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THE EFFECT OF ENVIRONMENTAL FACTORS ON THE PERFORMANCE OF POLYESTER OUTDOOR INSULATORS

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ABSTRACT

Surface tracking is one of the severe degradation mechanisms observed on polymeric insulators. There are too many factors associated with the degradation process, hence it is not easy to make an estimate about the useful service life of an insulator. However it is possible to reduce the variability observed in the tracking initiation times and tracking patterns by testing the samples in laboratory under predefined conditions.

In this study, by using the ASTM D 2303 Inclined Plane Tracking Test method the effects of Mechanical effect(compressive stress and tensile stress), ultraviolet (UV) radiation and wind pressure from different positions with respect to the surface of the sample under test have been investigated in detail.

All samples have been prepared by using polyester without any accelarator. In all cases tracking initiation times were reduced significantly depending on the external conditions. UV radiation and wind pressure caused carbonised tracking patterns with wide branches around the high voltage electrode.

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INTRODUCTION

Since the introduction of electricity in 19th century, there has been a growing demand for electrical energy. Higher voltages led the researchers to develop new types of insulators[1-8]. Many natural insulators, which were widely used at the beginning of this century have been replaced by ceramic or porcelain materials [9]. Many of these suffer from low impact strength,

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brittleness, inflexibility, cracking during the manufacturing process, etc. New polymeric materials have some advantages in such cases [10-18]. Various composites of polyester resin and also several polymeric materials are widely used throughout the electrical industry. Electrical aging of insulators is associated with a wide variety of phenomena such as breakdown, discharges, treeing, electron interactions with charges, etc. These factors can severely damage their dielectric properties and cause a total breakdown of the insulator. However in most cases this process takes quite along time, which makes it difficult to draw conclusions about the quality of the insulating material. Several test methods such as Inclined Plane Test, Comparative Tracking Index Test, Dust Fog Test, Differential Wet Tracking Test and Tracking Endurance Wheel tests have been developed for assessing the relative tracking and erosion resistance of polymeric insulating materials in a relatively short time under laboratory conditions. However usually most of them exhibit too many random factors, which reduce their reliability[19-22].

In this study, by using the ASTM D 2303 Inclined Plane Tracking Test method the effects of longitudinal compressive and tensile stress, ultraviolet (UV) radiation and wind pressure from different positions with respect to the surface of the sample under test have been investigated in detail [23-26].

On the other hand fractal dimension methode is intented to analyse the structure of surface tracking patterns in polymeric insulators. For this aim, three alternative mathematical algorithms have been used to establish the fractal dimensions of the tracking patterns as a function of the above three parameters.

EXPERIMENTAL

All samples have been prepared in the laboratory under the same conditions by using polyester resin mixed with 0.1% methyl ethyl ketone hydroperoxide as initiator and styrene as solvent. Initially they have been cured in the oven at 35°C for half an hour. The temperature was increased by 5°C every half an hour until a total curing time of 4 hours is reached. Test samples with the dimensions of 100mm*55mm*9mm were mounted at 45° to the horizontal of the test set-up (Figure 1) [19] . All experiments were performed at 4kV applied voltage and 0.36ml/h contaminant flow rate. The contaminant solution ammonium chloride(NH_4Cl), flows from the HV electrode down to the underside of the sample at a specified rate. The gap between the HV and earth electrode is defined as 50 mm. Furthermore, all of the experiments have been performed by using Inclined Plane Tracking Test, which is quite useful in representing the "wet tracking" phenemona. ASTM D 2303 suggests that for 4kV a flow rate of 36 ml/h provides the optimum results, which means short tracking initiation and track growth times and also a rapid crossover between the electrodes. This rapid process might lead to an unbranched tracking pattern with minor damage to the surface. All specimens were tested in a closed cabinet with an open roof and minimum air circulation. For each set at least 5 samples were used. ASTM D 2303 recommends to continue the test until the tracking pattern reaches 25 mm from the earth electrode, however to enable a complete structural pattern analysis, the experiment was not stopped until the gap between the earth and HV electrode has been crossed completely. After each experiment, specimens exhibit a carbonised, highly damaged, black tracking patterns and due to the burning, discoloured surface sections.

