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Effects of aging on the creep behaviour and residual lifetime assessment of polyvinyl chloride (PVC) pipes

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ABSTRACT

Creep crack growth has been investigated in a polyvinyl chloride (PVC) on circumferentially cracked round bars, on both virgin and aged pipes after 22 and 35 years service. The aim is to predict the resistance to creep failure of pipes under internal pressure by using the fracture mechanics for creeping solids (FMCS) tools. The approach consists of carrying out creep tests on both smooth and cracked specimens. This experimental database is utilised in order to demonstrate the effect of aging on the creep response of the material. A master curve is then plotted, allowing the creep lifetime assessment of laboratory specimens. On the basis of the master curve and under FMCS concept, a methodology for predicting creep failure of cracked pipes is suggested.

1. Introduction

Pipes are engineering structures that are extensively used for fluid (gas or liquid) supply. This paper is devoted to water supply for which hundreds of thousands of kilometres of polyvinyl chloride (PVC) pipes are involved. They are subjected, to a first approximation, to steady internal pressure, leading to a constant hoop stress (creep). The resistance to creep failure of such an extended network is of prime importance and the challenge is the same as that studied for the last decades on metallic materials (nuclear engineering structures for instance).

Many studies were involved in assessing the lifetime of pipes subjected to sustained internal hydrostatic pressure. Fracture mechanics for creeping solids (FMCS) concepts have extensively been used for metallic materials working at elevated temperature [1,2]. However, it should be noted that the main requirements of this approach are essentially mechanical in terms of constitutive relationships, regardless of the studied material.

Concerning polymeric materials, most studies about the viscosity have focused on small strains for which dynamic (periodic) tests are recommended [3]. Since very small strains are sometimes involved, this kind of test is considered as "load free". Accordingly, the concepts based on this hypothesis generally use linear viscoelastic theory that supposes that both elasticity (small strain) and viscosity (Newtonian behaviour) are linear. Storage and loss moduli are then determined with respect to either the temperature or the test frequency.

In the case of pipes subjected to internal pressure, small strain analysis might be inappropriate. Non-linearities in both the stress–strain relationship and viscous effects may appear. Especially, when there is a heterogeneous (multiaxial) stress state in the structure, assessment methods allowing the forecast of the durability of the structure need further investigation. Indeed, interest was essentially focused on polyethylene [4–6]. For instance, Ben Hadj et al. [4] utilised a global approach assessment, which takes the viscoplastic behaviour under multiaxial stress states into account. Recently, a local approach of fracture based on slow crack growth was proposed [7], which is physically motivated by comprehensive microscopic examinations of micro-mechanisms.

The PVC pipes under study have been in service for 22 and 35 years, respectively. The approach follows the aforementioned study (global approach of fracture mechanics under multiaxial stress state). The effects of aging on the creep behaviour (essentially on the creep strain rate) are investigated with the help of creep tests on smooth specimens. Additionally, the impact of these effects on the creep failure curve is highlighted, by creep testing cracked specimens.

The first part of the paper presents these PVC pipes of interest, with their respective origins. The specimen geometries are then detailed in terms of smooth and circumferentially cracked round bars (CCRB), as well as double edge notched tensile (DENT) specimens. A specific sampling of the specimens is set in order to

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