Polymer: Future Material of Insulator

Asha N and Ravindra G. Patil

Abstract: The paper describes the details of the some of the tests are carried on ceramic and polymer insulators to know the performance of the better insulator, and also the comparison of ceramic and polymer insulator are done with the manufacturing process. And finally concluded that polymer is the best insulator than ceramic insulator.

In the transmission and distribution of electrical energy, insulators have the important task of creating a barrier between live voltage and the ground, while providing strong mechanical support. Insulators are used at various locations in a power network and their insulation and mechanical characteristics must ensure a long-lasting barrier. Porcelain and glass-type insulators have been in use for over 100 years. More recently, new composite (Polymer) materials were introduced. The insulators are subjected to higher than usual levels of one or more accelerating variables such as voltage, temperature and stress.

Keywords: **Polymer, Ceramic, Flash over, Hydropobicity, Tensile strength and Puncture Voltage**

1. INTRODUCTION

Electrical insulator is a very important component in the electric power systems such as sub-stations, distribution and transmission lines. It prevents the loss of electric charge or current from conductors in electric power transmission lines. In earlier days, insulators were made of ceramic and glass materials. But now days, polymeric insulator were developed and its improvements in design and manufacturing in the recent years have made them attractive to utilities. An insulator is a material that resists the flow of electric charge. Overhead power transmission lines require both wires to conduct the electricity and insulators to isolate the wires from the steel towers or utility poles by which they are supported.

Insulator is an insulating material in a form designed to support a conductor physically and electrically separate it from another conductor or object. Insulators are used in overhead lines as cap and pin, line posts, long rod, railway insulators, jumper loops and in substations as supports, apparatus bushings, apparatus housing (transformer, surge arresters).

The insulators have conventionally been made of ceramics or glass. These materials have outstanding insulating properties and weather resistance but have the disadvantages of being heavy, easily fractured, and

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subject to degradation of their withstand voltage properties when polluted. There was therefore a desire to develop insulators of a new structure using new materials that would overcome these drawbacks. Hence composite insulators were developed.

Three types of insulators are:

i. Porcelain Insulators

ii. Glass Insulators

iii. Composite Insulators

i) Porcelain insulators

Porcelain insulators are made from clay, quartz or alumina and feldspar, and are covered with a smooth glaze to shed water. Insulators made from porcelain rich in alumina are used where high mechanical strength is a criterion. Porcelain has a dielectric strength of about 4–10 kV/mm.

Fig.1. 10kV Porcelain Insulator

ii) Glass insulators

Glass insulators were used to insulate lightning rods and cables from structures. Glass insulators are used in battery rest insulators, thread less insulators etc. Glass has a higher dielectric strength, but it attracts condensation and the thick irregular shapes needed for insulators are difficult to cast without internal strains.

Fig.2. Glass Insulator

iii) Composite insulators

A composite insulator consists of a core material, end fitting, and a rubber insulating housing. The core is of FRP (Fiber Reinforced Plastic) to distribute the tensile load. The reinforcing fibers used in FRP are glass (E or ECR – Epoxy corrosion resistant) and epoxy resin is used for the matrix. The portions of the end-fitting to transmit tension to the cable and towers are of forged steel, malleable cast iron, aluminium etc. The rubber housing provides electrical insulation. It covers the FRP Rod thereby protecting it from corrosion due to atmospheric exposure. Composite insulators are also known as polymeric or non-ceramic insulators.

Silicone rubber has superior electrical characteristics and weather resistance properties over a wide range of temperatures, for use in the housing. It is resistant to oxidation, has low surface energy, and resists degradation from ultraviolet radiation. These properties make silicone rubber a good choice for electrical insulators.