ENVIRONMENTAL CONDITIONS

HV insulators are subjected to several degradation and hence aging mechanisms throughout their service life. However it is possible to reduce the variability observed in the tracking initiation times and tracking patterns by testing the samples in laboratory under predefined conditions
To simulate these effects and hence gain a better understanding in the tracking phenomenon, polyester samples have been tested under three different enviromental conditions; Mechanical effect, Ultraviole Radiation and Wind Effect.

Mechanical effects

Especially during winter time excessive snow or ice load may be collected over the insulation lines. This can cause extra tensile stress on the conductors and insulating materials. Several researchers reported that the mechanical properties of the dielectric material strongly effect the initiation and growth of the electrical trees in homogenous materials [23-24]. In addition to that, it is believed, that excessive forces along the longitudinal axis of the polyester sample can cause also microscobic cracks or defects over the surface which eventually accelerate the tracking initiation time. To test this hypothesis, the test surface of the polyester samples is subjected to external compressive and tensile stresses, which can be calculated according to the equation.

$$\sigma_1 = \frac{6F_1 x}{bd^2} \qquad (1)$$

and

$$\sigma_2 = \frac{F_2}{bd} \qquad (2)$$

, where

σ_1: compressive stress at the point where polyester sample is connected to the setup (N/mm^2)

σ_2: tensile stress (N/mm^2)

F: applied force (N)

x: distance between the points, where force is applied and the polyester sample is connected to the set-up (mm)

b: width of the sample (mm)

d: thickness of the sample (mm)

Initially different weights are connected to the sample (Fig.2) and considerable compressive stress (F_1) is obtained on the test surface of the sample. Since longitudinal tensile stress (F_2) is very small compared to the compressive stress, it can easily be neglected for this set-up.

At the second stage, the test set-up is slightly modified and the weight is connected at 90° over the upper side of the sample through a balley. In this case, the weight pulls the sample in the opposite direction of F_1, which causes a significant tensile stress over the test surface. For both cases the breakdown times are shown in Figures 3&4.

UV radiation

The energy absorbed by the insulators due to UV radiation can cause excessive temperature increase and hence minor cracks within the material. For polymeric insulators, UV radiation can also reduce the hydrophobicity of the surface and in the long term may accelerate aging due to surface tracking or erosion. To simulate the UV effect and observe the local discharge phenomenon on the surface of the polyester samples, all test specimens have been subjected to UV radiation from different locations. Initially all samples are tested at room temperature at predefined conditions (4kV voltage and 36ml/h contaminant flow rate). To test the UV effect, a UV source, which produces light with the wavelength of 350nm, is placed in front of the sample with a 100mm distance. At the last stage, by keeping the same distance, the UV source is placed next to the sample on both sides at 30° degree. Change in temperature and tracking time due to the UV radiation is shown in Figure 5.

Wind effect

Wind can cause considerable forces and vibration on the transmission lines and HV insulators. Together with rain it can also cause localised discharges and flashover over the surface of the insulator. Mason stated that in static air, steam condenses on the upper electrode, which causes flow of contaminant to wander, so time to failure will be increased compared with tests in open laboratory [6]. To simulate the effect of the wind on the wet tracking observed on polymeric HV insulators, polyester samples have been subjected to continuous air circulation from different locations with respect to the surface under test.

The change in tracking initiation time due to the air circulation is shown in Figure 6. Surface tracking patterns of some polyester samples obtained ASTM D 2303 Inclined Planed Tracking Test is shown Figure 7. Breakdown times of polyester samples obtained ASTM D 2303 Inclined Planed Tracking Test for all conditions is given in Figure 8 .

