Methodology for Lifetime Prediction of Glass/Polyamide 6-6 Safety Pieces in the Domestic Distribution Network of Drinking Water

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Glass/polyamide 6-6 composites are now considered for the replacement of metallic parts of safety pieces used in the domestic distribution network of drinking water. But, before to be used, these materials must demonstrate their long term durability in a highly aggressive environment combining the chemical effects of three molecular reagents: water, oxygen and chlorine dioxide (ClO_2, a water disinfectant), and the mechanical effect of the hoop stress induced by the water pressure.

Accelerated ageing tests made on free additive polyamide 6-6 films in simplified environmental conditions (pure distilled water and dry air under atmospheric pressure) have confirmed that this composite matrix is highly sensitive to hydrolysis and oxidation [1,2]. But, the main reaction occurring at the operating temperature (typically 17°C) is the oxidation initiated by the chemical attack of ClO_2, which is a free radical in ground state. This reaction causes the cleavage of C-N bonds and the formation of carbonyl chain ends. Chain scission decreases the polymer molar mass and thus, destroys the entanglement network in the amorphous phase, liberating small macromolecular segments which rearrange locally and initiate a chemicrystallization. In the absence of mechanical stress, polyamide 6-6 loses its ability to sustain plastic deformation at a very low conversion ratio of the degradation reaction, in particular when the number average molar mass reaches a critical value of about 17 $kg.mol^{-1}$, corresponding to a critical interlamellar spacing of about 6−7 nm.

Starting from these observations, a semi-empirical model has been proposed to predict the "chemical-mechanical coupling" responsible for the premature failure of glass/polyamide 6-6 composites in service conditions. It is composed of three successive levels:

a) A "chemical" level whose the function is to calculate the profiles of molecular changes in the superficial layer in contact with disinfected water. This system of 11 differential equations has been derived from the mechanistic scheme previously established for polyamide 6-6 thermal oxidation [2], but completed with antioxidants and ClO_2 reactions. It couples the diffusion of molecular reagents (oxygen, antioxidants and ClO_2) across the composite parts with their chemical consumption by the chemical reaction.

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b) A “physical” level whose the function is to calculate the resulting macromolecular and morphological changes responsible for the initiation of premature cracks into the superficial layer. The scale changes are made by connecting two types of structure/property relationships in series. The classical Saito’s equation [3] allows to determine the average molar mass from the number of chain scissions, whereas the equations proposed by Fayolle et al. [4] give access to the crystallinity ratio and interlamellar spacing knowing the average molar mass.

c) And finally, a “mechanical” level whose the function is to calculate the time to failure under the combined effects of chemical degradation and water pressure. The empirical creep equation and the failure criterion are derived from the regression curves, i.e. the plots of hoop stress *vs* time to failure in Log-Log coordinates, obtained in pure distilled water. It is assumed that the chemical degradation modifies only the time for the transition between the ductile and brittle regimes of fracture. This time is linked to the average molar mass according to a power law.

The objective of the present communication is to give a detailed view of this semi-empirical model and to check its validity in real service conditions. It will be explained how the chemical degradation shifts the ductile-brittle transition towards lower times, but also increases significantly the slope of the regression curve in the brittle regime of fracture.

REFERENCES

1. C. El Mazry, O. Correc and X. Colin, A new kinetic model for predicting polyamide 6-6 hydrolysis and its mechanical embrittlement, *Polym. Degrad. Stab.* **97**, 1049–1059 (2012).
2. C. El Mazry, M. Ben Hassine, O. Correc and X. Colin, “Thermal oxidation kinetics of free additive polyamide 6-6”, *Polym. Degrad. Stab.* **98**(1), 22–36 (2013).
3. Saito O., On the effects of high energy radiation to polymers., *J. Phys. Soc. (Japan)* **13**(2), 198-206 (1958) and **13**(12), 1451–1464 (1958).
4. B. Fayolle, E. Richaud, X. Colin and J. Verdu, Review: Degradation-induced embrittlement in semi-crystalline polymers having their amorphous phase in rubbery state, *J. Mater. Sci.* **43**, 6999–7012 (2008).