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Experimental Study on Optimization of Filler Concentration of Silicon Rubber Compound Used in High Voltage Insulators

Allu Shanmukha Rao[1], Dr. N. Sumathi[2], Dr. N. Vasudev[3]
[1]*University College of Engineering Kakinada, Kakinada, Andhra Pradesh.*
[2]*Associate professor of EEE UCEK*
[3]*Retd. Additional Director & Group Head, CPRI Bangalore*

Abstract: ***In any power transmission system, insulators are essential for a reliable electrical power supply. The Efficiency of insulators will be decided by their electrical and mechanical properties. Recently in many of the power transmission systems, the conventional porcelain insulators are being replaced by polymeric insulators due to various advantages in their properties. Polymeric insulators have been increasingly popular in recent years as a result of their superior performance in contaminated environments due to their hydrophobic nature. However, research is still being carried out on Polymeric material with regards to ageing condition and feasibility for large scale utilization. Ageing of insulation is due to Environmental, Tracking and Erosion conditions. Ageing leads to immature failures and uncertainty in the performance of the insulators. The constituent materials and their properties have a significant impact on the performance of polymeric insulators. There is a strong need to look into newer filler materials which can be added to the existing polymeric base materials to constitute a composite. Keeping this in mind, in the proposed research uses Silicone rubber as base polymeric material and along with that additives are added to arrive at three different composites. A new filler material will be added to the base material forming a new composite. All these HTV Silicone rubber based composites are then tested the recovery of hydrophobicity, dielectric strength, hardness, specific gravity, tensile strength , ultimate elongation ,tear strength properties based on ASTM standards. Further, Inclined plane Tracking and Erosion studies are also conducted on the polymeric test samples for 6 hours to evaluate the SiR housing material suitability for outdoor insulator applications by subjecting them to AC high voltages under laboratory conditions as per IEC 60587 standards.***

Keywords: ***Recovery of hydrophobicity, dielectric strength, hardness, specific gravity, tensile strength, ultimate elongation, tear strength, inclined plane tracking and erosion, ageing, filler material.***

I. INTRODUCTION

The modern world's advancements are heavily reliant on a reliable supply of electricity. With increasing power demands, utilities must provide reliable and secure power delivery while also improving the technical and economic performance of the power distribution system. To carry electric energy from power plants to end customers, high-voltage power lines are commonly employed. Outdoor insulators are one of the most important components of the electric power transmission network, serving two main functions: 1) Isolate the transmission tower from the high-voltage source; 2) Provide a load-bearing platform capable of sustaining large overhead conductors well above the earth.

The life of a polymeric insulator is largely dependent on the durability of the housing material, its behaviour is intimately tied to that of the housing. The resistance to tracking and erosion, followed by hydrophobicity, are the most critical properties of the housing material. Epoxy resin, ethylene propylene rubber (EPR), and silicone rubber have all been tested in the development of housing materials for polymeric insulators around the world. However, the housing must be made of rubber for mechanical reasons, and rubber is the most common material used nowadays for polymeric insulators. Silicone rubber is made up of a base polymer, inorganic fillers, and a crosslinking agent, and it is not a one-of-a-kind material. Fillers are added to improve the tracking and erosion properties, in addition to their mechanical strengthening role.

SIR is the only housing material capable of transferring its water-repellent properties to a surface pollution layer. As a result, leakage currents are minimised and the possibility of flashover occurance is also reduced. Furthermore, these silicone rubber insulators don't need to be cleaned. High thermal stability, stable performance throughout a wide temperature range, and strong resistance to corona, ozone, and weathering are all characteristics of SiR. For more than 30 years, it has demonstrated its exceptional appropriateness for outdoor applications, even in the harshest of environments. Silicone rubber is a polymer that is commonly used to insulate outdoor areas. It keeps its hydrophobicity and the capacity to transfer it to adherent contaminants throughout its service life.

The deterioration of insulator material over time, or the impact generated after a specified duration of service in its field, is referred to as insulator ageing. Insulator ageing is primarily concerned with the deterioration of the outer sheath/shed. Deterioration of insulator materials is caused by the breakdown of large molecules, which results in a decrease in molecular weight. External influences cause the substance to break down slowly. It starts on the insulator's surface and works its way down into the substance. The insulator's electrical and mechanical performance degrades as it ages. Therefore, determining their life expectancy is problematic.

A. Motivation

As per the report utilities are gave the complaint that the polymeric insulators were failed in the northern region of india ,due to heavy snowfall during the winter season. Due to the heavy snowfall the contaminants deposited on the surface gets wet and form electrically conductive paths on the insulator surface. These events cause a flow of leakage current along the insulator surface, resulting in the formation of dry bands and pollutant flashover as a result. Power system reliability lost due to flash over occurrence. The reason for this is the use of less percentage of silicon rubber along with filler content, when making the composite insulating material. To overcome the pollution flash over, there is an emergency to develop a new composite insulating material to improve its performance in outdoor applications.

II. MATERIAL PREPARATION

The base polymer was mixed with a series of additives to make silicone rubber. HTV SiR is being produced for use as an outside housing material in AC composite insulators in the current study. To make the HTV silicone rubber, the basic polymer PolyDiMethyl-Siloxane (PDMS), reinforcing filler fumed silica, extending filler Alumina Tri-Hydrate (ATH), mould release agent silicone oil, colouring agent carbon black, and vulcanizing agent organic peroxide were carefully selected and blended.
To make the rubber mixture, the base material PolyDiMethylSiloxane (PDMS) was mixed with reinforcing filler and mould release agent in a Sigma mixer for one hour. In a sigma mixer, this material was again mixed with extending filler for one hour. Colorant, additive, and vulcanizing agent were used to make a master batch of the colouring agent, which was then added to the rubber mixture using a two-roll mill. In a two-roll mill, the rubber compound was mixed for 10-15 minutes. Figure 2.1 shows a flow chart for rubber compounding.

A. Sigma Mixer

Sigma blade mixers are used as batch mixers commonly employed for mixing high viscosity materials such as rubber. Sigma mixer is shown in the Figure 2.2.

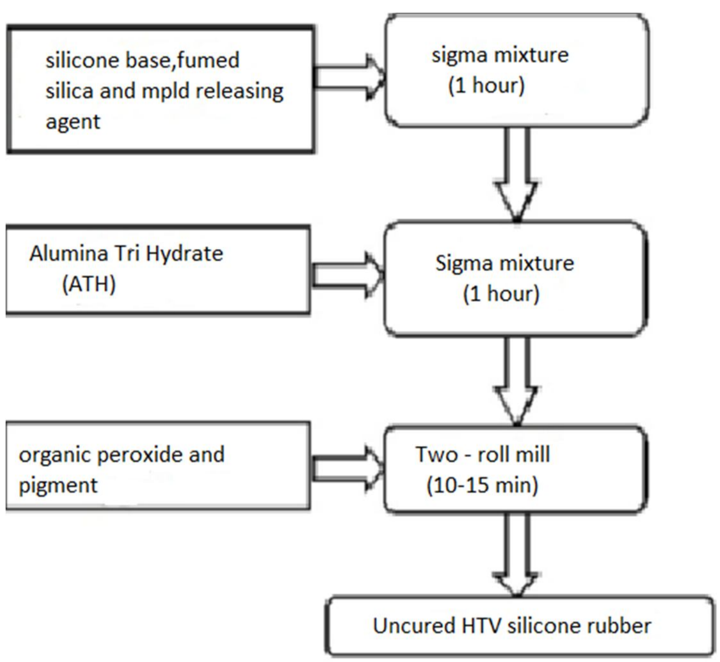

Figure 2.1: Flow chart for rubber compounding

Figure 2.2: Sigma Mixture

The basic component of the Sigma blade mixer is a rectangular trough that is curved at the bottom to form two half-cylinders. The two blades rotate at different frequencies as they approach each other. Typically, a two-to-one ratio is used. In order to generate mixing, both axial and tangential motion must be used. To avoid stagnant areas, the space between the blades and the shell is modest, about 1mm. The material to be combined was poured into the mixer through the top lid, which was then shut. The mixed substance was discharged by tilting the container assembly.