RESULTS AND DISCUSSION

At the beginning of their service life polymeric insulators are usually resistant to dangereous external effects, such as UV radiation, vibration, surface contamination, etc. However after a certain time, the due to the environmental factors, surface of the insulator tends to loose its hydrophobicity and hence external contaminants start gradually to be accumulated over the surface, which lead to dry band arcing and finally to surface tracking.

In this reseach, three factors effecting the lifetime of a polyester insulator are investigated. Initially the effect of excessive stresses on the tracking initiation time is observed. Especially during winter a considerable amont of ice and snow load is collected over the HV insulation lines. This results an increase in the tensile stress applied to the insulator and transmission lines. This excessive stress varies from region to region depending on the outdoor temperature. An example is given in Figure 9, where the stress is calculated for a HAWK 477 type of transmission line connected between two symetrically located HV poles having a total length of more than 15m and are seperated with a distance of 250m.

With the first set-up, by connecting an external weight of 5kg, a compressive stress of σ_1=4,7 N/mm^2 is obtained over the test surface, which in fact is equal to appr. %11.2 of the max. breakage tensile stress of the polyester. In this set-up the tensile stress for both surfaces was σ_2=0.07 N/mm^2 and hence neglected during the calculations. As it can be seen in Figure 3, tracking initation time tends to decrease linearly up to a certain stress. Since in most cases outdoor insulators are also not subjected to stresses more than %15 of the max. breakage stress, the experiments are not performed at higher stressses.

For measuring the effect of tensile stress, the set-up is slighly modified and a direct force in the opposite direction of F_1 (Fig.2) is applied to the sample. In this case, a tensile stress of σ=6.7 N/mm^2 (~%15.95 of the max. tensile stress) is obtained on the test surface of the sample. For tensile stress, the breakdown time seems to decrease up to 3 N/mm^2 tensile stress and then does not change up to a certain stress. Since the weight of the polyester sample is too low (0.075kg), its effect on the compressive and tensile stresses is neglected.

In the second part of the experiments, the effects of UV radiation is observed. All samples are subjected to UV source for 10min. before the tests and experiments were performed under high surface temperatures. From Fig.5, it seems that the initial surface temperature was significantly increased by the application of the UV source. However at the end of the test, the surface temperatures were almost equal for all cases. Again the breakdown time was reduced by the application of UV source, however the location of the UV does not affect the surface temperature, hence the breakdown times were almost same for all locations of the UV source.

The third stage investigates the effect of strong air circulation on the tracking initiation time. Without any conductor connected to the polyester sample, the load effect and hence tensile stress of the air circulation on the polyester sample will be negligible. For this reason only the effect of the air circulation on the path of the leakage current is investigated. Again as UV source, the fan is located at different sides of the samples. The breakdown time is greatly reduced by the application of wind, however in this case the location of the fan can effect the direction of the contaminant flow, and hence can further reduce the breakdown time, if it is located at 30° next to the sample.

The 4th and 5th stages of the experiments were based on observing the effects of some of the external conditions applied to the insulator at the same time. Wind force, applied to the conductor with a heavy ice load on it, increases the tensile stresses over the HV insulator (Figure 9). However in this stage, the effect of the air circulation on the breakdown time of a polyester insulator tested under 6,6 N/mm^2 tensile stess is investigated. In this case, the extra tensile stress caused by the fan is negligible, however rather than applying an extra load, the fan acts as a wind source which forces the liquid contaminant to follow a certain path. As expected, the surface discharges tend to increase and breakdown time has further reduced.

The last (5th) stage investigated the effect of the air circulation applied to samples under UV radiation. As expected, due to the air circulation, in this case the measured surface temperature seems to be lower than the samples tested under UV radiation without any other external effect. However despite this reduction of the temperatures, the tracking initiation times are further reduced by the application of wind. This can be explained due to the fact, that UV radiation causes internal heating and damage within the polyester and this aging is further accelerated by the application of the circulating

air and hence obtaining continuous contaminant flow, which lead to strong, effective surface discharges. As a consequence the surface temperature is further increased and the material loses it surface hydrophobicity.
Breakdown times for all conditions is given in Figure 8.

