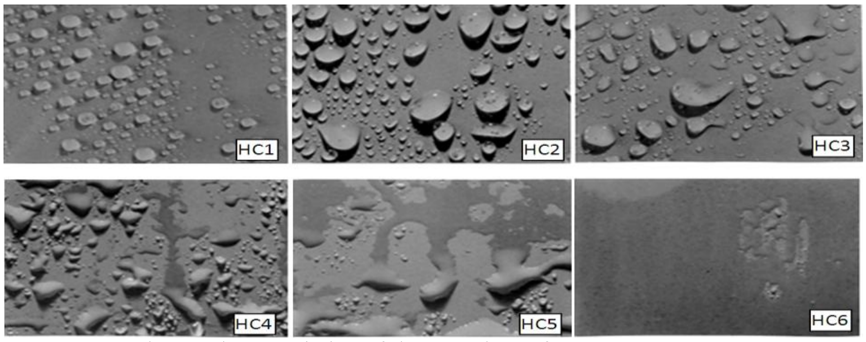
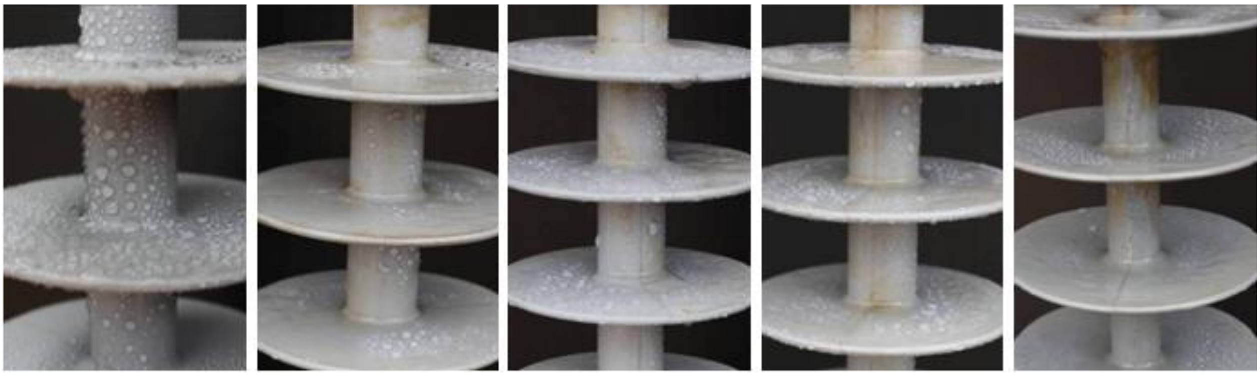


Fig. 6 Characteristics of the sample surface HC1-HC6 [15].



New Specimen | Tested Specimen No. 1 | Tested Specimen No. 2 | Tested Specimen No. 3 | Tested Specimen No. 4

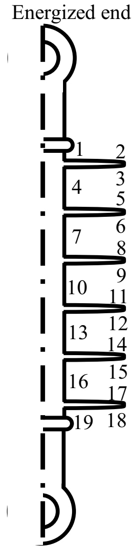
Fig. 7 Comparisons of hydrophobicity.

TABLE III
HYDROPHOBICITY AFTER 30,000 TEST CYCLES

Position	Specimen				
	New	No. 1	No. 2	No. 3	No. 4
1	HC 1	HC 4	HC 4	HC 3	HC 3
2	HC 1	HC 3	HC 3	HC 3	HC 3
3	HC 1	HC 3	HC 3	HC 2	HC 3
4	HC 1	HC 3	HC 3	HC 3	HC 3
5	HC 1	HC 3	HC 3	HC 3	HC 2
6	HC 1	HC 4	HC 2	HC 4	HC 3
7	HC 1	HC 3	HC 3	HC 3	HC 3
8	HC 1	HC 3	HC 3	HC 3	HC 3
9	HC 1	HC 3	HC 3	HC 3	HC 4
10	HC 1	HC 3	HC 3	HC 3	HC 3
11	HC 1	HC 3	HC 3	HC 3	HC 3
12	HC 1	HC 3	HC 2	HC 4	HC 4
13	HC 1	HC 3	HC 3	HC 3	HC 3
14	HC 1	HC 3	HC 3	HC 3	HC 3
15	HC 1	HC 3	HC 2	HC 4	HC 3
16	HC 1	HC 3	HC 3	HC 3	HC 3
17	HC 1	HC 3	HC 3	HC 3	HC 3
18	HC 1	HC 4	HC 2	HC 3	HC 3
19	HC 1	HC 3	HC 3	HC 3	HC 3

Position

Energized end



Ground end

D. ATR-FTIR Analysis

ATR-FTIR (attenuated total reflection fourier transform infrared spectroscopy) is chemical analysis for the chemical bonds inspection. In this study, side chins ($Si\text{-}CH_3$) at wave number 1258 cm^{-1} and back bonds (Si-O) at wave number 1010 cm^{-1} were analyzed. The changing in $Si\text{-}CH_3$ bonds were damaged by oxidation and crosslinking. The changing in Si-O bonds was damaged by scission and hydrolysis.

