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RESISTANCE TO SURFACE EROSION OF POLYMERIC MATERIALS USED FOR HV OUTDOOR INSULATION

1. Introduction

Over the last ten years polymeric materials got well-established as most suitable for HV outdoor insulation.

This is because of many advantageous properties of polymeric materials as compared to the conventional ones like glass and porcelain. But, first of all, what speaks in favour of the former is the possibility of using an advanced, highly effective, and automated production engineering.

Alongside with the growing range of their applicability the methods of evaluation and the optimum parameters selection are being devised.

What limits their applicability is ageing problems which in outdoor applications invariably lead to the deterioration of surface insulating and thereby of the whole product.

The first step taken towards selecting proper polymeric materials was the introduction of the methods testing their tracking resistance. This was aimed at eliminating bad materials which, when exposed to electric and environmental hazards (wet pollution layers), have a tendency of forming carbonized conducting paths.

These methods combined a simultaneous action of particular electrolytic solutions with voltage in this way testing the adverse effects the two factors above had on the polymeric material.

As a result the following methods were devised:

- "drop" test in accordance with IEC 412 [1],[2] recommendations with which it is possible to determine and sort out only those matrials which are most susceptible to tracking (e.g., phenol materials) and HV methods.

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- dust and fog test in accordance with ASTM D 2132-68,
- differential test in accordance with ASTM D 2302-69,
- inclined plane test in accordance with ASTM D 2303-68.

From the metods listed above only the last one (inclined plane test) won the international recognition and was formally recommended by IEC 587-1984 [3],[4].

Promising as all these methods were they did not yield, however, a satisfactory correlation between experimental results and the actual behaviour of the polymeric materials exposed to sever ambient conditions.

The main reason for this was that, in principle, the said tests were of short-duration and immediate character and the hazards and stresses used were many times more intensive than those normally observed under natural conditions and this, in turn, means that the mechanism of failure was not the same as that in regular service conditions.

Therefore, while not denying the necessity and usefulness of testing the tracking resistance of the materials, treating it as a preliminary selection during which those unsuitable materials can be eliminated, it was found necessary to complete this selection with ageing tests.

A measure of the service life of HV insulating element working under natural environment al conditions is its long term electric strength.

This strength can be comparably measured on unified material samples thus obtaining life curves for particular materials [5]. Is has been found that a very significant factor determining the life of an insulating element is surface erosion, i.e., an irreversible damage of the surface caused by external environmental effects [6].

Surface erosion, which at its early stage is uniformly distributed, is a primary effect followed by secondary effects such as: depositing of dirt, moisture absorption, non uniform field distribution, leakage current and local partial discharges (PD) which can gradually develop to produce full flashover.

It is therefore of primary importance that a method for testing a long term behaviour of insulating materials exposed to severe ambient conditions should explicitly evaluate the surface erosion as this very factor which determines the rate of further changes leading to the failure of an insulating material.

The best method for evaluating the resistance to surface erosion is ageing the sample materials by exposing them to UV radiation and artificial rain or spraying with conducting fog since these three factors uniformly affect the whole surface of an element.

Another significant factor damaging and eroding the surface of an element are partial discharges. However, their action is of a rather local character and they do not affect the whole of the surface.

The estimation of the surface erosion in the process of ageing can be made by means of electrical or physical methods.

The idea behind such an estimation is to find and possibly to apply means to improve the resistance thus extending the life of the insulation and increase its reliability.

2. Experiments

2.1. Materials

Two types of epoxy composites and a silicone rubber were tested: K1 - diane resin Epidian 5 (liquid curing agent BTMG) latent accelerating agent (filler: quartz flour), K2 - cycloaliphatic resin Araldit CY 184 (Ciba-Geigy)

- curing agent - HT 907(Ciba-Geigy)
- accelerating agent - DY 067(Ciba-Geigy)
- filler - quartz flour.

K3 - silicone rubber (Rhone-Poulenc)RTV 590 A

Samples for UV radiation test were cylinders 20 mm in diameter and 220 mm long while those for conducting fog and voltage test were the same with the exception that the cylinder was only 70 mm long.