CONCLUSION

In this research all polyester samples have been prepared in the laboratory and tested according to the ASTM D 2303 standard. Tests have been performed under three different conditions, such as mechanical stress, UV radiation and wind effect. All the tests performed in the laboratory indicates, that the breakdown time is greatly affected by the environmental effects. In most cases, the breakdown times were reduced %50 up to a certain level and then stayed almost the same. Beside the breakdown times, the tracking patterns of the samples also distinguish within each other. Especially for UV effect considerable damage has been observed on the surfaces of the insulators [7].

Results show that maximum distortion has been observed at straight air circulation+compressive stress and UV+straight air circulation. This results is found to be good agreement with experimental tracking initiation time.

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Figures

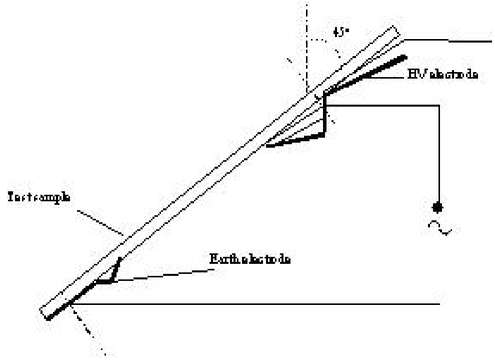


Figure 1. Test set-up

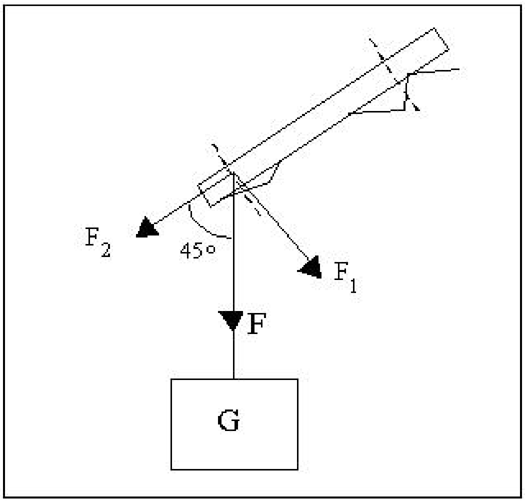


Figure 2. Test set-up for compressive force

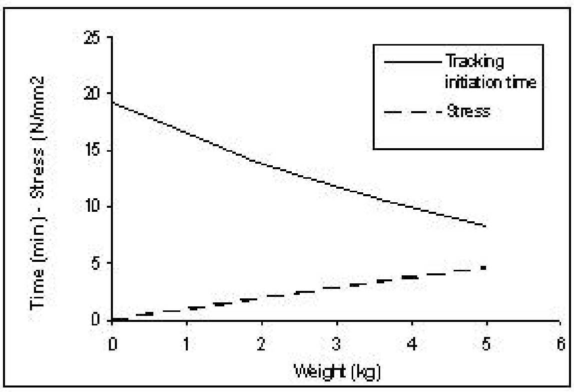


Figure 3. Tracking initiation time due to the compressive stress

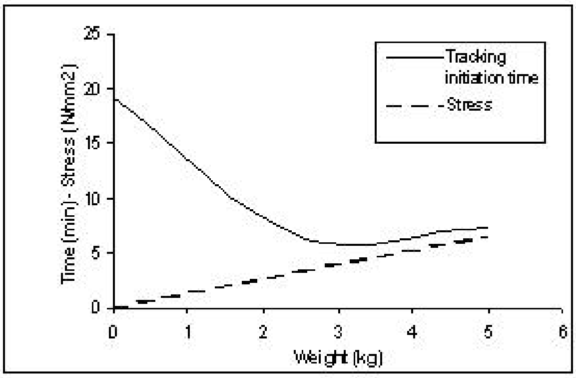
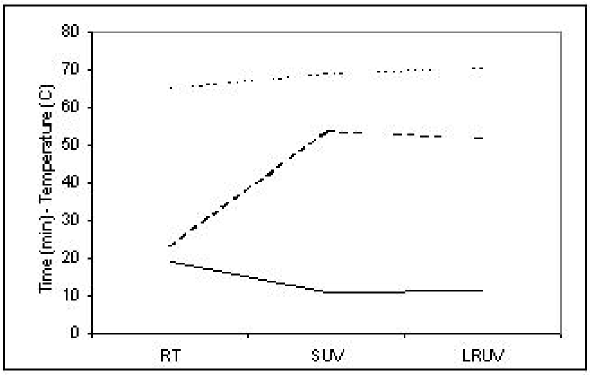


Figure 4. Tracking initiation time due to the tensile stress



RT : room temperature
SUV : UV source in front of the sample
LRUV : UV source located at 30° next to the sample
…. Surface temperature after test
---- Surface temperature before test
—— Tracking initiation time

Figure 5. Change in temperature and tracking initiation time due to the UV radiation

