**THE EFFECT OF HOUSING MATERIAL AND PROFILE ON THE POLLUTION AND AGEING PERFORMANCE OF COMPOSITE HV LINE INSULATORS**

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## INTRODUCTION

For many years there has been much discussion on the relative merits of EPDM and Silicone rubber (SiR) as housing materials for composite insulators. The hydrophobic properties of SiR were acclaimed as being the ideal solution for insulation in heavily polluted areas; initial pollution testing and service experience appeared to confirm this. However some SiR insulation began to exhibit flashovers or unexpected ageing after longer exposure; investigations revealed that the hydrophobicity of SiR was not constant, decreasing under environmental and electrical activity, in some cases very rapidly. In general, this loss is not permanent and hydrophobicity is "recovered" as low molecular weight components in the SiR slowly restore the surface hydrophobicity or encapsulate pollutants on the surface.

The possibility that SiR insulation could lose its advantage over EPDM, glass, porcelain and other hydrophilic insulating materials, notably in those conditions where it is most needed, has caused some utilities to rethink their insulation strategy and to design for a "worst case" scenario.

In general, the long-term ageing behaviour of a composite insulator depends on the overall and local electrical stress whose value, duration and position depends on pollution level, wetting, hydrophobicity loss/recovery and insulator profile. This is recognized by the recent IEC 60815-3 [1] where annex A warns against trying to put too much creepage distance into a given insulator length. This warning is borne out by results presented hereafter showing higher degradation on insulators with a longer creepage distance profile.

This paper presents some information on the effect of housing material and profile on both the pollution performance and ageing degradation of both SiR and EPDM rubbers when used with different profiles. The information is quite unique in that the tested insulators were all made with the same technology so that direct comparison of the effect of profile or material can be made; i.e. same profile, different material or same material, different profile.

## 1 MATERIALS AND PROFILES

In the following, the materials referred to are :

**EPDM** – High pressure injection moulded Ethylene Propylene Diene Monomer,
**SiR** – High pressure injection moulded high temperature vulcanized silicone rubber with ATH filler.

Two profiles are shown in figures 1 and 2. These are the "**M**" profile with a medium creepage to spacing ratio ($l_d/d$ = 3.2) and the "**L**" profile with a higher creepage to spacing ratio ($l_d/d$ = 4.2). The relative scale of these figures is 1. The shed repeat spacing is 55 mm.

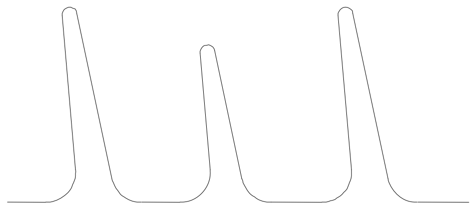

**Figure 1 "M" (medium) profile**

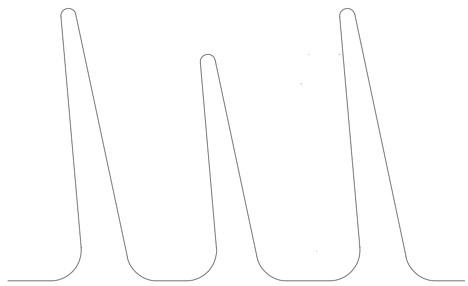

**Figure 2 "L" (long) profile**

When used on a 16mm rod insulator (120 kN) these profiles have a maximum diameter of 105 mm (M profile) and 137 mm (L profile)

## 2 BEHAVIOUR IN POLLUTION TESTS

### 2.1 Salt fog pollution tests

The salt-fog pollution tests were all carried out using the standard IEC 60507 procedure, including preconditioning. This means that SiR materials became largely hydrophilic and that for both materials any residual products from the moulding process are removed. All tests were maximum withstand tests.

The results are shown in Fig 3 in terms of withstand unified specific creepage distance (USCD). USCD is the term used in IEC 60815 to express specific creepage distance in with respect to the phase to ground voltage rather than the phase to phase voltage.