2.2. Testing procedure

2.2.1. Plotting life curves for different insulating materials under adverse ambient conditions (conducting fog)

The determination of the life curves of the materials studied as a function of the flashover voltage in conducting fog was carried out in 600 x 800 x 600 mm fog chamber. Due to limited dimensions of the chamber the cylinder-like test pieces of 1 = 50 mm length of a test piece between the electrodes were used.

The electrodes were aluminium strips 10 mm wide and 0,05 mm thick. The environmental hazards were stimulated by the conducting fog of the following parameters:

conductivity - $\gamma = 800\ \mu S\ cm^{-1}$,

precipitation - $O_p = 10 - 15\ mg/cm^2h$.

Stabilized voltage from TP 60 60/10 kV A transformer was applied to the test pieces. Time to flashover was measured for different electrical hazards: 2,5 - 2,2 - 2,0 - 1,6 kV/cm.

The tests were executed in 24 hrs cycles:

7 hrs - exposure to electrical hazards in conducting fog,

17 hrs - conditioning of test pieces in environmental conditions.

Time to flashover was related only to the time when the test pieces were exposed to electrical hazards in conducting fog.

2.2.2. Cyclic ageing

For testing the resistance against surface erosion, cyclic ageing of cylinder test pieces was used.

The ageing cycle comprised:

5 hrs of exposure to salt fog (salt concentration $s = 5\%$ NaCl, precipitation $O_p = 0,53$ mm(h),

18 hrs of UV radiation (mean intensity: 4,9 mg of decomposed oxalic acid per $cm^2 \cdot h$ at $t \leqslant 60^{0}C$),

1 hr for reconditioning under normal conditions ($20 \pm 5^{0}C$, $65 \pm 5\%$ relative humidity).

2.2.3. Procedures for estimating the degree of surface ageing and surface erosion

2.2.3.1. Electrical methods

A non destructive measurement of the critical voltage U_k, as the measure of the degree of ageing of the test piece examined was assumed, i.e. such maximum voltage at which the leakage current on the test piece does not exceed the agreed limiting value of 100 mA under conditions of a defined conducting fog and defined test system.

Parameters of salt fog: salt concentration $S = 5\%$ NaCl in water, precipitation $O_p = 0,53$ mm/h

Data of the test system: $I_z = 1A$ for $U_z = 16$ kV

The procedure of determining U_k consists of:

- full moistening of the test piece in the fog chamber (5 min),
- applying the test voltage and holding it for 10 min while recording all surface discharges over 40 mA.

The test voltage is gradually increased in 0,5 kV steps and held for 10 min until current pulses exceeding 100 mA occur.

The test voltage of a lower degree at which the conventional value of 100 mA has not been exceeded yet is assumed to be the value of U_k.

The procedure described above served to determine U_k both on prime test pieces and during the cyclic ageing.

2.2.3.2. Physical methods

a)Measuring mass loss

In order to quantitatively measure the magnitude of erosion, the mass loss were determined by weighing the test pieces at different stages of ageing process on an electronic balance with the weighing range of up to 1200 g and the accuracy of reading 0,01 g Mettler PT 120.

The first measurement was made on washed and dried test pieces. Furthermore measurements, taken during the ageing process, were made without washing the test pieces immediatedly after the 18 hrs UV irradiation.

b) Measuring the contact angle

From among many existing methods of measuring the extreme contact angle an intermediate one was chosen [7] where, by means of a microscopic circuit, the height (h) and diameter (d) of a drop were measured.

The contact angle is given by:

$$tg \frac{\theta}{2} = \frac{2h}{d}$$

The above relation holds only for small drops which diameter is not greater than 2 mm.

The measuring liquid was distilled water. The drops were placed on the surface tested with the help of a micropipette.

The measurement was performed on cylinder test pieces along the generating line most exposed to UV radiation. In order to check the effect of the shape of a test piece on the results of angle ϑ measurements, test measurements were performed on flat cylindrical pieces made of the same materials and not subject to ageing. The differences in the values of angle ϑ due to the shape of pieces were within the scatter of results. Prior to each measurement, the place where the measurement was to be made was washed with clean acetone using filter paper in order to remove impurities. 10 measurements were made for each test piece in more or less equal time intervals.