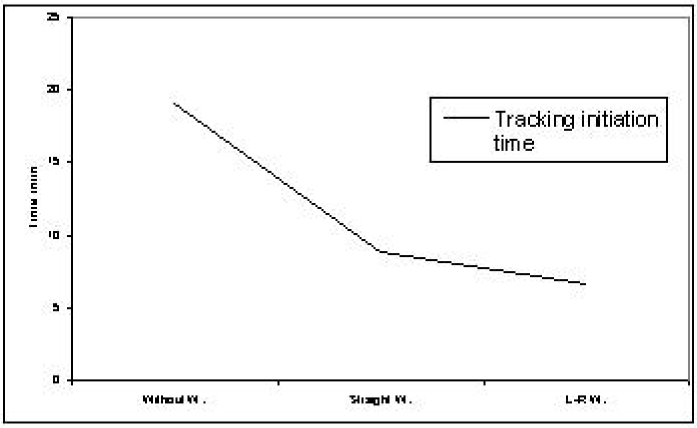


Figure 6. Tracking initiation time due to the wind effect

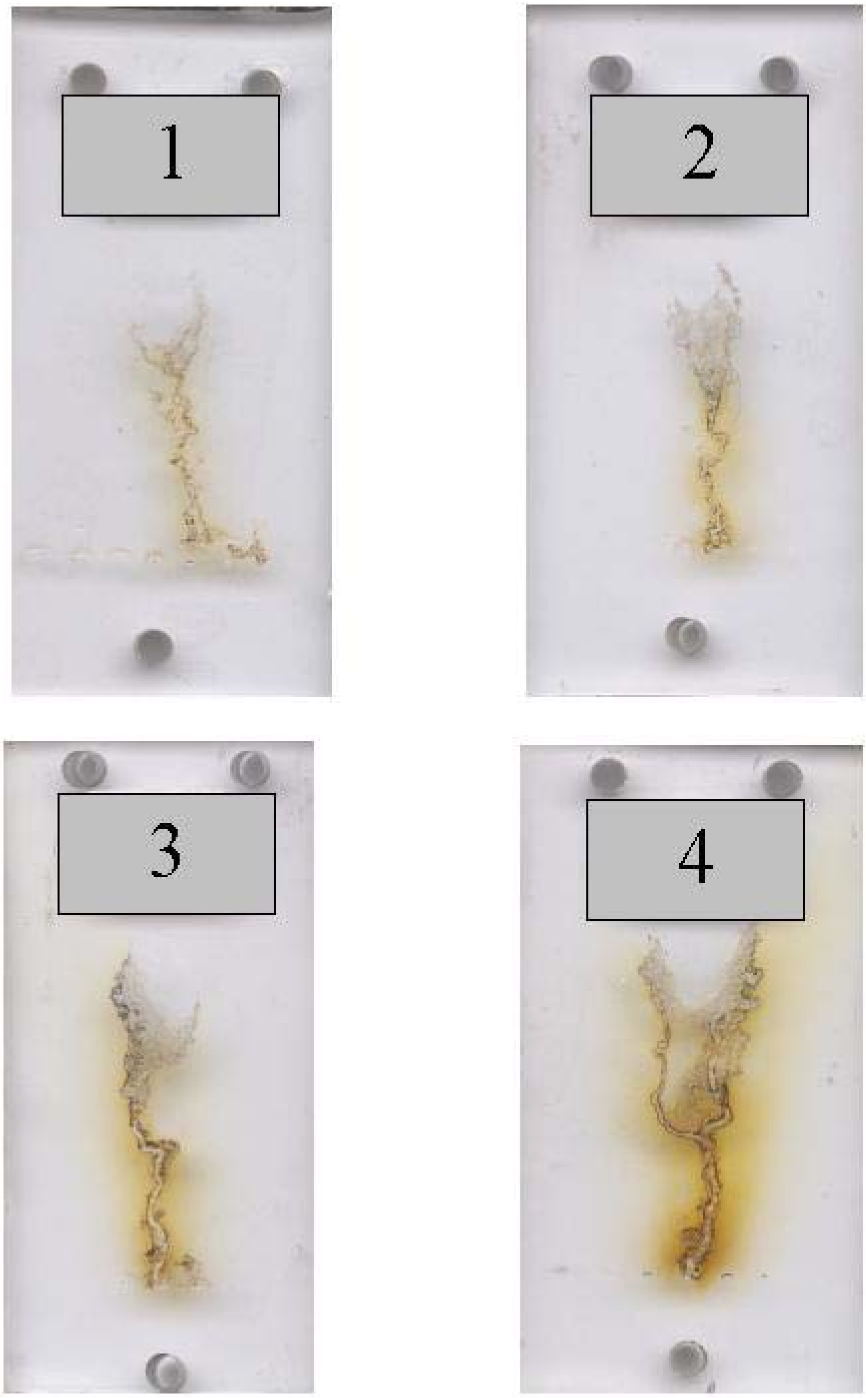


Figure 7. Surface tracking patterns of some polyester samples obtained ASTM D 2303 Inclined Planed Tracking Test : 1.Room Temperature, 2.Ultraviolet radiation, 3.Straight air circulation, 4.Straight air circulation and tensile stress.