B. Two-roll mill

A two-roll mill is used to incorporate additives into rubber. Figure 2.3 depicts a two-roll mill.

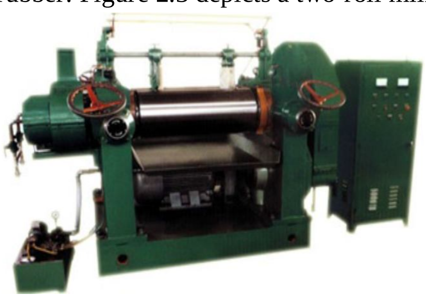

Figure 2.3: Two-roll Mill

These mixers are distinguished by forcing the mixture to travel repeatedly through compressive zones where dispersive mixing occurs, in addition to imparting laminar distributive mixing. Following the addition of additives, processing oil, or plasticizers to the rubber, the mill operator begins cutting the rubber from one side of the mill and passing it to the opposite side in order to cross blend the batch. The batch is cut from the mill at the end of mixing for storage or packing. The strong shear created at the mill nip, which breaks up agglomerates and pushes ingredient inclusion, is a primary advantage of roll mill mixing.

C. Formulations

Three formulations of HTV silicone rubber were prepared by varying the filler ATH content and silicone rubber content such as rubber compound with silicone rubber, ATH filler, mold releasing agent and curing agent.

1) *Silicone Base Preparation:* Silicone base was prepared using base polymer PDMS and filler fumed silica and mold releasing agent like silicone oil. Base polymer and fumed silica were taken in 1 by 1 weight ratio and were mixed along with mold releasing agent using sigma mixer for one hour to get homogeneous mixture. Flow chart is shown in the Figure 2.4.

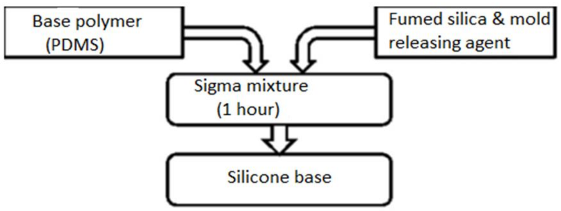

Figure 2.4: Flow chart for silicone base preparation

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2) *Preparation of Formulation*

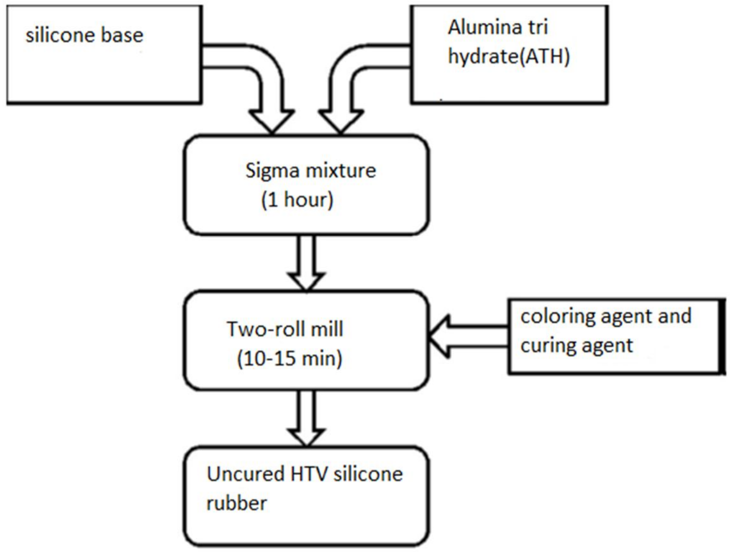

Figure 2.5: Flow chart for formulation

It consists of silicone base, ATH, colouring agent and curing agent. silicone base filler-ATH were taken and mixed for 1 hour in sigma mixture. Colouring agent and curing agent were added to this mixture in two-roll mill and mixed for 10-15min. Uniformly mixed uncured HTV silicone rubber compound was taken out from the two roll mill in the form of rubber sheet.

3) *Preparation of Rubber Sheets:* Rubber sheets of thickness 2mm and 6mm were prepared for testing the different properties of HTV silicone rubber compound. The sheets were prepared by compression molding machine. The curing temperature of the HTV silicone rubber was 160 degree centigrade and curing time was 10 minutes. Programmed compression molding machine with curing time and curing temperature defined was used. Molds of required size were taken and heated to 160 centigrade. The uncured HTV silicone rubber sample weighed according to the required the thickness and placed in the pre-heated mold. Pressure of 160 kg/cm^2 was applied and left for 10 minutes for curing. The cured rubber sheets were taken out and used for testing different properties. The rubber sheet used in this research work is made with the following percentages shown in table 2.1.

S.NO	MATERIAL	SAMPLE-1 (in "%")	SAMPLE-2 (in "%")	SAMPLE-3 (in "%")
1	Silicone rubber	46	48	43
2	ATH(Processing aid)	51	49	54
3	Mold releasing agent	1	1	1
4	Curing agent	1	1	1

Table 2.1 rubber sheet material prepared with different formulations

III. EXPERIMENTAL SET UP AND TEST PROCEDURE

Polymeric are widely employed in HV (High Voltage) applications due to their excellent characteristics and ability to withstand pollution. However, with time, they begin to degrade due to the combined effects of voltage and pollution. An accelerated ageing test is carried out in the laboratory to investigate the effects of ageing caused by the combined effects of voltage stress and pollution. Mechanical, electrical, physical, thermal, and material qualities are all important characteristics of rubber compounds. Mechanical properties such as tensile strength, ultimate elongation, and tear strength were investigated; electrical properties such as resistance to tracking and erosion, loss and recovery of hydrophobicity by corona ageing test, dielectric strength, and arc resistance were investigated; and physical properties such as hardness (shore-A) and specific gravity were investigated for three different composite filler materials according to ASTM and IEC standards.

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A. Inclined Plane Tracking and Erosion test (IPTE test)

IPTE tests are performed with a continuous duty 50 Hz 230 V / 15 kV AC testing transformer with a 5 percent output voltage stabiliser that may be changed up to around 10 kV and a rated maximum current of 1 A. During the IPTE test, the test samples are exposed to a constant 4.5kV AC rms voltage for six hours. On the high voltage side, a 33 k (200 Watt) series resistance is utilised, and the liquid contaminant flow rate is set to 0.6 ml/min. Figure 3.1 depicts the schematics of an AC Inclined Plane test setup.