Fig 3 polymer insulator

2. Process Flow Chart of Ceramic and Polymer Insulator

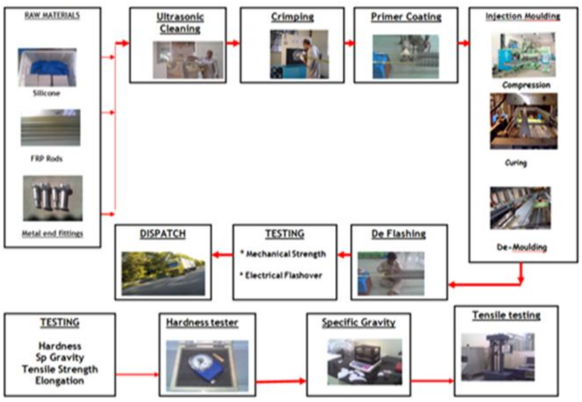


Fig 4 Manufacturing process of polymer insulator

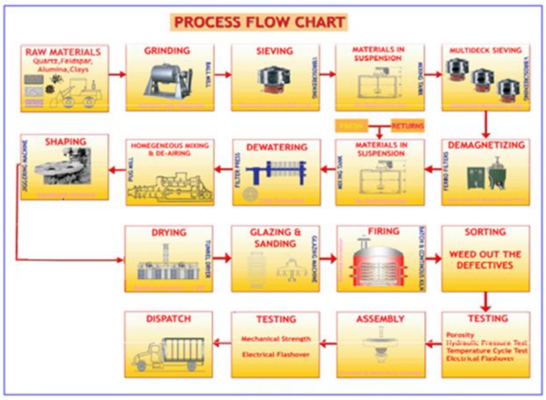


Fig 5 Manufacturing process of ceramic insulator

Manufacturing process of polymer insulators needs less cost, power and also easy compared to ceramic insulators

3. TESTING OF INSULATORS

Objective of testing

To ensure the defect free insulators at the stage of dispatch and if any problem persist then approach method is carried out:

1. Identification of the problems and collection of data.

2. Analysis of data (using pareto analysis).

3. Causes and effect diagrams for the analysis of major defects.

4. Action plan

The testing of insulators is classified as:

i. Type test

ii. Routine test

iii. Acceptance test

Type test are those tests carried out to prove conformity with the design and specification. These are intended to prove the general qualities and design of given type of insulators.

Routine test are carried out on each and every insulators to ensure good quality of insulators.

Acceptance test are carried out on samples taken from a lot for the purpose of acceptance of the lot.

For different insulators, different tests are carried out depending on the application and the service requirement.

.a) Following definitions of terms used in testing of insulators

Flashover: A disruptive discharge external to the insulator, connecting those parts which normally have the operating voltage between them.

Puncture: A disruptive discharge passing through the solid insulating parts of an insulator.

Dry impulse with stand voltage: The specified impulse voltage which the insulator shall with stand, without flashover or puncture. The specified power frequency voltage which the insulator shells withstand under wet conditions

Wet power frequency withstand voltage: The specified power frequency voltage which the insulator shells withstand under wet conditions.

Mechanical failing load: The maximum specified type of mechanical load which can be reached by the insulator.

Electromechanical failing load: The maximum load which can be reached when a string insulator unit is tested under few conditions prescribed under I

Table.1: Ems test reading of ceramic insulator

b) Type test:

Sample number	Tensile breaking load (KN)	Remarks	Sample number	Tensile breaking load (KN)	Remarks
1	482	Cap broken	11	494	Cap broken
2	486	Cap broken	12	478	Cap broken
3	476	Cap broken	13	486	Cap broken
4	492	Cap broken	14	482	Cap broken
5	480	Cap broken	15	490	Cap broken
6	484	Cap broken	16	480	Cap broken
7	486	Cap broken	17	488	Cap broken
8	479	Cap broken	18	478	Cap broken
9	488	Cap broken	19	484	Cap broken
10	482	Cap broken	20	492	Cap broken

i) Electromechanical test (For suspension type): This test is consists of application of tensile stress of 21/2 times the maximum working tensile strength for about one minute along with the voltage. Then after this test the insulator is tested for 75 of dry spark voltage

Statistical Evaluation

Table.2: Test evaluation result

N	Sample size	20
X	Mean failing load	484KN
R	Rated E-M failing load	420KN
S	Standard deviation	5.183KN
(R+3S)	Acceptance formula	435.55KN

Conclusion: Since X obtained is greater than (R+3S), the result meets the requirements of the specification.