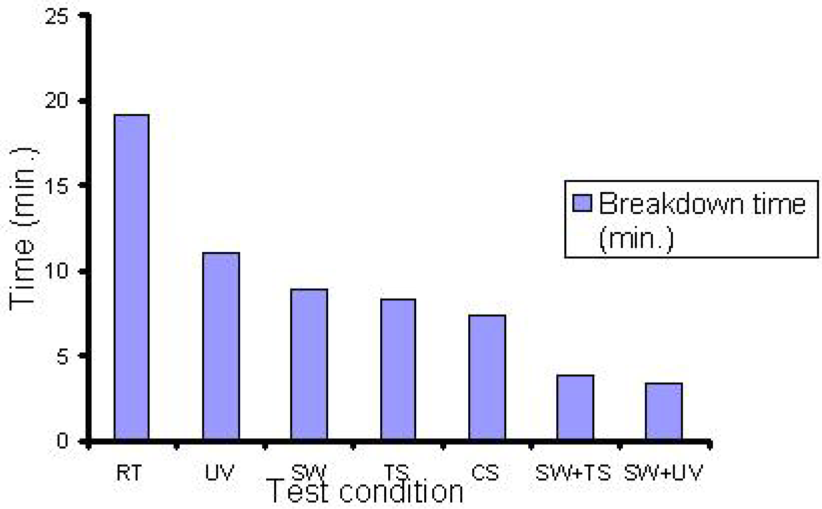


Figure 8. Change in breakdown times due to the environmental conditions

RT: room temperature, UV: ultraviolet radiation, SW: straight air circulation, TS:tensile stress, SW+TS : straight air circulation and tensile stress, SW+UV: straight air circulation and ultraviolet