2.3. Measurement results

The measurement results of life curves for flashover voltage of materials K1 and K2 are plotted in Fig. 1. Fig 2 presents the measurement results of the critical voltage U_k for K1, K2 and K3 materials during their laboratory cyclic ageing. Fig 3 gives the measured values of U_k for the basic epoxycomposite, K1 and for its modifications K10 and K11. Figs 4 and 5 present the measured mass losses of the test pieces examined. The measurements of angle ϑ during cyclic ageing for the same test pieces are presented in Fig. 6.

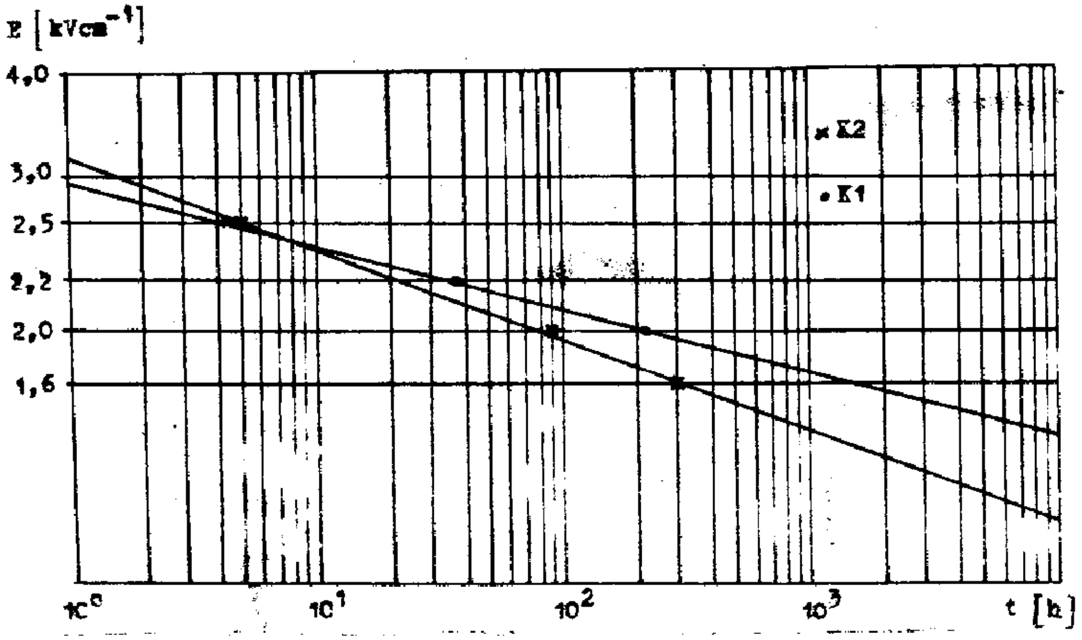

Fig. 1. Life curves in the function of flashover voltage under conducting moist conditions for K1 and K2, probability is p = 63%

