Predicting failure of pressurized uPVC pipes

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Introduction

Unplasticized Poly(Vinyl Chloride) (uPVC) pipes can fail due to ductile tearing, hairline cracking or brittle fracture (figure 1b). These failure modes are typically encountered during burst tests, where an internal pressure is applied on pipe segment at a certain temperature and the time-to-failure -the time upon which the pressure suddenly drops- is measured. In this study an approach is developed to predict the outcome of burst tests to circumvent this costly experimental method.

Hypothesis

- Not only ductile tearing, but also hairline cracking and brittle fracture are initiated by plastic deformation.
- Upon loading plastic deformation will accumulate according to:
  \[ \dot{\gamma}_{pl} = \dot{\gamma}_{exp} (\gamma_0, T, p, \tau) \]
- Failure occurs when the plastic strain is equal to a critical strain \((\gamma_{cr})\), where the polymer enters its softening region.
- The critical strain is constant for a wide range of applied stresses and temperatures, therefore the time-to-failure under static conditions can be calculated with:
  \[ t_f = \frac{\gamma_{cr}}{\dot{\gamma}_{pl} (\gamma_0, T, p, \tau)} \]

Model

The equivalent plastic deformation rate \((\dot{\gamma}_{pl})\) is calculated with a pressure modified Eyring relation:

\[ \dot{\gamma} (\gamma_0, T, p, \tau) = \gamma_0 \cdot \exp \left( \frac{-\Delta U_0}{R \cdot T} \right) \cdot \exp \left( \frac{-\mu \cdot p \cdot V^*}{k \cdot T} \right) \cdot \sinh \left( \frac{\tau \cdot V^*}{k \cdot T} \right) \]

Both activation energy \((\Delta U_0)\) and activation volume \((V^*)\) are determined from tensile yield stress data for a range of strain rates and temperatures (figure 2a). The time-to-failure for short term tensile creep experiments (figure 2b) can be predicted with a constant value for the critical strain \((\gamma_{cr})\). For these predictions only one reference point is needed to find \(\gamma_0\), which is dependent on both thermal and mechanical history of the sample. Furthermore, the pressure dependence \((\mu)\) of the material is necessary to apply the model to different (3D) loading conditions. This pressure dependence for uPVC is determined from the slope in figure 3a.

Validation

The model predictions are compared with the burst test data of Niklas et al. [1] as shown in figure 1a. The lines in this figure are not only guides to the eyes, but actual predictions. An accurate prediction is obtained for both stress (slope of the lines) and temperature (the horizontal shift of the lines) dependence, using only one reference point.

Conclusions

- The model predictions agree quantitatively with data from Niklas et al. [1] (figure 1a).
- The model predictions hold for all three failure modes.
- Both the stress and temperature dependence are predicted accurately.
- The presented approach enables us to make long term strength prediction using only short term tensile experiments.

References: