Lifetime prediction of an external protection of cold-shrinkable joint in EPDM rubber subjected to thermal ageing

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ABSTRACT

The aim of the present work is to use an accelerated ageing procedure in order to derive a tool allowing the prediction of the stretch ratio at failure of an industrial Ethylene-Propylene-Diene Monomer (EPDM) rubber used as an external protection of a cold shrinkable joint.
To achieve this goal, the main idea is to combine two complementary levels: The average molar mass of the elastically active chains (i.e. between crosslinks) M_c (indicator of the macromolecular network degradation) with the fracture mechanics approach and the intrinsic defect concept (both determined at macroscopic scale of material). By introducing the time-temperature equivalence principle, a shift factor obeying to an Arrhenius law is derived, and master curves are built as well for the average molar mass as for the ultimate mechanical property. Fracture mechanics tests are also achieved and the square root dependence of the fracture energy with the average molar mass is pointed out. Moreover, it is shown that the mechanical response could be approximated by the phantom network theory, which allows to relate the strain energy density function to the average molar mass. Assuming that the fracture of a smooth specimen is the consequence of a virtual intrinsic defect, whose size can be easily estimated, the stretch ratio at break can be therefore computed for any ageing condition. The estimated values are found in a very nice agreement with experimental data, making this approach a useful tool when designing rubber components for moderate to high temperature service environments.

KEYWORDS

Rubber, EPDM, Thermal ageing, Failure prediction, Lifetime, Intrinsic defect, Fracture mechanics.

INTRODUCTION

During operation, rubber components can be subjected to complex environmental conditions (light, humidity, temperature, oxygen, etc.). Indeed, chemical and physical ageings are known to strongly modify the mechanical responses of such materials, but also the ultimate properties such as the strain at break. Especially, in the presence of oxygen, the modification of the chemical structure of the elastomeric material is essentially attributed to the macromolecular chain scissions and crosslinking mechanisms, in addition to the break and reformation of network crosslinks [1-4]. These mechanisms induce the alteration of the mechanical properties [4-6]. Many analytical techniques are used to investigate chemical ageing of polymers allowing the measurement of their chemical, physical and mechanical properties [4, 7, 8]. Since natural ageing is a long time process, accelerated thermal ageing tests are often used to shorten their exposure duration and predict their operating life time. Indeed, from these tests, results for lower temperatures are generally obtained using the time-temperature equivalence principle [9-13].

LITERATURE BACKGROUND

Swelling tests: Average molar mass measurements

When a rubbery polymer network is placed in a suitable solvent (presenting a good chemical affinity with the polymer), the polymer tends to absorb the maximum of solvent in its free volume (Fig. 1).

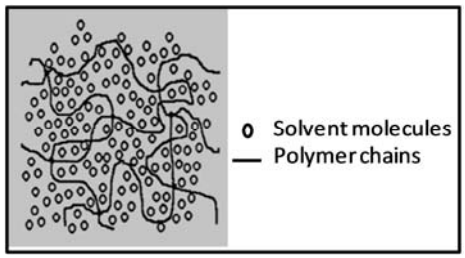

Fig.1. Polymer network swollen in an adequate solvent.

This reversible physical process causes the network volume expansion in the three space directions as shown in Fig. 2.

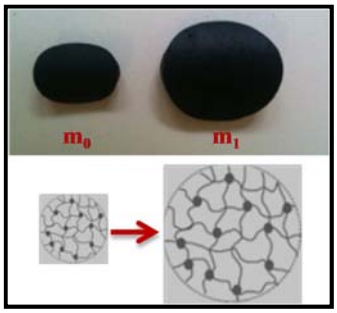

Fig.2. EPDM swelling in the cyclohexane solvent.

The swelling ability depends on the interactions between the polymer chains and solvent molecules, in addition to the length of polymer chains between crosslinks which is defined by the average molar mass of the elastically active chains M_c. This parameter is given by the Flory-Rehner relationship for a 4-functional network [14-15]:

$$M_c = -\frac{0.5\, V\, \rho_{polymer}\left(V_{r0}^{1/3} - 0.5\, V_{r0}\right)}{ln(1-V_{r0}) + V_{r0} + \chi\, V_{r0}^2} \quad \textbf{(1)}$$