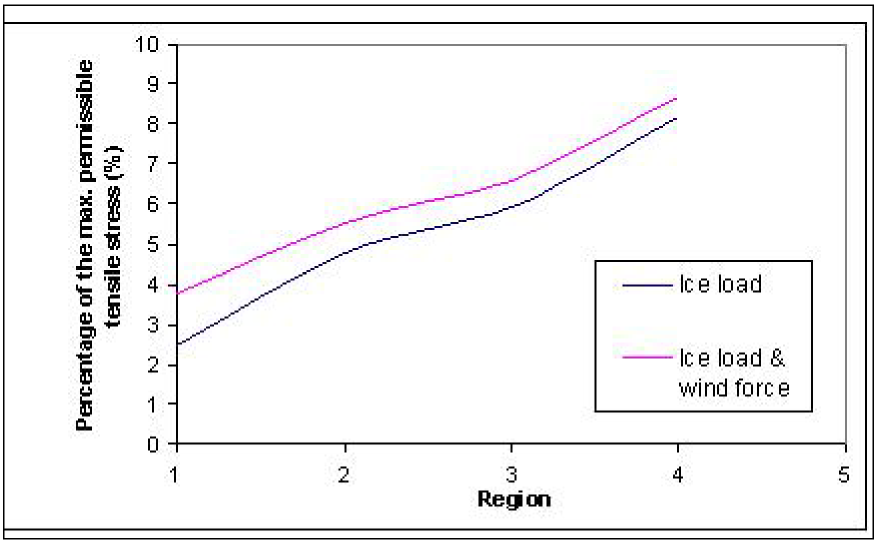


Figure 9. Change in the tensile stress due to the region

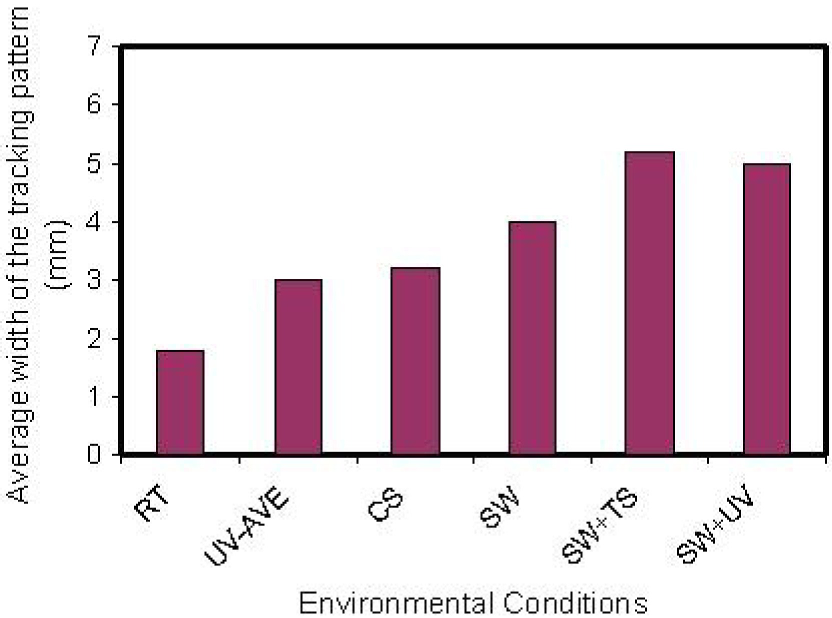


Figure 10. Dependence of average width of the tracking pattern of polyester insulator with various environmental factors such as ultraviolet radiation, compressive stress, wind effect, tensile stress + wind effect and wind effect + UV