Polymer: Applied voltage=50KV (for 160 KN Insulator)

Table.3: EMS test on polymer insulator

Sample number	**Tensile breaking load (KN**	Duration(mint)	Failing load(KN)	Remarks
1	28	96	240	Socketside crimp sliped
2	26	103	270	Socketside crimp sliped

Remark: Table 1 and table 2 show the withstanding load of 160 KN polymer insulators is more than 420 KN ceramic insulators.

ii) Impulse frequency flashover test:

The insulator used in the field, must also be tested against the high voltage surges caused by lightning etc. For this test the generator developing lightning voltages is employed, it develops a very high voltage at frequency of several hundred thousand cycles per second. Such a voltage is applied to the insulator and the spark over voltage is applied to the insulator and the spark over voltage is noted.

Ceramic insulator: (120 KN Insulator)

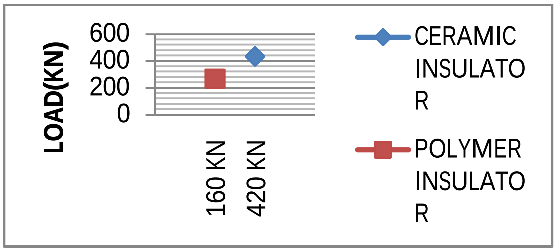
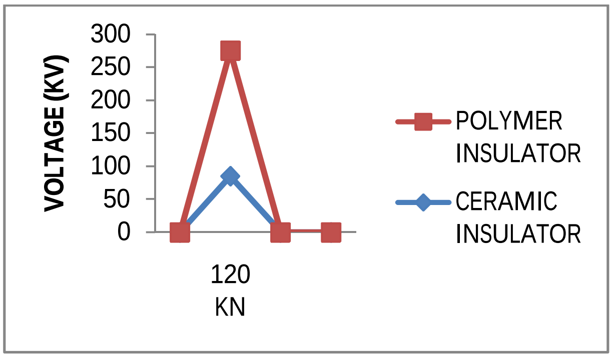


Table.4: Impulse test reading on ceramic insulator polymer insulator:

Test sample number	Test voltage KV (rms)	Remarks
1	85	Withstood
2	85	Withstood
3	85	Withstood

Table.5: Impulse test reading on polymer insulator

Test sample(KN)	Test Voltage KV(rms)	Remark
90	185	Withstood
120	190	Withstood
160	200	Withstood
420	380	Withstood



Remark: Table 4 and table 5 shows the withstanding voltage of 120 KN insulator for polymer are more the ceramic.

iii) Wet power frequency voltage withstand test:

Before the commencement of test, the insulator shell be exposed to the artificial rain produced for at least one minute before application of voltage and then throughout the test. A voltage of about 75 % of the test voltage as determined shall be applied and then increased gradually to reach the test voltage in a time not less than 5 seconds. The test voltage shall be maintained at this value for one minute. The insulator shall not flashover or puncture during the application of the test voltage.

Ceramic insulators: (120KN Insulator)

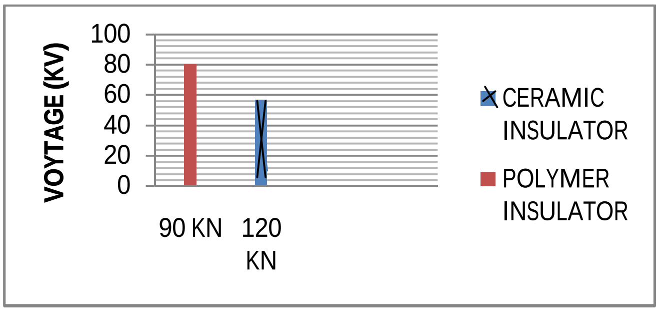
Table.6: Power frequency readings on ceramic insulator

Test sample number	Test voltage KV (rms)	Remarks
1	57	Flashed over
2	57	Flashed over
3	57	Flashed over

Polymer insulator:

Table.7: Power frequency readings on ceramic insulator

Type of sample(KN)	Test voltage(KV)	Remark
90	80	Flashed over
120	85	Flashed over
160	140	Flashed over
9 ton	150	Flashed over



Remark: Table 6 and table 7 show the power frequency withstanding voltage of 90KN polymer insulator are more than 120KN ceramic insulator**.**

c) Routine test:

i) Visual examination: visually inspection on both type of insulator are examined like surface finishing, glaze, overall finishing

ii) Mechanical strength test :