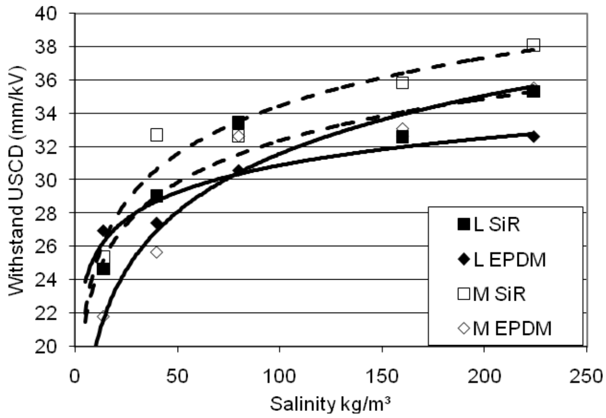


**Figure 3 Salt fog withstand characteristics of different profiles and materials (USCD)**

In terms of USCD necessary to withstand a given salinity, it can be seen that the "normal" creepage distance M profile gives the worst performance; requiring the most creepage distance per kilovolt. The long creepage distance L profile is better. If these same results are plotted as a function of insulating length, the M profile is again less effective than the L profile, showing approximately 25% less withstand at 80 kg/m³ and above.

It is interesting to note that the hydrophilic SiR profile requires 5% to 10% more specific creepage than the EPDM equivalent, notably at higher salinities. Since the EPDM is not totally wettable (IEC 62703 WC 4-5) and is totally unaffected by the preconditioning flashovers, the surface does not wet out completely in salt-fog tests which means that there will be some dynamic dry band formation promoting movement of partial arcs; this can retard flashover. On the other hand, the SiR can become totally hydrophilic in salt fog conditions (IEC 62703 WC6) leading to a lower flashover voltage. Another possible explanation is non-linear wetting due to variations in hydrophobicity along the insulator; on porcelain insulators non-uniform surface conductance can cause up to 25% reduction in flashover strength.

These results go somewhat against popular belief and underline the importance of testing for worst case conditions. Comparison with traditional glass and porcelain insulation shows that a totally hydrophilic SiR composite insulator has little or no advantage in salt-fog conditions whereas EPDM has a 10% to 15% better performance.

**2.2 Solid layer pollution tests**

The solid layer pollution tests were all carried out in the Sediver St. Yorre and CEB pollution chambers using the standard IEC 60507 procedure. Both EPDM and SiR insulators were rubbed with jewellers "rouge" to remove any hydrophobicity before applying the pollution layer with the spray-on technique. All tests were $U_{50}$ determinations by the up and down method. Tests were a carried out at different ESDD and standard NSDD. For the M profile both EPDM and SiR rubbers were tested, for the L profile only SiR was used. The tests were carried out immediately after the artificial pollution layer had dried, i.e. there was no time for the SiR rubber insulators to begin to encapsulate the pollution layer. The results are shown in Fig. 4.

Other tests were carried out after the polluted SiR insulators had "recovered" for 10 days after the pollution application, these insulators showed up to 25% improved performance at an ESDD of 0.5 mg/cm².

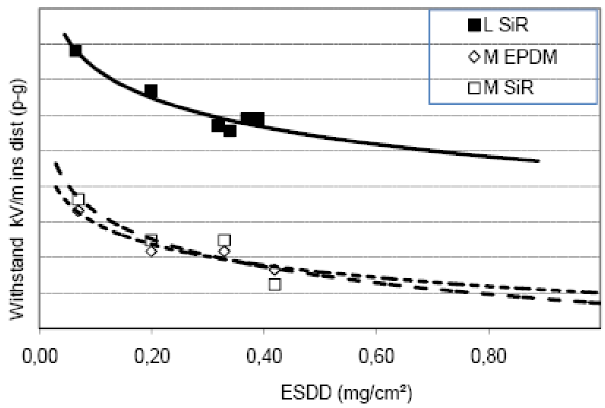


**Figure 4 Solid layer characteristics of different profiles and materials (shown as withstand voltage per metre of insulating length)**

Under solid layer pollution there seems to be little difference in the behaviour of the M profile with EPDM material or hydrophilic SiR. Again the L profile is more effective than the M profile, both in terms of USCD and voltage per unit insulating length.

To illustrate the influence of NSDD on recovery time tests were carried out at varying NSDD on SiR insulators which were allowed to recover for varying times. These results have already been reported in a CIGRE brochure [2] where it was stated that the higher the NSDD the longer the time needed for the SiR to transfer hydrophobicity to the artificial layer; up to 10 days were necessary for an NSDD of 2 mg/mm². On the other hand, the quantity of NSDD did not seem to influence the flashover performance for the levels chosen.