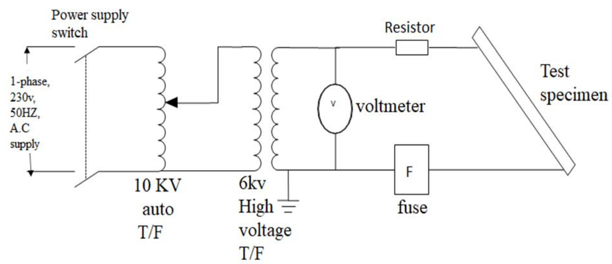

Figure 3.1: Schematic diagram of IPTE test

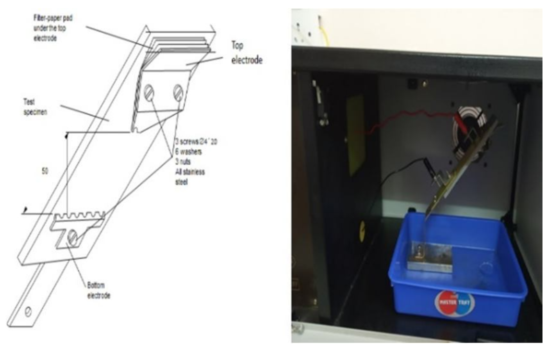

Fig3.2: IPTE experimental test set-up

Conditions for tracking and erosion test

1) No over current tripping i.e the leakage currents should not exceed more than 60mA.
2) No tracking and erosion takes place on the surface
3) Tracking occurred longer than 25mm with radius greater than 0.25mm from the bottom electrode, the sample treated as failed .
4) Without tracking if only erosion occurred. The depth of the erosion is more than 3mm depth, the sample treated as a failed.

B. Recovery of Hydrophobicity by Corona Ageing Test

The pin-plane electrode system for corona ageing is shown schematically in Figure.3.3, where T1 is a voltage regulator with a capacity of 20 kVA, T2 is a test transformer with a rated voltage of 15 kV and capacity of 10 kVA, V is a capacitor voltage divider, Rp is a 25 k protecting resistor, and Pin and Plane make up the pin-plane electrode system for corona ageing where the tip curvature STRI is used to calculate contact angles. The STRI guide is use to determine the degree of hydrophobicity of the insulators' surfaces.

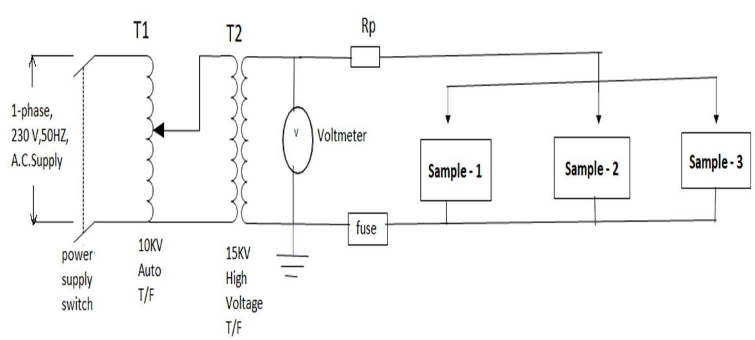

Fig 3.3 : schematic diagram of corona ageing test

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C. Hardness Test


Fig 3.4: hardness measurement of polymeric test sample

The shore-A durometer is a portable tool that uses a truncated cone indenter tip and a calibrated steel spring to measure the resistance of rubber to indentation. When the durometer is placed on a flat rubber sample, the indenter point of the durometer is forced back toward the durometer body. The spring opposes and resists this force. After strong contact between the durometer tip and the sample, a reading is taken within two seconds.The average value was obtained from three readings. The hardness was measured using an HTV silicone rubber sheet with a thickness of 6 mm. This test was performed in accordance with the ASTM D 2204 reference standard.

D. Dielectric Strength

Dielectric strength is the maxium voltage required to break the insulating material. Higher dielectric strength indicates higher quality of insulator ,it means it will not pass current through it. so the insulator should not loose its properties for its maximum voltage.

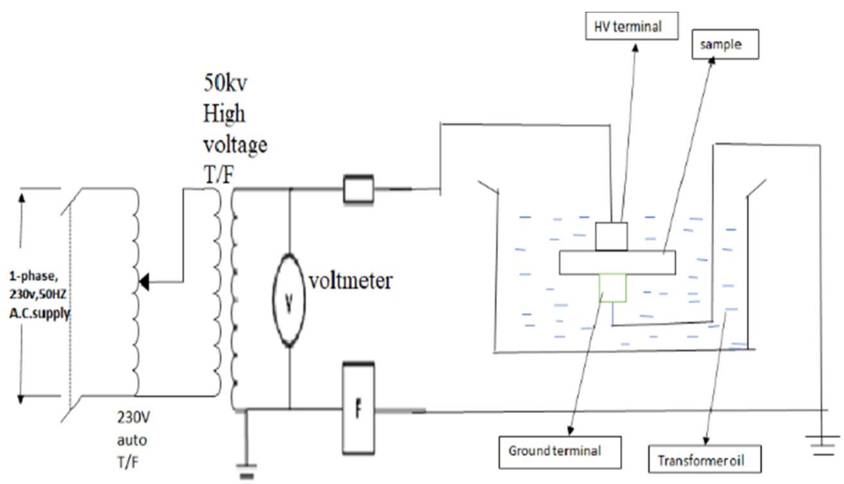

Fig 3.5: 50kv breakdown voltage tester

Break down voltage was measured using 50kV BDV tester as shown in Figure 3.5. A 150mm X 150mm test samples were cut from a rubber sample with a thickness of 2mm and analyzed in an oil medium according to ASTM D 149/IEC 60243. The specimen was sandwiched between top electrode of size 30mm and bottom electrode of size 20mm. Test voltage was applied at the rate of rise 2kV/second up to the breakdown. Voltage at which the specimen got punctured was divided by specimen thickness and noted as dielectric strength. Dielectric strength is measured in kv/mm.

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E. Dry Arc Resistance

Arc resistance is the electrical property of polymer material. It makes the surface of the insulating material become conductive. When an electric current flows through an insulator's surface, a conductive path is formed on the surface of the polymer insulator over time or the polymeric material's capacity to resist a high voltage and low current electrical arc. The time it takes to make a polymer material electrically conductive under high voltage and low current laboratory conditions is known as arc resistance. The time it takes for an arc to form is measured in seconds.

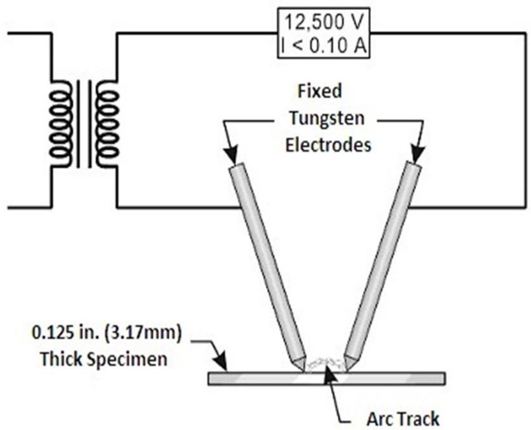

Fig 3.6: schematic diagram of arc resistance tester.