In this test, the insulator is mounted on a steel pin and 21/2 times the maximum working load is applied for 1min. this test is also called as bending test

Ceramic insulator:

Table.8: Mechanical reading on ceramic insulator

Product / item(KN)	Load (KN)
70	42
80	48
90	54
100	60
120	72
125	75
160	96
190	114
210	126
300	180
420	252

Polymer insulator:

Table.9: Mechanical reading on polymer insulator

Product / item(KN)	Load (Tonne)
90	5.5
120	7.2
160	9.6
Stay arm insulator	4.9
Bracket insulator	4.9
9 tonne	7.7

Remark: Table 8 and table 9 show the Mechanical withstanding capacities of polymer insulator are more than ceramicinsulator.

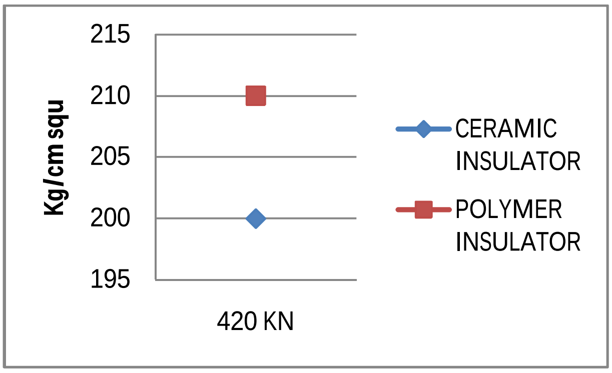
iii) Hydraulic pressure test: (for ceramic insulator)

In this test, the insulator is subjected to a pressure of 200 kg/cm^2 hydraulically in the head portion for about 2 to 3 seconds and in case of any cracks, the pieces shackles.

Crimping pressure test: (for polymer insulator)

The insulator crimping is subjected to a pressure of 210 kg/cm^2 about 2 to 3 seconds

Remark: the polymer insulator as the high pressure withstanding than ceramic insulator



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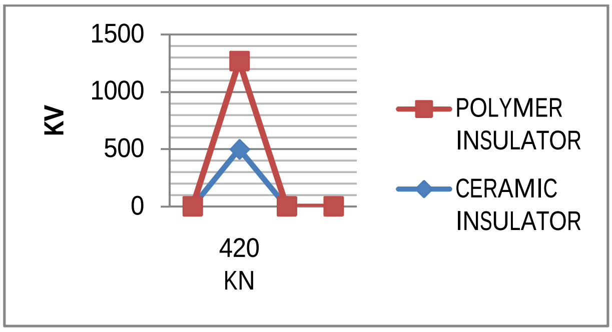
iv) Electrical flashover test:

This is done in order to ensure that the insulator does not fail under normal working load with some factor of safety. Here, any puncture in the insulator is detected.

For ceramic insulator: Normally 70 to 80 KV is applied

For polymer insulator: normally 150 KV is applied



Remark: withstanding electrical voltage for polymer insulator are more

d) Sample test:

i) Verification of dimensions (for both type of insulators)

Following physical dimensions shall be checked on 10 samples in accordance with the drawing approved by customer

1. Disc diameter
2. Unit spacing
3. Creepage distance
4. Verification of eccentricity

ii) Verification of locking system:

Locking of clip in the insulators are checked by pushing the clip from minimum to maximum force

Ceramic insulators (for 420 KN)

Table.10: locking system readings of ceramic insulator

Sample no	F min(N)	F max(N)	Remark
1	139	590	Satisfactory
2	289	625	Satisfactory
3	216	632	Satisfactory
4	226	640	Satisfactory
5	257	678	Satisfactory
6	222	630	Satisfactory

Polymer insulator (for 160 KN)

Table.11: locking system readings of ceramic insulator

Sample no	F min(N)	F max(N)	Remark
1	95	510	Satisfactory
2	114	529	Satisfactory
3	128	518	Satisfactory

Remark: Table 10 and table 11 show the locking capacity of 160 KN polymer insulators is more than 420 KN ceramic insulators.

iii) Water absorption (For polymer)

The 30mm cutted samples are dipped in the water first sample is cleaned and weighted and the dipped in water for 3 hr than weighted the difference are measured

