Can physical ageing cause embrittlement of our gas distribution network?

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Introduction

About 22,500 km of unplasticised poly(vinyl chloride) (uPVC) pipe is in use in the Dutch gas distribution network. These pipes will reach their initially estimated service life in the near future. Nevertheless, leak survey data reveals no decrease in the integrity of this part of the network[1]. Therefore, the question arises if (and how long) the pipes can remain in the ground without concessions to safety.

Most leaks occur due to incidents during excavation activities (third party damage). The lifetime of a uPVC pipe is therefore limited by its impact behaviour: brittle behaviour upon impact will impose a significantly higher risk than ductile behaviour. The goal of this study is to determine the influence of physical ageing on the impact behaviour of uPVC pipes.

Impact behaviour

The impact behaviour of uPVC pipe specimen is studied using instrumented falling weight tests at a range of temperatures. Three types of failures are observed: ductile (Fig. 1), semi-ductile (Fig. 2) and brittle failure (Fig. 3). A histogram f the absorbed energy up to the maximum force is shown in Fig. 4. The ductile failure mode resists significantly more impact energy than the brittle failure mode.

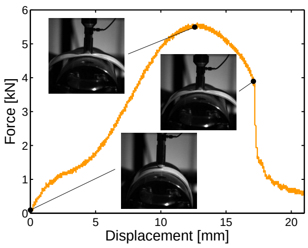


Fig. 1 *Ductile failure*

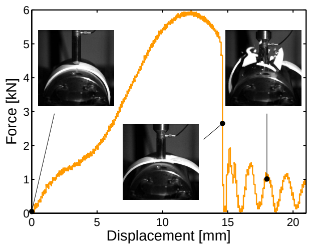


Fig. 2 *Semi-ductile failure*

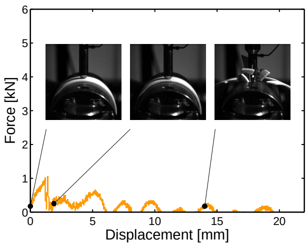


Fig. 3 *Brittle fracture*

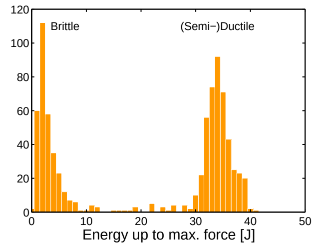
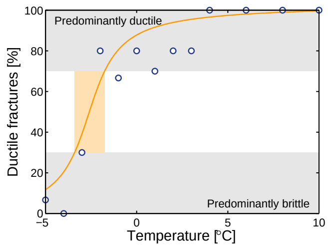


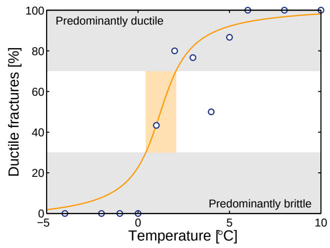
Fig. 4 *Histogram absorbed energy*

Ductile-to-brittle transition

With decreasing temperature the failure behaviour shifts from ductile towards brittle fracture (Fig. 5). These measurements are conducted for samples that received different ageing treatments. A stepfunction (inverse of tangent) is fitted through the data points to determine the transition temperature range, which is indicated in orange. After ageing the transition range shifts towards higher temperatures (difference between Fig. 5a and 5b).



(a) As received specimen



(b) Aged specimen

Fig. 5 *Ductile-to-brittle transition for as received specimen (a) and aged (∼120 years at 10°C) specimen (b)*

Modeling the influence of ageing

The transition temperature range is plotted versus the ageing time of the samples (translated towards the average ground temperature of 10°C) in Fig. 6. The blue rectangle gives the temperature transition range for the sample which did not receive a heat treatment (as received)

The ductile-to-brittle transition of glassy polymers can be predicted by assuming a yield stress threshold above which the polymer behaves in a brittle way [2]. The predicted kinetics of the transition temperature change as a function of ageing is shown with a solid line in Fig. 6. For the predictions an initial age of 20 years at 10°C was assumed. The model describes the kinetics found with the measurements correctly.

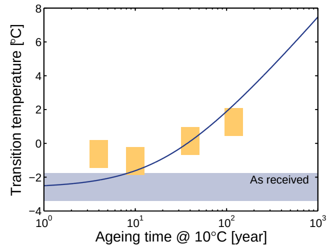


Fig. 6 *Transition temperature range versus the ageing time at 10°C*

Conclusions

The answer to the question in the title is yes and is supported with experimental data and model predictions. Physical ageing causes the ductile-to-brittle transition temperature to shift towards higher temperatures. In future work rejuvenated samples will be tested to determine wether the predicted shift in transition temperature still holds for "younger" samples.

Acknowledgements

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References:

[1] HERMKENS R. J. M. ET AL.; *Proceedings of PPXIV* (Hungary, 2008)

[2] ENGELS T. A. P. , ET AL.: *Predicting age induced embrittlement of glassy polymers* (Polymer, submitted)