Fig 3.7: Arc resistance tester

Flat specimens of size 150mm X 150mm were cut from the cured HTV silicone rubber sheet of thickness 2 mm. Arc resistance tester was used to measure the arc resistance as shown in Figure 3.7. When the test was began, the test sample was positioned below the electrodes, and an arc was formed between the two electrodes. The spacing between both the electrodes was kept at 6 mm in accordance with ASTM D495. Arc resistance was defined as the time it took to generating conductive channels on the specimen by arcing.

F. Tensile Strength

Tensile strength is defined as the maximum tensile stress applied in stretching a specimen to rupture. Or the force required to break the rubber specimen is called as tensile strength. It is expressed in megapascals or kN/cm^2. It is necessary to measure the task needed to get its rupture of a rubber material to qualify a rubber mechanically.

Tesnsile strength is the mechanical property of the material. Tensile tests determine how strong and stretching an object is. Following calculations can be made from the tensile strength results: (1) tensile strength at yield point (2)tensile strength at break point. (3)strain (4)tensile modulus (5)elongation at yield point (6)elongation at break point. Tensile tests are usually performed on electro-mechanical or universal testing machines are easy to maintain and fully standardized.

1) *Experimental Test Set Up To Measure The Tensile Strength And Ultimate Elongation:* Tensile strength tests are performed on universal testing machine ,also called as tensile strength testing machine. The universal testing machine consists of test frame which is equipped with load cell, self tightening roller tensile grips, testing software and extensometer.

Fig 3.8: Universal Testing Machine

Tensile strength is usually measured as the amount of force in N/mm^2 needed to pull a test sample to the point of material failure. Three polymeric test samples were cut into a dumbell shape with dumbbell cutter press.

Fig 3.9: dumbbell cutter press .

Fig 3.10: dumbbell shaped samples.

Specimen thickness is measured with digital micrometer and input directly into the software. Width is measured with vernier caliper and input directly into the software. Test was carried out using universal testing machine as shown in Figure 3.8. This test is performed by placing a dumbbell shaped model test sample in the between the grips or jaws of a universal testing machine. gradually pull the grip until the dumbbell shaped test sample broken. As the pull progress the sample is extended from top end at a uniform rate, which is proportional to the rate at which load or pull force increases. Further pulling of the test sample beyond the proportional limit and elastic stress limit, leading to permanent elongation or deformation of the test sample. The tensile strength of a specimen is the force applied to it at the time of rupture. The stress and strain curve can be used to determine tensile strength and ultimate elongation. This test was performed in accordance with ASTM D 412.

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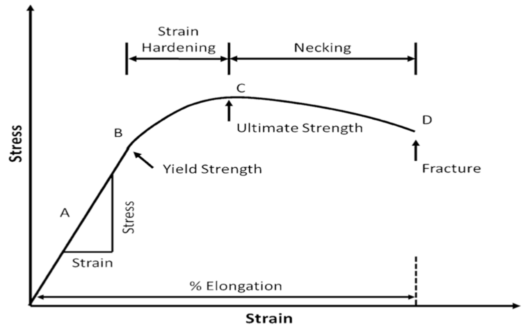

Fig 3.11: stress and strain curve

G. Ultimate Elongation

When tensile stress is applied to a rubber specimen, its elongation is defined as the percentage increase in its initial length. The elongation at the time of specimen rupture is referred to as ultimate elongation. It's calculated in percentages. The rubber's hardness and tensile strength are inversely proportional to its elongation. That is, while a material's hardness and tensile strength are higher, its elongation is lower. Stretching hard, high-tensile-strength materials requires more force than stretching soft, low-tensile-strength materials.

Figure 3.12: Dumbbell shaped specimen for tensile strength and ultimate elongation test

H. Tear Strength

When strain is applied to a rubber sample, tear strength or tear resistance refers to the resistance to the growth of a cut or nick. Tear resistance is a crucial concern when removing the cured rubber from the mould. As illustrated in Figure 3.13, the test specimens were made according to ASTM D 624. The test specimen was cut from cured rubber sheet with a thickness of 6 mm with a standard die, and the test was performed on a universal testing machine.

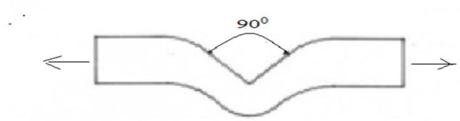

Fig. 3.13 : Sample for testing tear strength test

The sample was placed in the testing machine's grips, and a uniform pulling force was applied to it until it broke, as illustrated in Figure 3.8. The tear resistance of the sample is calculated by dividing the force at the site of rupture by the thickness of the specimen. The value was calculated after testing three specimens. This test was performed in accordance with ASTM D 624**.**

I. Specific Gravity

Fig 3.14: digital specific gravity balance meter

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The ratio of a material's density to the density of a reference substance is known as specific gravity. Water is almost often the reference substance. As illustrated in Figure 3.14, the specific gravity of HTV silicone rubber was determined using a digital specific gravity balance metre.

The technique for determining the specimen's specific gravity is straightforward: a known amount of cured HTV silicone rubber sample was weighed in air, the weight was saved, and the sample was then placed in the water container of the digital specific gravity balance metre. This test was performed in accordance with ASTM D792 as the reference standard.

IV. RESULTS AND DISCUSSIONS

Different electrical and nonelectrical properties of HTV silicone rubber compound are mainly studied in this research work. Results of the research work are presented here for different compositions of SiR material.

A. *Electrical Properties*

Electrical properties like inclined plane tracking and erosion test, recovery of hydrophobicity by corona ageing test, dielectric strength test, dry arc resistance test were examined for each different formulations of SiR material.

1) *Inclined Plane Tracking and Erosion Test:* Resistance to tracking and erosion test was conducted in AC voltage following the constant voltage application method (Method-I IEC-60587 and ASTM D2303) continuously for six hours duration. The constant voltage of 4.5kV AC was applied to the SiR samples. The results of the tests are presented and discussed below.

a) *Sample-1:* On the silicone rubber samples (S1.1, S1.2, S1.3, S1.4), there was no tracking or erosion, and all samples sustained the 4.5kV test voltage, with the exception of sample S0, which had a low concentration of silicon rubber and a high quantity of filler. As seen in Figure 4.1, sample S0 failed the IPTE test early on. Materials added as impurities or fillers in other silicone rubbers have a huge effect on the performance of SIR insulators, as they enhance the concentration of dynamic LMW components. It has been discovered that increasing the ATH filler type in HTV silicone rubber has a significant impact on the anti-tracking capabilities.

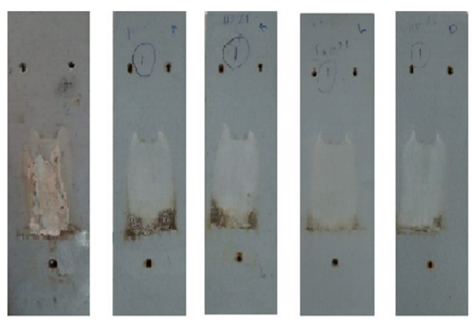


Fig: S0 Fig: s1.1 Fig: S1.2 Fig: S1.3 Fig: S1.4

Fig :4.1 Test samples after the IPTE test

The hydrophobicity of the test samples was also noticed in addition to the tracking and erosion. All of the samples lost their hydrophobic nature immediately after the test, as seen in Figure: 4.2. A material's hydrophobicity is determined by the presence of Low Molecular Weight Components (LMW) on its outer surface. The greater the LMW on a material's surface, the higher its hydrophobicity, and vice versa. The loss of hydrophobicity is caused by the removal of low molecular weight components from the surface, which are eliminated either by excessively wetting conditions combined with the application of electrical field, or by dry band arcing caused by carbon tracking on the surface.