Table.12: Water absorption readings of polymer insulator

Sample no	Dry weighted(gm)	Saturating weight, S(gm)	% of water obsortion,T
1	7.5593	7.562	0.036
2	7.3492	7.351	0.033
3	7.3728	7.377	0.033

T=(S-D)/D*100

Water diffusion (for polymer)

The samples are boiled in container for 100 hr in deiodised water 0.1 %, Nacl after boiling the specimen are placed in another container filled with top water at ambient temperature for 15 min with 3 hr specimen removed and dried each specimen is put between the two electrode, voltage is incensed at 1 KV/S up to 12 V

Temperature cycle test (For ceramic insulator)

The test is conducted to bring out minute irregularities in the shell material, which reduce the mechanical strength. For this test insulator is first heated in water at 70oC for one hour and is then immediately cooled in water at 70C for another hour. The heating and cooling cycle is performed 4 times in succession and the time taken for transfer of insulators must be as small as possible. After such temperature cycles the insulator is dried. It should be noted that after this test the glaze of the insulator should not be damaged.

Remark: The ambient temperature is sufficient for polymer insulator, but ceramic insulator needs more temperature

iv) Porosity test: (for ceramic insulator)

The porosity of material of the insulator can well be determined by the penetration test. In this test, recently fired insulator is broken into pieces. This insulator is dipped in a solution of surgical spirit containing about 1gm/lit of cooling material like fuchsin for 12 hours at a pressure of 150kg/cm2. At the end of 12 hours the samples are removed and examined. After that if any slight porosity of the material is indicated by the deep penetration of the dye into it then the whole is rejected.

Fig 6 (a): Porosity test machine

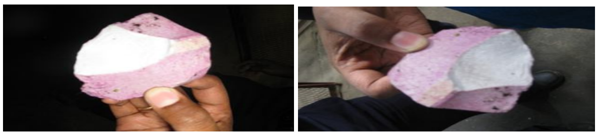


Fig 6 (b): Penetration of the dye, Fig 6 (c): No penetration

Non-porosity is one of the important properties that an insulator has to posses. Without this, with air gaps amidst the insulation, the dielectric strength of the insulators suffers. Therefore this is the most crucial test of all.

Dye penetration test: (for polymer)

Samples shall be cut of length 10 +/- 0.5 mm specimens are placed vertically on a layer of steel/glass balls of diameter 1 to 2 mm in a vessel, a dye is poured in a vessel time taken by dye to rise though specimen is measured, time taken should be more than 15 mint, if penetration is appeared that sample is rejected

Remark: penetration test for polymer insulator is easy and duration also less compared to porosity test for ceramic insulator**.**

vi) Puncture voltage test:

For such test the insulator is suspended in insulating oil and a certain minimum potential is applied. The value of this potential in case of suspension insulator is 1.3 times that of dry flashover voltage. The good insulator should not puncture under this test.

For ceramic insulator (160 KN Insulator)

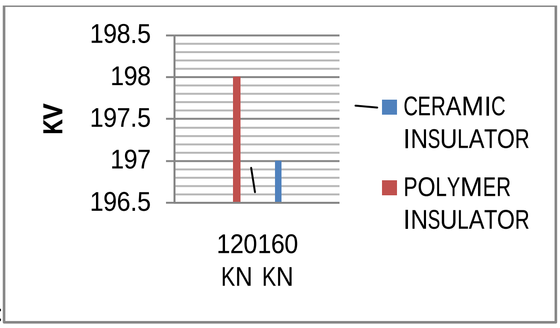
Ta**ble.13: Puncture test reading of ceramic insulator**

Sample no	Voltage (KV)	Remark
1	192	Punctured
2	194	Punctured
3	196	Punctured
4	197	punctured

For polymer insulator (120 KN Insulator)

Table.14: Puncture test reading of polymer insulator

Sample no	Voltage (kv)	Remark
1	193	Punctured
2	196	Punctured
3	198	Punctured



Remark: Table 13 and table 14 shows the punctured voltage for 120 KN polymer insulator are more than 160 KN ceramic insulator.

v) Tensile strength test (for polymer insulators)

Tensile strength test is used to evaluate the tensile (tension) properties of vulcanized thermo-set rubbers and thermoplastic elastomers.