After 30,000 test cycles, ATR – FTIR analysis was conducted on 19 positions of specimen surface for chemical bond inspection. The example of ATR –FTIR spectrum on position 2 of tested specimen surface is illustrated in Fig. 7. ATR – FTIR analysis results for all position of all tested specimens are illustrated in Table III. Significant reduction in $Si\text{-}CH_3$ and Si-O bonds of tested specimens was obtained comparing with new specimen.

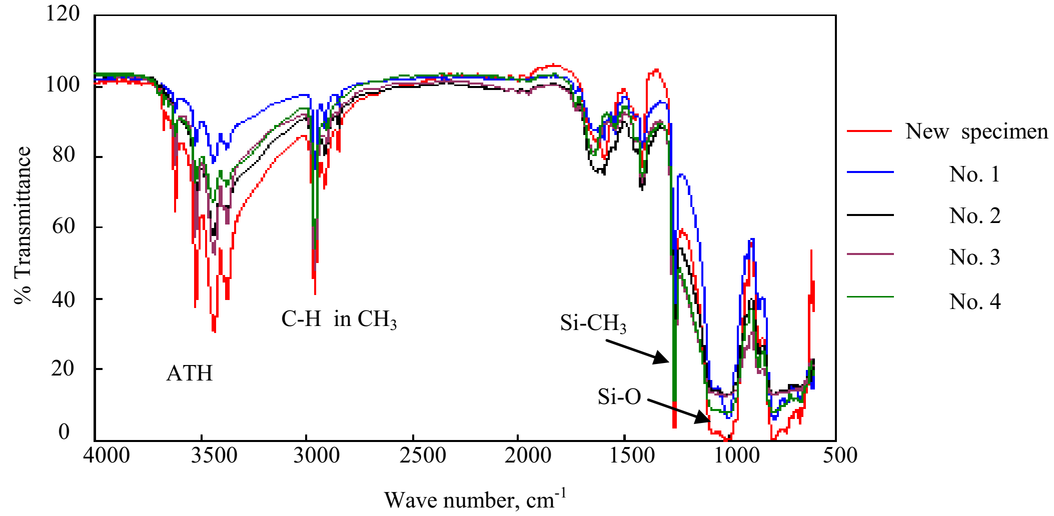
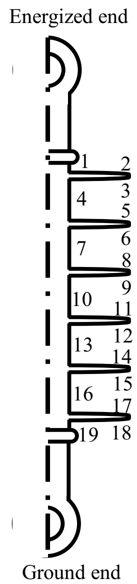


Fig. 8 ATR- FTIR spectrum of tested specimen at position 2.

TABLE III
TRANSMITTANCE AFTER 30,000 TEST CYCLES

Position	Transmittance of $Si\text{-}CH_3$ (1258 cm^{-1}), % New Specimen	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4	Transmittance of Si-O (1010 cm^{-1}), % New Specimen	Specimen No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4
1		65.41	32.91	24.77	-		28.55	5.97	4.72	-
2		21.61	13.4	19.27	8.11		4.15	10.03	9.48	4.48
3		21.62	12.45	5.55	8.33		4.15	7.88	2.94	3.08
4		48.51	23.12	19.65	81.38		19.95	0.66	3.54	53.12
5		33.23	19.08	11.51	5.34		4.25	6.68	7.29	1.78
6		53.95	9.42	4.76	12.99		17.82	6.21	3.04	3.99
7		43.38	21.68	34.22	70.0		12.68	1.09	7.34	33.92
8		59.07	13.1	11.39	8.56		27.09	7.1	8.37	2.34
9		76.01	13.94	5.88	19.37		51.08	8.25	4.21	5.79
10	100	12.81	24.36	15.22	68.57	100	2.74	0.51	9.38	33.9
11		10.81	13.93	14.24	6.88		7.86	9.97	9.28	4.06
12		62.19	17.72	31.13	11.42		17.75	5.7	5.93	7.96
13		26.91	19.21	11.7	77.61		6.94	1.13	3.41	53.81
14		5.36	13.1	11.33	5.93		4.09	6.6	9.49	2.06
15		60.94	13.65	16.61	26.35		18.2	7.44	9.6	2.51
16		76.29	14.69	8.47	69.93		4.09	0.33	2.13	38.35
17		5.76	11.67	23.33	0.62		3.83	8.03	5.51	3.04
18		10.99	13.8	15.04	8.7		2.53	7.3	9.3	4.9
19		76.29	70.46	80.33	-		49.4	46.87	62.57	-

Position



E. Hardness Measurement Results

After 30,000 test cycles dip wheel test, hardness was measured on tested specimen surface comparing with new specimen surface. Measurement method is based on the ISO 868-Shore hardness [16]. Increasing in hardness indicate that oxidation crosslink of polydimethylsiloxane was occurred. Increasing in hardness was obtained from the measurement results, as show in Fig. 9. Increasing of hardness confirmed the chemical reaction in silicone rubber.