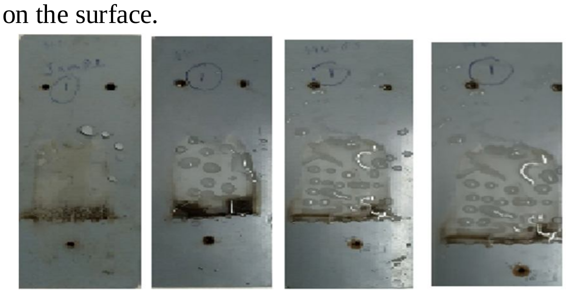


Fig 4.2: Test samples immediately after the IPTE test

All of the samples regained their hydrophobic character within 48 hours, as seen in Figure 4.3. Low molecular weight components are present naturally in many materials, but their number can be artificially enhanced by adding another material to them; for example, alumina trihydrate can be added to silicone rubber insulators to raise their LMW content in the bulk. Even if a considerable amount of LMW is present in a material, it does not guarantee that it is hydrophobic. To maintain good hydrophobicity, a material must be able to move LMW components from the interior bulk to the surface as their concentration on the surface decreases owing to hydrophobicity loss.

A stable cross structure exists in cured silicone rubber. Silicone rubber cannot be dissolved by solvents and does not melt even at extreme temperatures under optimum conditions. It has been discovered that some low molecular weight components always exist in silicon rubbers, which may be extracted from the inner bulk of the material and brought to the surface using appropriate solvents. Rain and wetness will cause the surface hydrophobicity of an insulator to recover if water is transformed into such a suitable solvent in some way. Natural diffusion, on the other hand, causes the movement of low molecular weight chains within the material even when no external solvent is used. Due to the removal of a significant amount of LMW from the surface, a transfer of LMW from the inner side to the surface occurs as a result of this diffusion process, which tends to restore LMW content on the surface and, therefore, hydrophobicity.

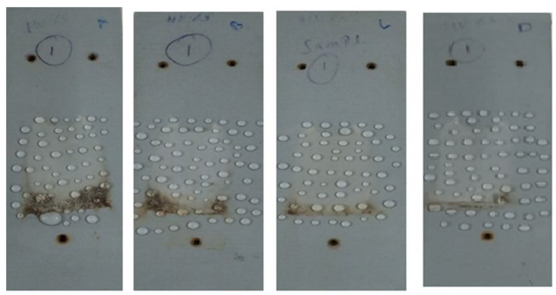


Fig 4.3: hydrophobic nature of the test samples

b) *Sample-2:* The silicone rubber samples (S2.1, S2.2, S2.3, S2.4) showed no evidence of tracking or erosion, and all specimens withstood a 4.5kV AC test voltage, with the exception of sample S0, which contains a low concentration of silicon rubber and filler. As seen in Figure 4.4, sample S0 failed early in the IPTE test. The anti-tracking capabilities of HTV silicone rubber are discovered to be greatly influenced by increasing the ATH filler type.

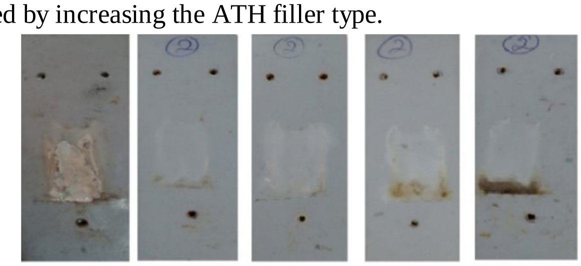


Fig:S0 Fig: S2.1 Fig: S2.2 Fig: S2.3 Fig: S2.4

Fig4.4: samples have no tracking and erosion

The hydrophobicity of the test samples was also checked, in addition to tracking and erosion. All test samples lost their hydrophobic characteristic immediately after the test, as shown in Figure:4.5. Similar to sample-1, there is a decline of hydrophobicity.

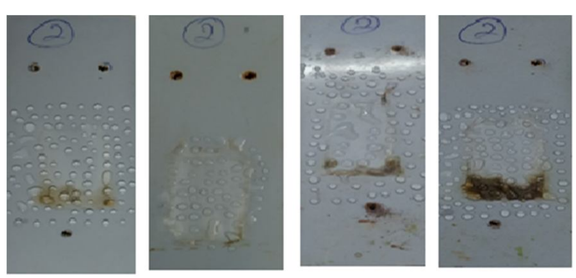


Fig 4.5: HC after the test

Within the 48 hours all the test samples regain its hydrophobic properties similar to the sample-1 as shown in Figure:4.6.

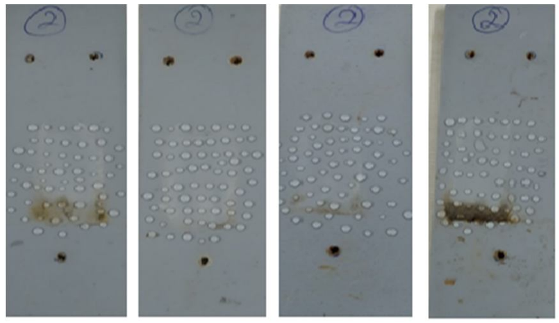


Fig 4.6: HC after the 48 hours of the test

c) *Sample-3:* Similar to sample-1, no tracking or erosion was seen on the silicone rubber samples (S3.1, S3.2, S3.3, S3.4).

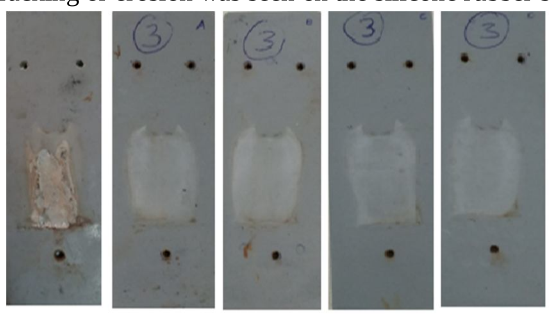


Fig 4.7: samples after the IPET test

The hydrophobicity of the test samples was also examined, similar to sample-1, in addition to assessing the tracking and erosion.

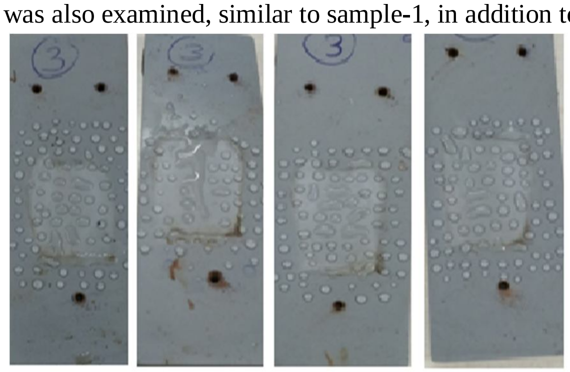


Fig 4.8: samples immediately after the test

Within the 48 hours all the samples regain its hydrophobic nature similar to the sample-1 shown in Figure:4.9.

