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XLPE insulation under thermomechanical stress – a model-like explanation of the behaviour of an "intelligent" material

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Résumé

Cette présentation porte sur un modèle décrivant le comportement mécanique du polyéthylène réticulé en tant que matériau visco-élastique compte tenu en outre de l'état de réticulation. La présentation du modèle est appliquée au processus de production en rapport avec les relations de volume spécifique dépendant de la température et les états de déformation générateurs de tension. Les conclusions tirées prouvent que les résultats obtenus au cours des essais de contraction sont dus uniquement à des empêchements de la contraction thermique et ne sont influençables à l'aide d'aucune mesure en raison des caractéristiques physiques fondamentales du matériau. Le comportement élastique constamment réactivable par des cycles de chaleur doit être maintenu uniquement par les mécanismes d'adhérence assurant la conservation de l'équilibre des forces au cours de toute la durée de vie du câble.

1. Introduction

Ever since plastics have been used in cable engineering, one particular characteristic of these otherwise outstanding materials has caused annoyance: the tendency of the extruded layers - in either insulation or sheath form - to become shorter (see shrinkage tests, e.g. [1, 2]).

It is widely known that this behaviour results from mechanical tensions caused during the cooling process [3, 4, 5]. The processing and cooling conditions are however regarded as exerting, in part, considerable influence, particularly because of the viscoelastic behaviour of plastics. In this regard, especially in the case of XLPE insulation, a great lack of understanding about the behaviour of plastics exists.

The paper is thus designed to explain the behaviour of XLPE, fundamentally and in practice, when used in core insulation in the medium and high voltage cables, by means of the model-like description of its elastic and viscoelastic behaviour, additionally taking into account the state of cross-linking.

2. The fundamentals of plastics' material behaviour**2.1 Retardation and relaxation of viscoelastic materials**

When subjected to external, mechanical stress, plastics exhibit marked creep behaviour. In a so-called retardation experiment (stress $\sigma = \text{const.}$), they react spontaneously like elastic materials, with an elongation ε_0 ($t=0$) according to Hook's Law. Over time the material responds by means of significant tension-dependent and temperature-dependent creep (figure 1.1; [6, 7, 8]).

If the material is subjected to constant strain, it reacts spontaneously by means of a stress response according to elastic behaviour (Hook's Law), and over time by means of a temperature-dependent reduction of the mechanically-acting tension, so-called stress relaxation (figure 1.1; [6, 8]). It is characteristic that over time the relaxing tension approaches a limit which, as an elastically-acting stress, persists in the long term (figure 1.1). If the load on the deformed materials is removed at time t_x , the residual, elastic portion reduces spontaneously (figure 1.2). If the long-term deformation acting is significantly larger than

Abstract

In this paper a model is described which explains the mechanical behaviour of XLPE as a viscoelastic material, additionally taking into account the state of cross-linking. The model is applied to the production process in connection with the links between temperature-dependent specific volume and tension-producing deformation conditions. The findings show that the results obtained from shrinkage testing are solely attributable to the restriction of thermal contraction, and, due to the fundamental physics of the material, cannot be influenced by any measures whatsoever. The elastic behaviour, constantly reactivated by heating cycles, must be solely maintained by the adhesion mechanisms responsible for retaining the balance of forces throughout the entire lifetime of the cables.

the elastic elongation limit of the material (approx. 0.5% to 1.0% elongation) [6], then, after reduction of the time-dependent deformation (viscoelasticity), some residual deformation remains (figure 1.2). The residual deformation is generally accepted to be irreversible [6].

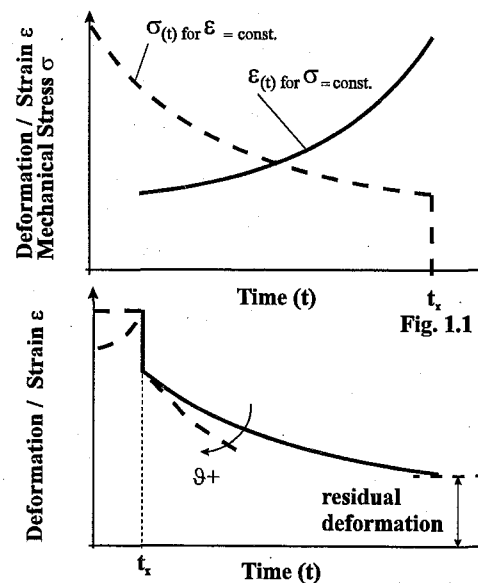


Fig. 1 Relaxation and retardation behaviour of plastics

2.2 Thermal contraction and shrinkage behaviour

The specific volume of plastics is dependent on temperature, just like all solids. Some plastics exhibit considerable changes in volume with temperature. This leads to the well-known linear coefficient of heat expansion. Because this is an isotropic characteristic from the physical point of view, this means, in effect, as a law for materials, that changes in dimension are equal in all directions (see also figure 8, reference curve in [4] for XLPE), when no hindrance exists.

In general two conclusions should be drawn from this physical behaviour especially for cooling periods (decreasing material temperature):