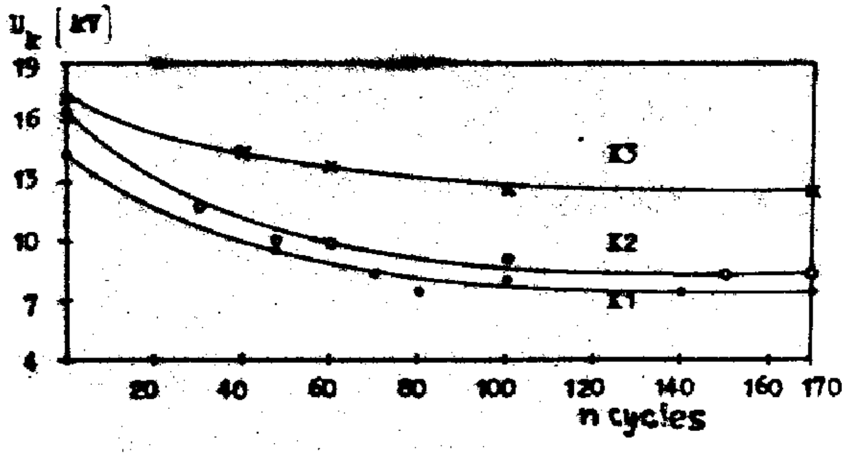

Fig.2. Critical voltage U_k in cyclic ageing of K1, K2 and K3

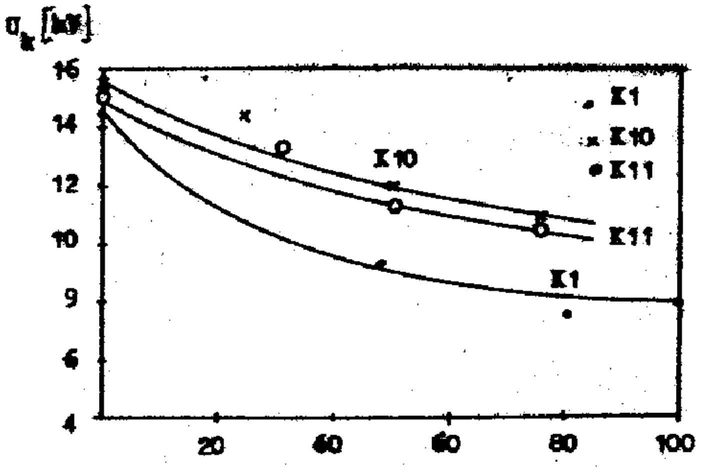

Fig.3. Critical voltage U_k in cyclic ageing of modifications of K1 composite

3. Measurement results - discussion

The life curves presented in Fig.1 distinguish particular polymeric materials well and permit the determination of their service life under high moisture conditions. The measurements are relatively time consuming and do not allow for all significant environmental factors affecting the outdoor insulation (e.g. UV radiation). Besides, a marked scatter of results can be noticed which leads to unreliable estimations concerning

