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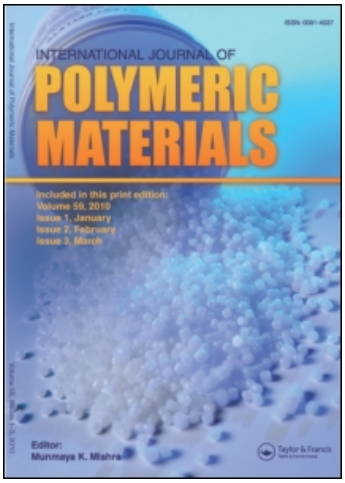

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Prediction of Service Durability of Polymer Insulating Materials

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Suggestions are made for a solution to the problem of predicting the durability of the most commonly employed electrical insulating polymer materials—polyethylene (PE) and polyvinylchloride (PVC), by investigating the kinetics of the dominant ageing process resulting in a decrease in the operating characteristics of these materials and by selecting structure sensitive measures of ageing. The kinetics for the change in the values measured in the process of long-term ageing of polymer products is studied and design formula for durability prediction are given.

KEY WORDS Durability, prediction, insulating materials, polyethylene, polyvinylchloride

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RESULTS AND DISCUSSION

In the process of the long-term use of polymer-containing products the polymers undergo ageing and degradation caused by environmental and service conditions. Technical diagnostic methods are used to predict the durability of such materials and to exclude their use beyond the reliable useful lifetime. These methods are based on investigation of the dominant physical-and-chemical process leading to the loss of polymer properties and on the selection of ageing measures.

In the present paper the prediction of durability is considered for the case of PE and PVC based insulating polymer materils used in cable products.

Composite polymer materials are used for cable and wire insulation. PVC contains over 5 different components. There are considerably fewer additives in PE. Most commonly they are antioxidants of one or two types, light stabilizers, or dyes. The total content of additives is up to 10% by mass.

Long-term ageing processes result in a change in the component's proportion, for example, in consumption of the antioxidant in PE and desorption of the plasticizer in PVC. Proceeding from this fact we determined measures of ageing which allow diagnosis of the changes in cable insulation composition. For PVC the measureable value chosen is ΔG, which is determined by isothermic thermogravimetry of cable insulation (sheath) microsamples. For PE the measureable value is Ts which is determined by a nonisometric microcalorimetry method.[1,2]

The investigation of low-voltage PVC insulated cables and wires subjected to long-term use showed that operational failures were caused by an increase in PVC rigidity, loss of cold endurance and insulation cracking. From the kinetics of PVC

mass change, accumulation of diene sequences in PVC, etc. It was established that plasticizer desorption is the dominating ageing process during PVC use and storage conditions.[1] A method of predicting durability based on the change in plasticizer content is suggested.

The analysis of mass transport on the cable surface using the criterion Bi (Bio) showed that plasticizer desorption was limited by the process of plasticizer volatilization from the cable surface. In this case the predicted PVC mass change in the ageing process may be described by the equation:

$$\left(\left(\frac{G}{Go}\right)^{1-n}\right) - 1 = (n-1)k\cdot\tau \tag{1}$$

where Go and G are the original and current sample masses, mg; n is the empirical coefficient; k is the mass loss rate constant, s^{-1}; and τ is the ageing time, s.

Evaluation of plasticizer content change is made using the value ΔG which is dependent on plasticizer content and is determined by isothermic thermogravimetry of a small (20–30 mg) PVC insulation (sheath) sample according to mass loss in temperature-time conditions providing complete plasticizer removal (sample exposure at 350°C for 20 min).

A linear dependence of ΔG on the content of some plasticizers in cable PVC compounds were established.

When predicting PVC insulation durability the remaining service life τ serv. is calculated according to the formula:

$$\tau \text{ serv.} = \frac{\dfrac{Gk + a\Delta\text{Gorig.} - b^{n-1}}{Gk + a\Delta Gi - b} - 1}{(n-1)k} \tag{2}$$

where Gk, a, b, and n are the empirical coefficients determined for each PVC grade; ΔGorig. is the value for the original, prior to use, state; and ΔGi is the value during operation.

During long-term use, PE insulated cable and wires exhibit failures in the form of spontaneous insulation destruction (cracking). As investigations show, the destruction of low-voltage cable PE insulation of small wall thickness in this case is attributed to thermo-oxidative degradation processes.[2] Thus it is possible to predict the durability of a cable product by determining the induction period or a value having a correlating relationship with this period.

A method is suggested for the evaluation of the induction period of PE cable compounds with the help of non-isothermic differential scanning calorimetry (DSC) using small cable insulation (sheath) samples of 3–5 mg.

Figure 1 shows a DSM spectrum, where (2) is the auto-oxidation peak, the value of temperature corresponding to the peak start (Ts) is evidently connected with the induction period.[3] A computer program based on the two tangent lines method was used for a true determination of Ts.