There are two methods that are employed according to ASTM Standards:

Test method A- Dumbbell and Straight Section Specimens

Test method B- Cut Ring Specimens

The method that we have employed is Test method A and Dumbbell specimen is used.

Test procedure:

1 .Measure the thickness and width of the dumbbell rubber sample using Vernier calipers and scale.

2. Place one end of a dumbbell specimen in the upper grip of the testing machine.

3. Attach the lower grip of the machine by means of the gripping mechanism to the dumbbell specimen in the upper grip.

4. Care has to be taken to place the dumbbell specimen symmetrically in the grips of the testing machine so that tension is uniformly distributed over the entire cross-section of the sample.

5. Using the scale measure the initial gap (initial length) between the upper and the lower grip.

6. Provide a particular load or force to the machine in units of Newton.

7. Start the grip separation motor or mechanism for normal testing, and allow it to run.

8. At a particular point i.e. at breaking load, the rubber sample ruptures and breaks apart. Note down all the values indicated in the machine. Immediately stop the grip separation motor.

9. Using a scale measure the gap (elongated length) between the upper and the lower grip when the motor is stopped.

10. using all the parameter values that have been noted, calculate percentage elongation and ultimate tensile strength of the rubber sample using the following formulae.

1. Percentage elongation = (elongated length / initial length) x 100

2. Ultimate tensile strength = breaking load / (width x thickness)

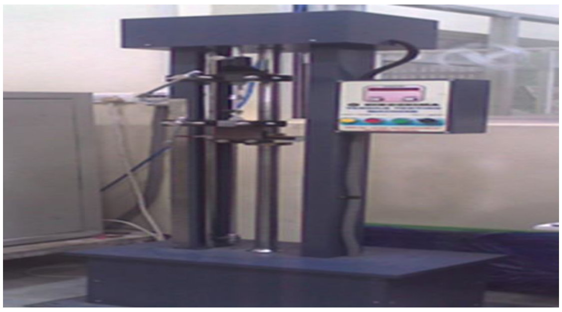


Fig.7 Tensile strength testing machine

Calculations:

SOLID RUBBER SAMPLE

Thickness of rubber sample before the test is 2.1mm and width is 6mm.

After applying load:

Initial length is 87mm and elongated length is 220mm

Breaking load = 53N

Percentage elongation = (elongated length / initial length) x 100

= (220 / 87) x 100

= 252.87%

Ultimate tensile strength = breaking load / (width x thickness)

= 53 / (2.1 x 6)

= 4.2 N/mm^2

Observations:

From the test conducted on the samples and calculations, we can conclude that ultimate tensile strength of Solid rubber material is higher. Hence it is more flexible in nature. So this type of materials can be used for making composite insulators as one is strong.

Table.15 tensile test readings on polymer insulator

Thickness(mm)	Width (mm)	Initial length (mm)	Initial reading(mm)	Final reading (mm)	Load (N)	Tensile strength(cm^2)	Elongation (%)
2.23	5.5	51	70	135	65.2	527.5	92.9
2.22	5.5	53	73	110	47.7	387.8	50.7
2.20	5.6	56	75	140	69.5	524.3	86.7
2.22	5.6	57	77	140	63.9	514.5	81.8
2.22	5.5	56	76	140	69.9	527.1	84.2

vii) Hydrophobicity test (for polymer insulator)

Scope:

The superior electrical performance of composite insulators and coated insulators stems from the hydrophobicity (water-repellency) of their surfaces. The hydrophobicity will change with time due to exposure to the outdoor environment and partial discharges (corona).

Seven classes of the hydrophobicity (HC 1-6) have been defined; HC 1 corresponds to a completely hydrophobic (water-repellent) surface and HC 6 to a completely hydrophilic (easily wetted) surface.

These classes provide a coarse value of the wetting status and are particularly suitable for a fast and easy check of insulators in the field.

Test equipment:

The equipment needed is a common spray bottle and a H.V High Frequency Resonant variable voltage corona generator. The spray bottle is filled with tap water and it produces a fine mist. The water shall not contain any chemicals, as detergents, tensides, and solvents. Complementary equipments which could facilitate the judgment is a magnification glass, a lamp, and a measuring-tape.