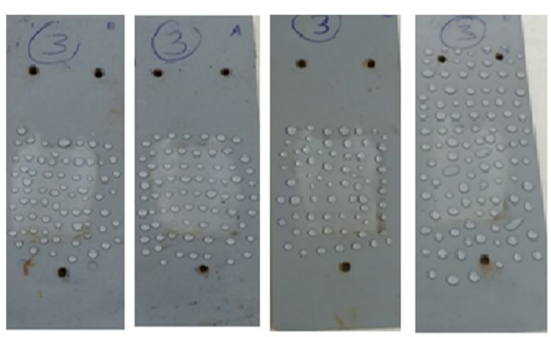


Fig 4.9: HC after 48 hours of the test

S.NO	SAMPLE NO	REMARKS
	S0	Failed at 4.5kv AC
SAMPLE-1	S1.1	Withstood 4.5kv AC
	S1.2	Withstood 4.5kv AC
	S1.3	Withstood 4.5kv AC
	S1.4	Withstood 4.5kv AC
SAMPLE-2	S1.1	Withstood 4.5kv AC
	S1.2	Withstood 4.5kv AC
	S1.3	Withstood 4.5kv AC
	S1.4	Withstood 4.5kv AC
SAMPLE-3	S1.1	Withstood 4.5kv AC
	S1.2	Withstood 4.5kv AC
	S1.3	Withstood 4.5kv AC
	S1.4	Withstood 4.5kv AC

Table 4.1: Sample conditions after 4.5 kV IPTE

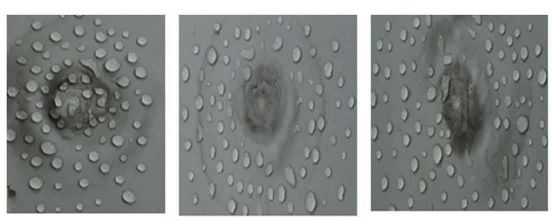
The failure of S_0 can be mainly due to the low percentage of silicone rubber material in the polymer matrix. The image of the samples was obtained at the end of each test and hydrophobicity was assessed using the STRI guide. It is also perceived that there is loss in hydrophobicity of the samples with the progression of test shown in Table 4.2.

sample	Unaged	aged
Sample-1	S1.1 - HC-1	HC-6
	S1.2 - HC-1	HC-4
	S1.3 - HC-1	HC-5
	S1.4 - HC-1	HC-5
Sample-2	S2.1 - HC-1	HC-3
	S2.2 - HC-1	HC-3
	S2.3 - HC-1	HC-3
	S2.4 - HC-1	HC-3
Sample-3	S3.1 - HC-1	HC-3
	S3.2 - HC-1	HC-4
	S3.3 - HC-1	HC-3
	S3.4 - HC-1	HC-3

Table 4.2: loss of hydrophobicity after IPTE

Among the three compositions S_2 & S_3 performed well in IPTE by means of recovery of hydrophobicity

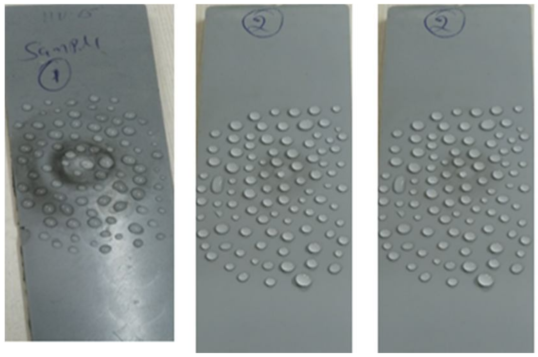
2) *Recovery of Hydrophobicity By Corona Ageing Test:* The hydrophobicity of all the samples was determined, and they were categorised into seven classes, ranging from HC1 to HC7. The hydrophobic and hydrophilic surfaces HC1 and HC7, respectively, are completely hydrophobic and hydrophilic. The difference in contact angle, which reflects a hydrophobic transfer, was discovered after exposing corona to three different substances. The surface lost its hydrophobicity after the corona was created on the sample, as shown in Figure4.10, and within 48 hours, the surface regained its hydrophobic nature, as classified as HC1.



Sample-1 sample-2 sample-3

Fig 4.10: change of hydrophobicity after the corona ageing test.

Within 48 hours, all of the samples regained their hydrophobic nature due to the transfer of LMW from the inner side to the surface, which begins due to this diffusion process and tends to restore LMW content on the surface and, therefore, its hydrophobicity.



Sample-1 Sample-2 Sample-3

Fig 4.11: samples recover hydrophobicity with in 48 hours

sample	Aged sample HC classification	Within 48 hours HC classification
Sample-1	HC-2	HC-1
Sample-2	HC-5	HC-1
Sample-3	HC-5	HC-1

Table:4.3 hydrophobicity of samples.

3) *Dielectric Strength:* Break down voltages and dielectric strength values of different formulations as shown in Table 4.4. HTV silicone rubber used in high-voltage outdoor applications must have a dielectric strength of at least 17.5kV/mm as per the standard. As indicated in Table 4.4 the cured silicone rubber compound's BDV (Break Down Voltage) is proportional to the concentration of the filler ATH. Formulation 3 has a higher Dielectric strength, which decreases as the ATH content of the material decreases.

Sample group	Sample dimensions	Co-sample	Break down voltage	Dielectric strength
Sample-A	(15mm*2mm*15mm)	Sample-A1	40KV	19.45kv/mm
		Sample-A2	37.8KV	
Sample-B	(15mm*2mm*15mm)	Sample-B1	35.9kv	18.7kv/mm
		Sample-B2	38.9kv	
Sample-C	(15mm*2mm*15mm)	Sample-C1	39.4kv	19.625kv/mm
		Sample-C2	39.1kv	

Table 4.4: Dielectric strength values for different formulations of silicone rubber

The dielectric strength test was passed by all three groups of samples, according to ASTM D 149/IEC 60243 standards.

4) *Dry Arc Resistance:* Figure 4.12 depicts the arc resistance values of various formulations of HTV silicone rubber for high voltage outdoor applications, as well as the specified minimum value. For HTV silicone rubber used in high-voltage outdoor applications, the standard minimum arc resistance value is 200 seconds. The arc resistance of the 48 percent cured rubber compound with the 49 percent concentration of filler ATH has been determined to be the highest. Figure 4.12 depicts the results of the tests on the three test samples.

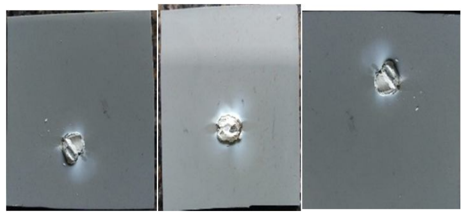


Fig 4.12: samples after the dry arc resistance test

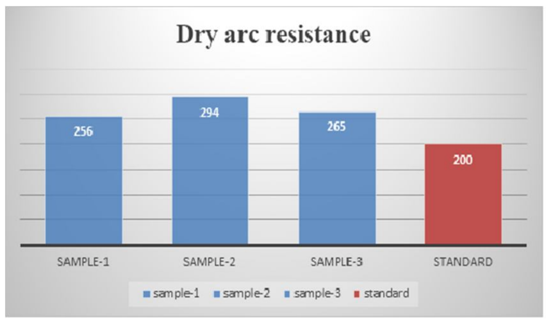


Figure 4.13: Arc resistance values for different formulations of silicone rubber

All the samples pass the dry arc resistance test as per the ASTM-495-1973 standard.