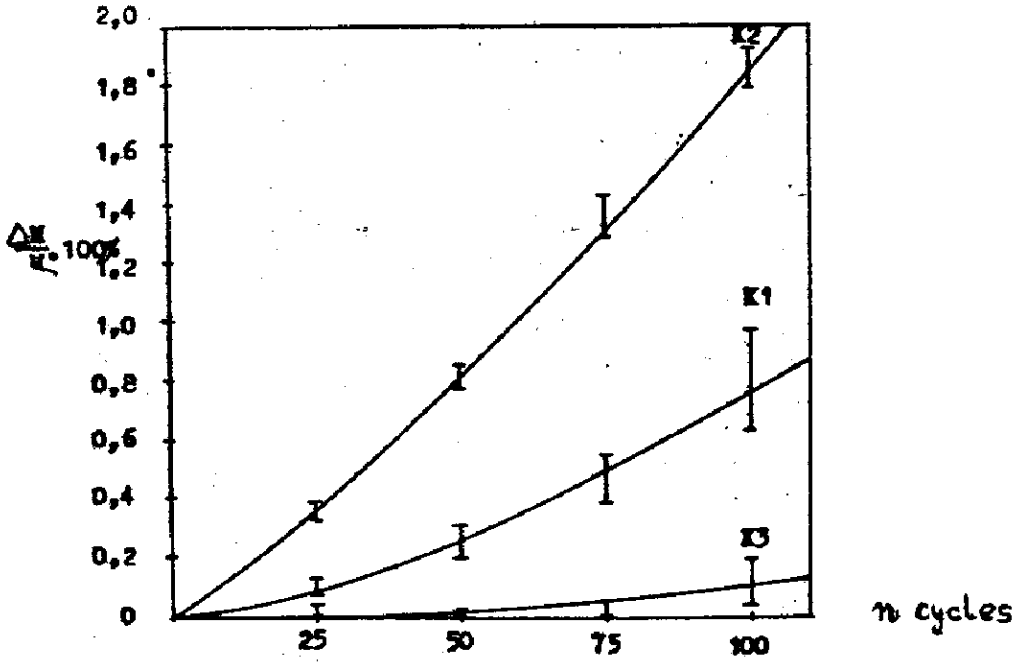

Fig.4. Surface erosion in cyclic ageing of K1, K2 and K3

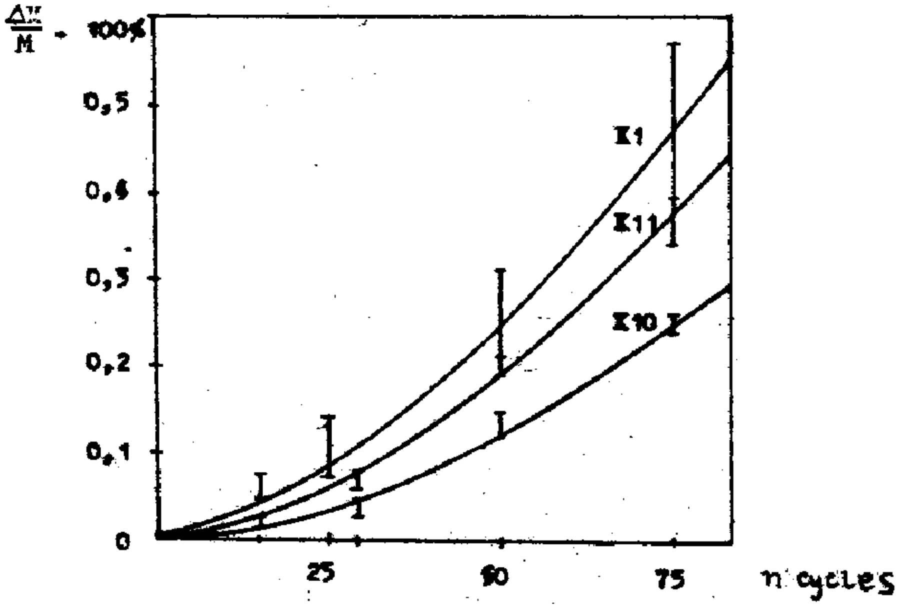

Fig.5. Surface erosion of modifications of K1 composite in cyclic ageing

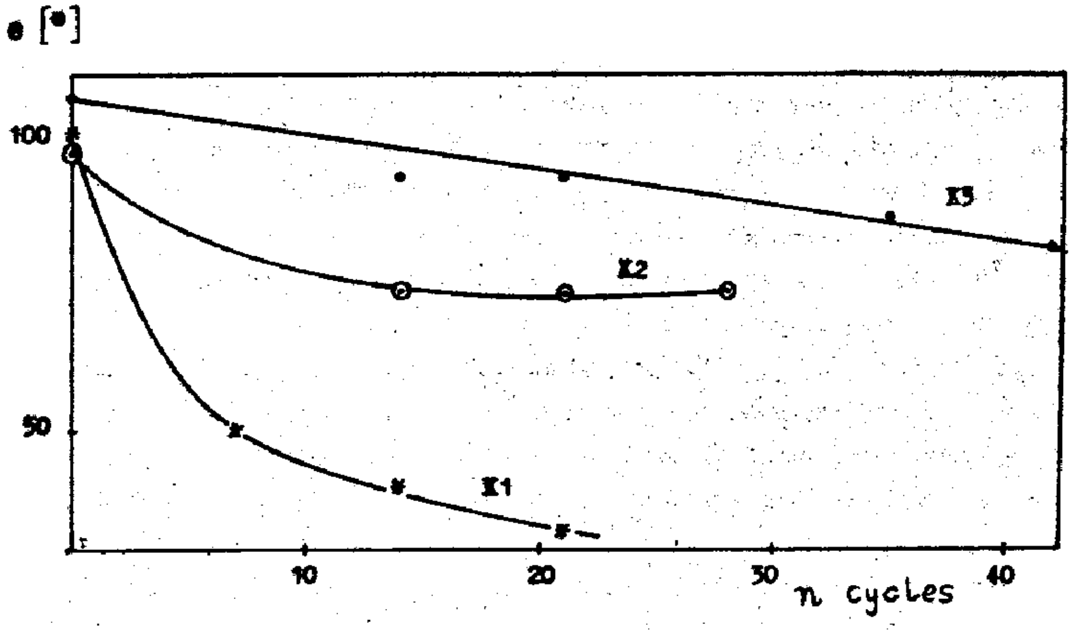

Fig.6. Contact angle of K1, K2 and K3 in cyclic ageing

the life of an insulating element. The method of cyclic ageing permits a more detailed observation of the process of surface ageing and of erosion developement.

The measured values of the critical voltage U_k characterize the surface electro- insulating properties of the materials studied. The values of U_k for particular polymeric materials decrease during ageing until they stabilise at a certain level differing from material to material. Therefore, the evaluation of materials based on U_k values is equivalent to that based on life curves.

The method of measuring the value of U_k clearly distinguishes the surface electro-insulating properties in materials of different chemical composition as it is the case with K1, K2 and K3.

However, in the case of materials of a similar structure where only slight differences in some components occur, this method turns to be not sensitive enough and the differences can hardly be observed (CF Fig.3). The measurement results of mass losses shown in Figs. 4 and 5 illustrate the magnitude of surface erosion.

The surface erosion is clearly different for each of the chosen three types of polymeric materials K1, K3 and K2. The rate of erosion depends on the structure of the polymer.

The behaviour of the insulating element is determined by its surface electric strength which, as follows from Fig.3, stabilises. On the other hand, the mass loss for all materials tested during about 100 ageing cycles was constantly growing. So the mechanism of erosion is quite different and cannot be correlated with the electro-insulating properties of the polymeric materials. However, erosion, as being an independent factor must be taken into account when trying to evaluate the material since,under severe conditions, it may limit its application.

The method of measuring the surface erosion can succesfully be used when trying to estimate modifications of the same original material. In such cases the electric method is not sensitive enough, is too time consuming, and not very selective. On the other hand, a fast advancing erosion categorises particular composites already at the first stage of ageing (up to 50 cycles) see Fig.5). All three composites, K1, K10 and K11, are based on a liquid diane resin Epidian 5, Composites K10, K11 which are the modifications of K1 show smaller surface erosion than the basic composite K1. Ordering of composites according to the measurements of mass losses (Δm) corresponds to their long term strength (Fig.3).