As for the salt-fog tests, the argument for testing for worst case conditions is strong on the basis of these results; heavy NSDD deposits can require quite long periods of recovery, during this time the SiR "advantage " is lost and the insulation level is little or no better than that of other materials.

## 3 AGEING BEHAVIOUR

### 3.1 The problem of increasing creepage distance

Faced with pollution problems, utilities have nearly always found a solution by simply increasing creepage distance. With traditional glass and porcelain insulation this is done by either using longer insulators or, when length is limited, by using a longer creepage distance profile. Long creepage profiles unfortunately follow the law of diminishing returns; the more complex the profile, the more pollution is picked up (or less is washed off) and as neighbouring sheds and ribs get closer together this increases local e-field, dry-band arcing and shed to shed breakdown hence reducing withstand performance. However manufacturing and material constraints limit the maximum creepage distance per unit length to a level where there is still a benefit in most cases.

For composite insulators the story is a little different. The reduced material thicknesses, precise moulding technology (for one-shot process insulators) and variable shed spacing (for assembled shed process insulators) mean that it is possible to pack much more creepage per unit length into an insulator. For these insulators the law of diminishing returns still applies, i.e. doubling creepage does not double the withstand value, but another potentially dangerous factor appears: ageing, tracking and erosion.

As creepage per unit length increases, so does local electric field – notably on the housing between sheds. This field strength depends both on shed diameter and packing; increase the shed diameter or reduce shed spacing and the local field will increase. As this field increases so does the risk of seeing local discharges and arcing leading to loss of hydrophobicity (for SiR insulators) and possible erosion or even tracking.

Results from test station exposure have confirmed this problem.

### 3.2 Results from test station exposure

Figures 5 to 7 show the results of identical, concurrent exposure at a test station in South Africa. Three different insulators were exposed: two "long leakage" L profile insulators at 31 mm/kV (USCD 54) in both SiR and EPDM, and one "normal leakage" M profile SiR insulator at 25 mm/kV (USCD 43). As shown in 1 above, the insulator profiles only differ by their shed diameters. All the insulators were the same length and under the same voltage.

The environment at the test station is known for being very severe; 12 to 18 months exposure will generally reveal any weak points of an insulator. Such test stations are known to reduce or totally remove hydrophobicity from Silicone rubber insulators, either permanently or periodically.

Figure 5 shows the L profile SiR insulator. There is erosion between sheds, indicative of heavy arcing and current activity.

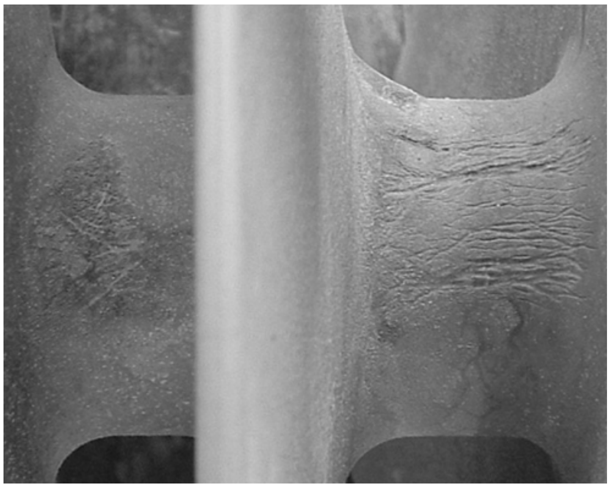

**Figure 5 Erosion damage on L profile SiR at 31 mm/kV.**

Figure 6 shows the L profile EPDM insulator with much less erosion between sheds, resulting from both the superior tracking/erosion resistance of the EPDM and probable reduced activity due to the more even wetting of the hydrophilic layer.