B. Mechanical Properties

Tensile strength, ultimate elongation, and tear strength were investigated for each formulation, and the results were plotted in the graph.

Figure 4.14 depicts the tensile strength of HTV silicone rubber for high-voltage outdoor applications for various formulations and the standard minimum value. HTV silicone rubber with a minimum tensile strength of 4 N/sq.mm is employed in high-voltage outdoor applications. The tensile strength of Formulation 3 is stronger, however it diminishes as the filler ATH concentration is reduced.

The ultimate elongation values for various formulations and the standard minimum value of HTV silicone rubber for high-voltage outdoor applications are shown in Figure 4.15. HTV silicone rubber used in high voltage outdoor applications has a standard minimum elongation value of 100 percent. Elongation is greater in Formulation-2 than in Formulation-3 and Formulation-1.

Figure 4.16 displays the tear strength results for several formulations of HTV silicone rubber for high voltage outdoor applications, as well as the required minimum value. Tear strength of HTV silicone rubber used in high-voltage outdoor applications must be at least 12 N/mm. Tear strength is stronger in Formulation-3 and diminishes as the filler ATH content increases. When the filler concentration rises while the silicone rubber concentration falls, the tensile and tear strength of the rubber compound increases.

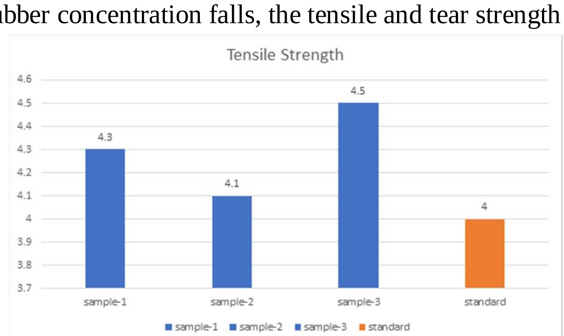


Figure 4.14: Tensile strength values for different formulations of silicone rubber

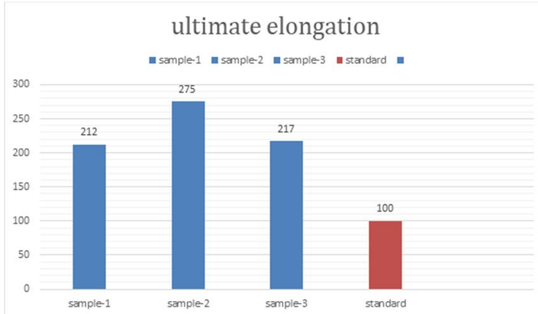


Figure 4.15: Ultimate elongation values for different formulations of silicone rubber

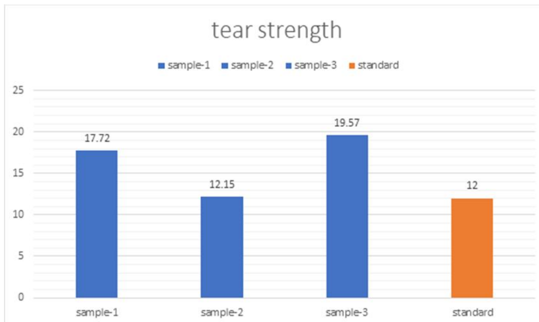


Figure 4.16: Tear strength values for different formulations of silicone rubber

Base silicone has the highest value of tensile strength, tear strength and ultimate elongation. When the concentration of filler is high then rubber compound shows higher values of tensile strength, tear strength and ultimate elongation which implies that to get better mechanical properties filler content must be higher.

C. Physical properties

Physical properties of different formulations of HTV silicone rubber made by varying the concentration of filler ATH were studied and compared with the standard formulation. The formulations are designated as S_1, S_2 and S_3. Hardness (Shore A), specific gravity were recorded for each formulation and shown in the Figure 4.16 & 4.17

1) Hardness

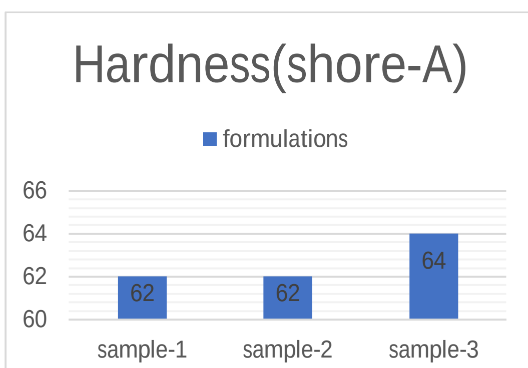


Fig4.16: Hardness values for different formulations of silicone rubber

The hardness (shore-A) values for various formulations are shown in Figure 4.17, as well as the standard range for hardness values. HTV silicone rubber has a defined hardness range of 61 to 75 for outdoor use. The hardness values of Formulation S3 were determined to be in the standard range when compared to those of Formulations S2 and S1. When compared to the other formulations S1 and S2; S3 was shown to be the most effective. Rubber with a hardness of less than 61 is soft, whereas rubber with a hardness of more than 75 is too hard for high-voltage outdoor use. With increasing ATH filler loading, the hardness value is increased.

2) Specific Gravity

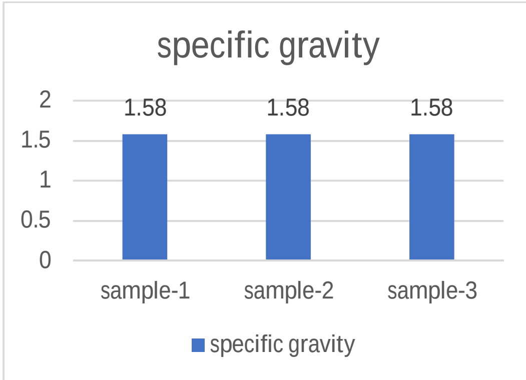


Figure 4.17: Specific gravity values for different formulations of silicone rubber

Figure 4.17 depicts the specific gravity values for various formulations as well as the specific gravity standard value range. HTV silicone rubber has a specific gravity of 1.52 to 1.58. all the three formulations meets the specified requirements as per the standard ASTM D 792.

V. AGEING OF THE MATERIAL PERFORMANCE

To improve the sample's ageing performance, it was subjected to a continuous 100-hours inclined plane tracking and erosion test at 6kv. Test specimen can tolerate upto 92 hours of exposure.

Fig 5.1 sample after 100 hours IPTE test

For 33kv,66kv………..765kv.
Standard creepage distance is (500-800)mm &
Standard Specific creapage distance is 20 mm/kv
Specific creapage distance = (creepage distance ÷ applied voltage)

$$20 = (500 \div V\sqrt{3})$$
$$V = (500 \div 20\sqrt{3})$$
$$V = (500 \div 34.6)$$
$$V = 14.56KV$$

For 50mm creapage distance $v = (50 \div 34.6)$
$= 1.44kv$

1.44kv is sufficient to initiate tracking and erosion on the insulator sample surface over a 50mm creapage distance. The applied voltage of 6 kV is four times the actual value. As a result, the tested specimen is more suited for outdoor use.