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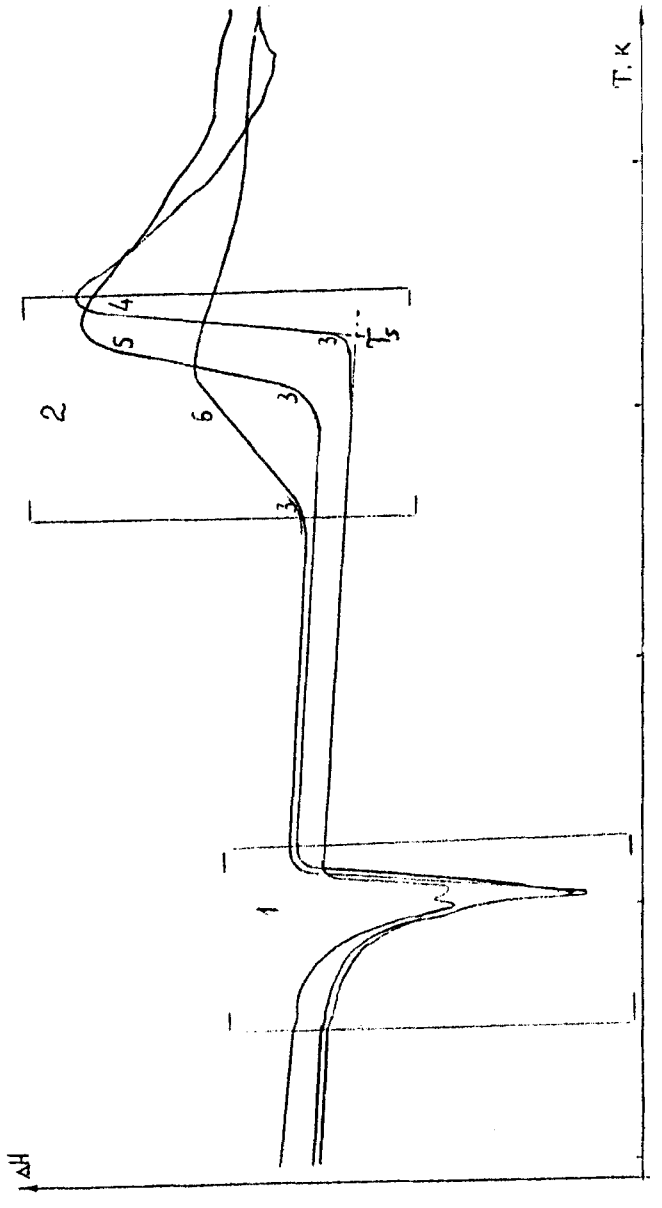

FIGURE 1 Dependence of heat flow ΔH on temperature T at an increase rate of 10 K/min and an air flow rate of 35 ml/min.
1 = melting area,
2 = thermal oxidative area,
3 = temperature of the beginning of auto-oxidation Ts,
4 = original PE insulation,
5, 6 = aged at the temperature of 343 K for 1200 h (5) and for 17,400 h (6) cracked.

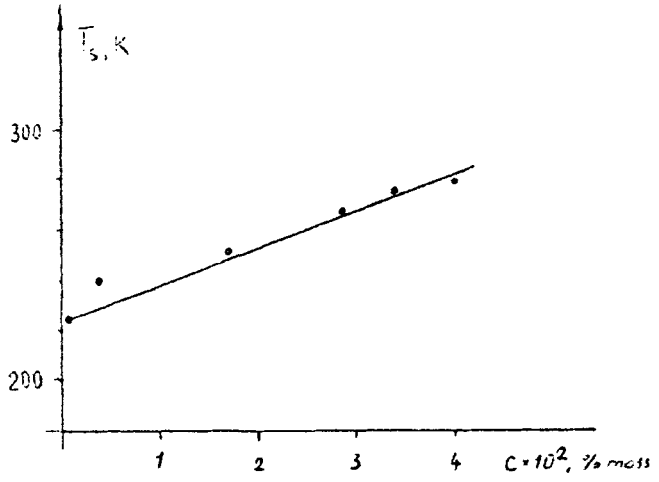

FIGURE 2 Dependence of Ts value on the stabilizer content (diaphen) in PE insulation (compound 107-01K).

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It was established that the Ts value change rate is of zeroth order in isothermic ageing.

To predict the durability of PE insulation according to the Ts value, the minimum limit admissible (Ts.adm.) value corresponding to the critical (non-working) concentration of the stabilizer used is determined by the dependence between the antioxidant content and the Ts value (Figure 2).

A minimum Ts value which does not change with further decreases in the stabilizer content is taken as the admissible limit value. In the case when the obtained Tsi value of the cable (wire) insulation under diagnosis during use exceeds the admissible limit value, the remaining service life (serv.) is calculated according to the formula:

$$\tau \text{ serv.} = \frac{\text{Tsi} - \text{Ts.adm.}}{\text{Ts.orig.} - \text{Tsi}} \tau \tag{3}$$

τ is the use time up to the moment of diagnosis, s. Ts.orig. and Tsi are the original and current Ts values, C

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