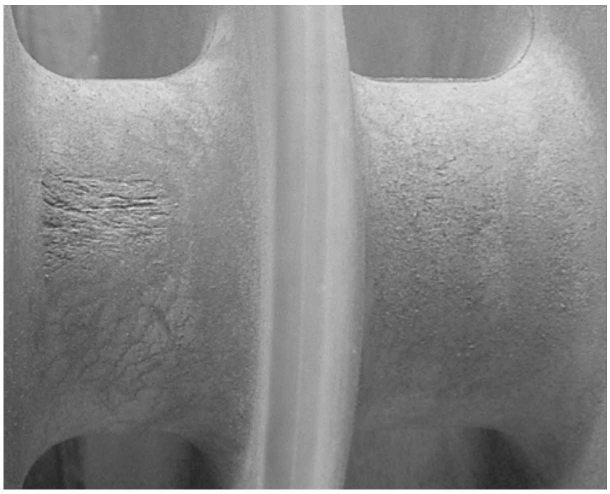

**Figure 6 Erosion damage on L profile EPDM at 31 mm/kV.**

Figure 7 shows that the low creepage distance insulator has no erosion, even though there are injection points and slight mould flashes (often accused as inception points for erosion)

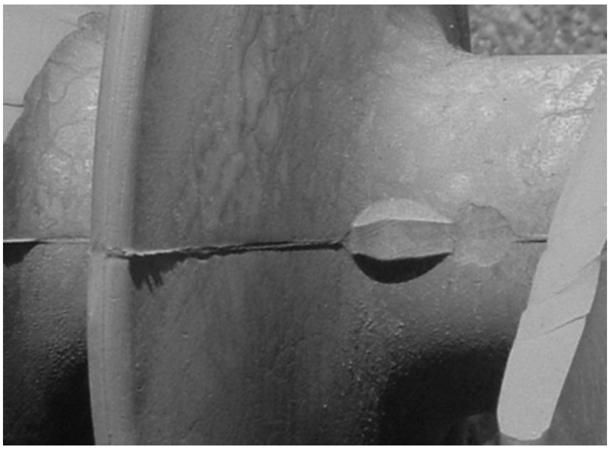

**Figure 7 Absence of erosion damage on M profile SiR at 25 mm/kV.**

### 3.3 Discussion

The illustrations clearly show that the shorter "normal" creepage insulator does not suffer any erosion. It can also be deduced (for the SiR insulators) that the pollution withstand performance of the shorter creepage insulator (which was already acceptable since no flashovers occurred during the exposure) will not be greatly different to that of the longer creepage insulators where local field produces more dry bands and hydrophilic areas, thus increasing flashover risk.

These results underline the importance of approaching creepage distance specification with care and attention. The manufacturer should not blindly propose a higher creepage distance insulator without considering all the possible effects of creepage "packing". The end-user should not blindly require high creepage per unit length without considering the possible life-shortening result of his requirement. Conversely one cannot take the results shown here to mean that reducing creepage distance is safe in all conditions. As explained in the Annex of IEC 60815-3, the zones where the insulator behaves correctly (low risk of flashover and low risk of erosion and tracking) depend on many factors, both of the insulator profile/materials and the environment.

In the past when reduced creepage has been used, the decision has generally been made solely on the basis of the pollution flashover performance without taking into account long-term effects on the materials.

## 4 CONCLUSIONS

Clause 2 demonstrates that, as far as pollution performance of composite insulators is concerned, there is no discernable difference between the behaviour of an EPDM insulator and that of a SiR insulator that has lost hydrophobicity. In salt-fog the SiR can even perform less well than its EPDM counterpart.

The circumstances where SiR can lose hydrophobicity depend on the combination of a multitude of factors, determined by both the environment and the shape and material of the insulator. Predicting whether a critical combination will occur is a delicate task requiring intimate knowledge both of the insulator and the environment. In the absence of such knowledge it is preferable to design for a worst-case scenario and choose an insulator design with sufficient withstand performance when hydrophilic.

The results from exposure of two different profiles at a test station, where the more highly stressed profile showed no erosion compared to the longer creepage and less stressed profile, illustrate clearly the risks of packing too much creepage distance into the profile of composite insulators.

A supplementary conclusion is that if high creepage per unit length is unavoidable, then a material with high tracking and erosion resistance and correctly designed interfaces is necessary to reduce the effects of any possible surface activity. Alternatively, glass or porcelain insulators – whose erosion resistance is much higher and whose pollution withstand behaviour is often equated to that of EPDM insulators – are viable solutions.

In all cases extreme vigilance is required to ensure that satisfactory pollution performance is obtained without increasing the risk of housing material degradation.

**References**


1 *IEC 60815-3, 2008, Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 3: Polymer insulators for a.c.*

2 *CIGRE Brochure 158, Polluted insulators: A review of current knowledge (2000)*