Specifications of corona generator:

1. H.V High frequency resonant variable voltage corona Generator with output of 0 to 35 kV AC.

•Input voltage: 230V/ 50Hz

•Phase: Single phase @ 50Hz

•Maximum output voltage: 35kV (Resonant type)

•Maximum current: 5mA

•Resonant frequency: 27 kHz

•Peak RF current: 10A

•Total energy in joules: 100 Joules

•Voltage control: Yes starting from 0 to 35kV

•Grounding: Yes minimum 10 ohms required

•ON duration: maximum 1 hour continuously

2. Low voltage plate of 300mm x 300mm and a 3 static H.V Termination with metallic probes of 25mm x 25m

Test setup:

Fig.8 Hydrophobicity test setup

Test procedure:

1. The surface of selected samples shall be cleaned with isopropyl alcohol. Allow the surface to dry and spray with water. Record the HC classification. Dry the sample surface.

2. Treat the surface with corona discharges to destroy the hydrophobicity. This can be done utilizing a high frequency corona tester. Holding the electrode approximately 3mm from the sample surface slowly move the electrode over an area approximately 1”x 1”. Continue treating this area for 2-3 minutes, operating the tester at maximum output. The sample is placed around 3mm below the corona probe so that corona discharges are clearly visible. Dielectric strength of air is 3kV/mm. The voltage is gradually increased from zero and around 30kV, the corona discharges are visible. The surface of rubber is treated with these corona discharges.

3. Immediately after the corona treatment, spray the surface with water 1 – 2 times per second from a distance of 25cm. The spraying shall continue for 20 – 30 seconds. The judgment of the hydrophobicity class shall be performed within 10 seconds after the spraying has been finished.

4. Record the HC classification as shown in the fig.4.3.8. The surface should be hydrophilic with an HC value of 6. If not, dry the surface and repeat the corona treatment for a longer time until an HC of 6 is obtained. Dry the sample surface.

5. Allow the sample to recover and repeat the hydrophobicity measurement at several time intervals. Silicone rubber should recover to HC 1- HC 2 within 24 to 48 hours, depending on the material and the intensity of the corona treatment.

Criteria:

The actual wetting appearance on the insulator has to be identified with one of the seven hydrophobicity classes (HC), which is a value between 1 and 6. The criteria for the different classes are given in below table. Also the contact angle (θ) between the water drops and the surface must be taken into account. The contact angle is defined in fig. 4.3.7. There exist two different contact angles, the advancing contact angle (θa) and the receding contact angle (θr). A drop exhibits these angles on an inclined surface.

The receding angle is the most important when the wetting properties of an insulator shall be evaluated. The inclination angle of the surface affects the θr.

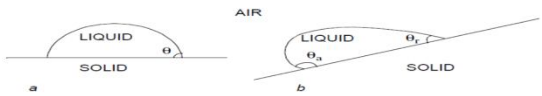


Fig.9: Contact Angle

a. horizontal plan

b. inclined plane

Where θa = advancing angle

θr = receding angle

HC	Description
1	Only discrete droplets are formed. $\theta_r \approx 80°$ or larger for the majority of droplets.
2	Only discrete droplets are formed. $50° < \theta_r < 80°$ for the majority of droplets.
3	Only discrete droplets are formed. $20° < \theta_r < 50°$ for the majority of droplets. Usually they are no longer circular.
4	Both discrete droplets and wetted traces from the water runnels are observed (i.e. $\theta_r = 0°$). Completely wetted areas < 2 cm^2. Together they cover < 90% of the tested area.
5	Some completely wetted areas > 2 cm^2, which cover < 90% of the tested area.
6	Wetted areas cover > 90%, i.e. small unwetted areas (spots/traces) are still observed.

Criteria for the Hydrophobicity Classification(HC1-6)

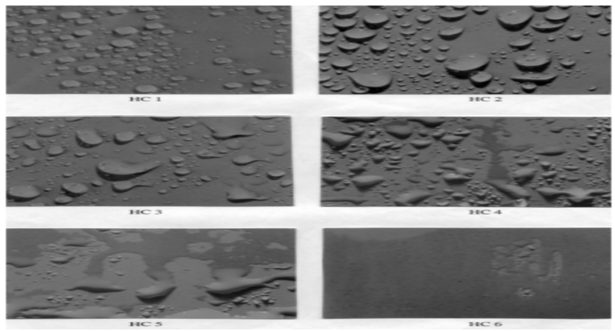


Fig.10 Typical examples of surfaces with HC from 1 to 6

Advantages of hydrophobicity for electrical outdoor insulation:

1. In contrast to hydrophilic materials, hydrophobic surfaces prevent complete wetting due to fog, dew or rain and therefore more isolated droplets are formed.