VI. CONCLUSIONS

Electrical and non-electrical properties of SiR materials were examined in this study. The IPTE test was carried out on SiR material in order to determine whether existing SiR insulator housing materials were suitable for outdoor use. Following is a summary of the findings of the detailed research:

Low percentage of Silicone rubber(13%) along with ATH filler fails to sustain the applied voltage for six hours and there was massive erosion observed on the specimen in inclined plane tracking and erosion test. 46 wt%(S1), 48 wt%(S2), 43 wt%(S3) Silicone rubber with 51 wt % (S1), 49 wt % (S2) ATH and 54 wt % (S3) ATH filler samples could able to resist the applied voltage for six hours duration. Adding ATH filler to the silicone rubber matrix increased tracking and erosion resistance.

All the three samples recover the hydrophobicity within 48 hours in corona ageing test. Immediately after the test, sample-1 not much effected to the corona compared to sample-2 and sample-3.

The hardness value found increased with the higher ATH filler loading. Sample having 43% silicone rubber and 54% ATH filler concentration increases the hardness compared to the sample having 48% silicon rubber, 49% ATH filler concentration and sample having 46% silicone rubber, 51% ATH filler concentration.

Dielectric strength can be increased by increasing the ATH filler concentration. Sample having 43% silicone rubber and 54% ATH filler concentration increases the dielectric strength compared to the sample having 46% silicone rubber, 51%ATH filler concentration and sample having 48% silicone rubber, 49% ATH filler concentration.

By increasing the Silicone Rubber concentration, tensile strength and tear strength can be improved. It is possible to attain the highest tensile and tear strength. the sample having 43% silicone rubber and 54% ATH filler concentration. And it increases with the sample having 46% silicone rubber, 51% ATH filler concentration and the sample having 48% silicone rubber, 49% ATH filler concentration.

Sample having 48% silicone rubber and 49% ATH filler concentration has the higher ultimate eliongation and it decreases with the sample having 43% silicone rubber, 54% ATH filler concentration and the sample having 46% silicon rubber, 51% ATH filler concentration. The arc resistance value increases by increasing the silicone rubber concentration. Highest arc resistance can be obtained the sample having 48% silicone rubber, 49% ATH filler concentration and it decreases with 43% silicone rubber, 54 % ATH filler concentration and the sample having 46% silicone rubber , 51% ATH filler concentration.

All the three different formulations of test samples pass the following tests as per ASTM & IEC standards.

1) Inclined plane tracking tracking and erosion test
2) Recovery of hydrophobicity by corona ageing test
3) Hardness test
4) Dielectric strength test
5) Arc resistance test
6) Tensile strength test
7) Ultimate elongation
8) Tear strength
9) Specific gravity

Among all the three samples, sample-3 shows the better electrical and non-electrical performance. Which has the higher ATH filler concentration (54%). The sample performance increases by increasing the ATH filler concentration along with the increasing silicone rubber as base material.

VII. SCOPE FOR THE FUTURE WORK

Current research focuses on analysing the behaviour of polymeric insulators subjected to laboratory conditions. The silicone rubber material is added with a new filler material and the sample is analysed for outdoor suitability. A new composition of material is developed to withstand long term ageing performance, which can be used for outdoor applications.

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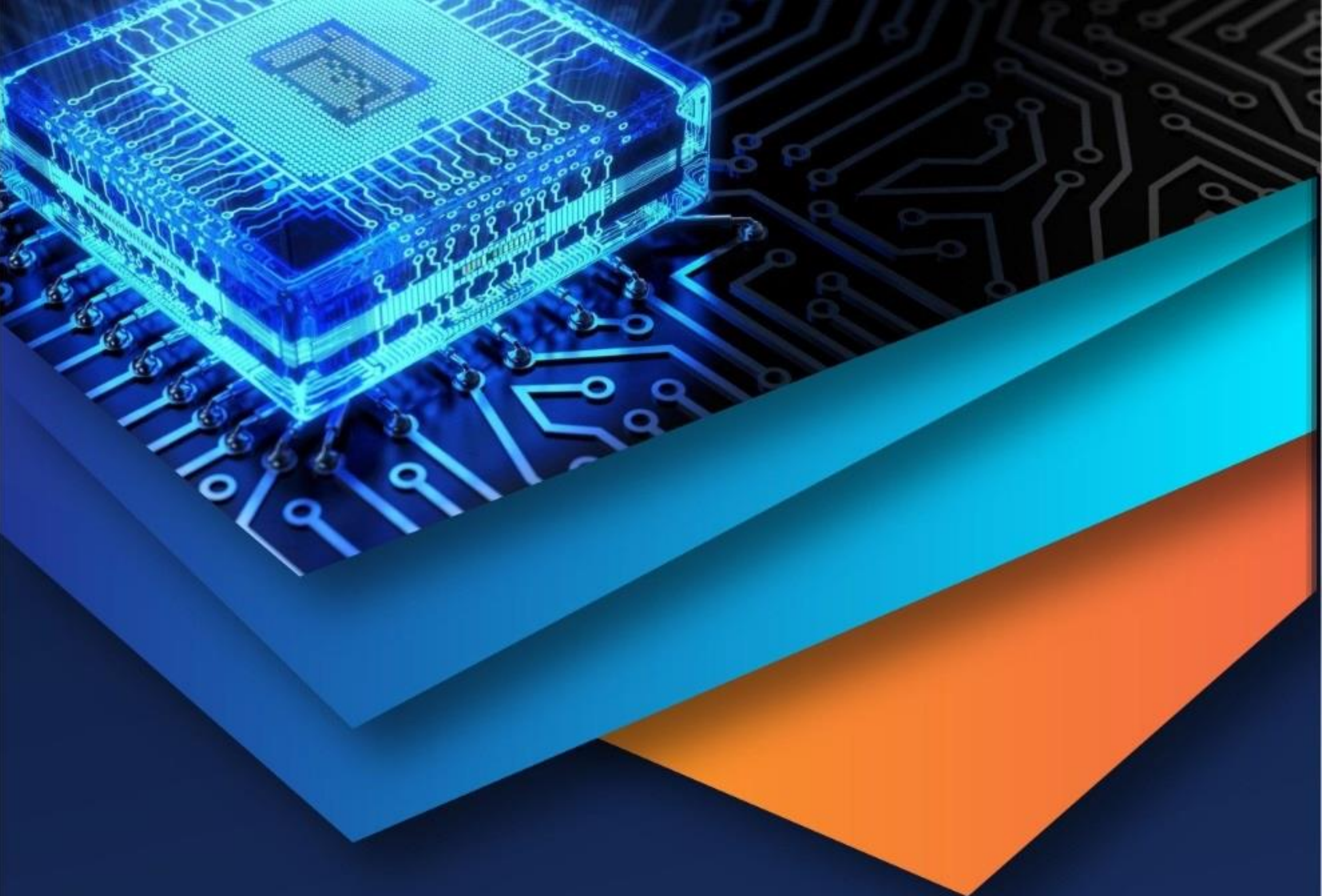

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