The measurement of mass losses is, in the case of composites of similar chemical composition, more selective and very usefull when designing new and better materials.

The measurement results of the contact angle Θ show, at the early stage of ageing, a relatively small scatter ($<10\%$). As the ageing proceeds, the scatter of results grows for worse materials (e.g.K1) even up to 20%.

Together with ageing of epoxy materials containing quartz filler (K1, K2) their surface gets more rough due to outcropping of quartz grains (the so called "chalking"). At some point this phenomenon renders the measurement of angle Θ impossible - water drops spread over. At the initial stage of ageing, when the surface erosion is evenly distributed, the changes in angle Θ correlate well with the results of U_k measurements. The observed drop in the critical voltage, U_k, is always accompanied by the decrease angle Θ which is equivalent to worsening of surface water repellent properties.

At a certain stage of ageing (after ab. 35 cycles) a net of microcracks was observed on the surfaces of silicone rubber K3. The cracks developed as the ageing went on. This phenomenon requires explanation, i.e. the question is to be answered whether it would occur in the case of test pieces made only of K3.

4. Conclusions

1. The evaluation of polymeric materials based on the ageing characteristic of U_k is convergent with that based on life curves for flashover voltage in a conducting fog.

2. There is no direct relation between the susceptibility to surface erosion and surface electro-insulting properties of the material. However, an increased susceptibility to erosion can limit the life of the material and its applicability in particular constructions.

3. Resistance to erosion is more effective and selective in discriminating between composites of the same chemical structure than the time consuming electric methods.

4. At the early stage of ageing, at the uniform distribution of surface erosion, there is a good correlation between values of U_k and Θ.

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