2. Complete wetting would result in electrically conductive layers, which are the reason for leakage currents. These leakage currents can dry the wet layer and form small

electrical arcs, which can attack/damage the surface and may intensify until a complete flashover. Hydrophobicity reduces leakage currents, which finally lowers the flashover probability. In other words hydrophobicity results in better insulator reliability.

3. Due to the lower discharging activity, the surface is less influenced so that erosion is reduced and life expectancy of the insulator is improved.

Dow corning rubber sample

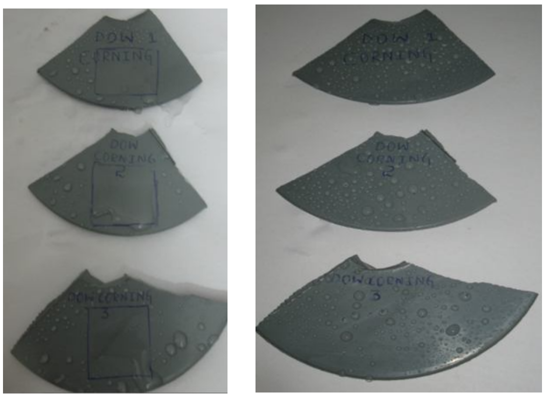


Fig.11 Sample 1 before test and after treating with corona discharge

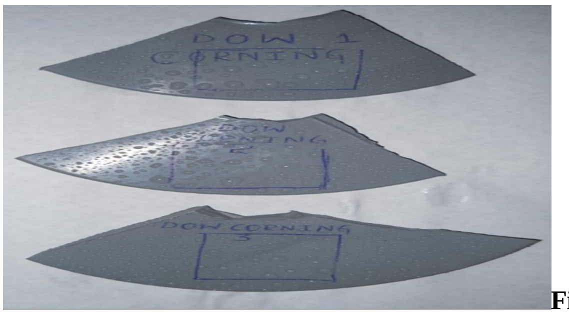


Fig.12 Sample 1 after recovery of hydrophobicity

Observations on sample:

The one type of rubber sample tested is of 'Dow Corning' make. The hydrophobicity classification is observed to be HC 1 before the test as shown in fig.4.3.9. After treating the samples with corona discharge the hydrophobic property of the silicone rubber is destroyed and the classification is observed to be HC 5 as shown in fig.4.3.9. It is observed that the sample has recovered its hydrophobic property within 24 hours after the test and the classification is observed to be HC 1 or HC 2 as shown in the fig.4.3.10. This sample is found to be suitable for composite insulators

From the above tests conducted on ceramic and polymer insulator, finally concluded that polymer is best insulator

4. Comparison between porcelain and composite insulators

Weight ratio of Porcelain to Silicone Composite insulator for Railway Traction applications is 3:1.

Weight ratio between porcelain insulator and composite long rod insulators for transmission line applications is more than 10:1 making composite insulators an ideal insulator for lines with limited right of way.

Fig.13 Traction and Long Rod Insulators

5. Conclusion

Non-ceramic insulators, particularly silicone composite insulators, are being widely adopted all over the world. This report provides details of the design, manufacturing and the three tests that are carried on composite insulators to evaluate its performance by simulating the environmental conditions. Based on this study, the following conclusions can be drawn and some suggestions made:

- Silicone composite insulators have been widely adopted in several countries in different high voltage applications such as insulators for distribution, transmission and traction, bushings, instrument transformers, surge arrestors, etc.
- Several advantages of silicone composite insulators have been cited for its increased adoption, such as better pollution performance, lower weight, flexibility, shock resistance, etc.
- One of the main advantages cited for silicone polymers is their high hydrophobicity and also retention of this characteristic under hostile environment. This has been the main reason for its increased adoption for housing/shed material in high voltage applications.
  So finally concluded that polymer is best insulator compared to ceramic insulators.

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