IV. Conclusion

Silicone rubber polymer insulators were tested under salt water dip wheel test and were subjected to electric field at ac 35 V/mm for 30,000 test cycles. Surface tracking and shed puncture were observed on the specimen surface after 30,000 test cycles. Dry band arc discharge and corona discharge caused surface damaging of the tested specimen. In addition, decreasing of hydrophobicity was measured on tested specimen surface when comparing with the new specimen. UV and heat from the dry band arc discharges and corona discharges caused loss of hydrophobicity. SDD of tested specimens in range 0.4-0.7 mg/cm^2 was measured. The pollutions caused dirt on the specimen surface.

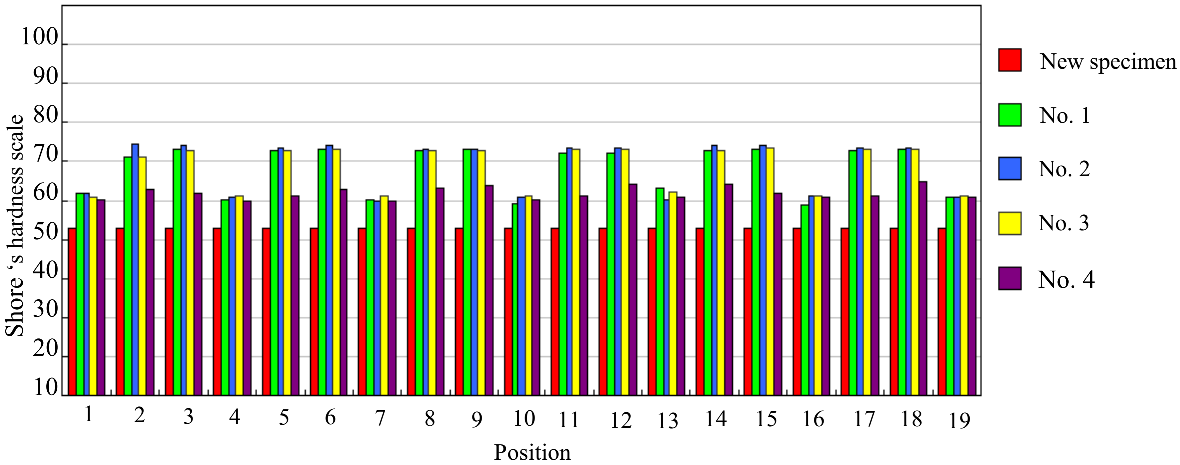


Fig. 9 Hardness of specimen surface after 30,000 test cycles.

ATR-FTIR analysis results showed the chemical change of side chain ($Si\text{-}CH_3$) and backbone (Si-O). The observation results were confirmed by chemical analysis results. Furthermore, hardness measurement results show that the tested specimen harder than the new specimen.

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Janejira Grasaesom was born in Nakhon Ratchasima Province, Thailand, in 1986. She received B.Eng. in Electrical Engineering from Suranaree University of Technology, Nakhon Ratchasima, Thailand, in 2007. She is currently a master degree student in School of Electrical Engineering, Institute of Engineering at same the University. Her research topics interesting are high voltage technology application, high voltage insulation technology and power system technology.

Suchart Thong-om was born in Surin province, northeastern of THAILAND, in 1987. He received B. Eng. in Electrical Engineering from Suranaree University of Technology, Nakhon Ratchsima, in 2009. Currently, He is a master degree student in school of Electrical Engineering, Suranaree University of Technology. His research topic interesting is High voltage insulation technology.

Worawit Payakcho was born in Phra Nakhon Si Ayutthaya, Thailand, in 1986. He received his B.Eng. in Electrical Engineering from Suranaree University of Technology, Nakhon Ratchasima, Thailand, in 2007. He is currently a graduated student in school of Electrical Engineering, institute of Engineering at same the University. His interesting areas High voltage Technology applications, High Voltage Insulation Technology and Power System Technology.

Boonruang Marungsri was born in Nakhon Ratchasima Province, Thailand, in 1973. He received his B. Eng. and M. Eng. from Chulalongkorn University, Thailand in 1996 and 1999 and D. Eng. from Chubu University, Kasugai, Aichi, Japan in 2006, all in electrical engineering, respectively. Dr. Marungsri is currently an assistant professor in School of Electrical Engineering, Suranaree University of Technology, Thailand. His areas of interest are high voltage insulation technologies and electrical power system.