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Water diffusion in glass fiber reinforced polyurethane foam (R-PUF): hygro-mechanical coupling and durability of mechanical properties

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1 Introduction

The insulation of MarkIII membrane of the Liquid Natural Gas Carriers (LNGC) consists of a load-bearing system made of panels in reinforced polyurethane closed cell foam (R-PUF). The reinforcement which consists of chopped glass fibers dispersed perpendicularly to the rise direction, offers yield strength and elastic moduli greater than pure polyurethane foam (PUF).

During the shipping, the cargo containment could be potentially subject to rare risk events which can be water leakage through the wall ballast tank. To define of the damage severity of event, both water diffusion mechanisms and mechanical properties degradation must be evaluated. The challenge of this study is to appreciate the role or impact of polymer matrix, porous structure and fiber reinforcement on the R-PUF system immersed in water.

2 Non-Fickian water diffusion

The classical Fick's law is generally used for modelling the water diffusion in polyurethane solid and closed-cell foam. However, the experimental mass evolution of thick plates immersed in water, at room temperature, reveals several anomalies in sorption behavior of R-PUF, especially during the transient regime of fiber reinforced direction. A highest coefficient of moisture expansion in rise-direction can be an explanation of this anisotropy. The best-fit of experimental data with the use of Weitsman's hygro-mechanical coupling model [1] could be a validation of these interpretations (figure 1).

We propose a model for the water diffusion coupled in R-PUF cubic sample 50x50x50 mm which are the micromechanical representative elementary volume (REV) [2].

3 Polyurethane degradation affects durability of mechanical properties

The stress-strain behavior of R-PUF REV samples has characterized by compression tests on in rise direction (Figure 2). In linear elastic region, cell edges are bent by loading and membranes of closed cells are stretched by deformation. In second time, anelastic region results of molecular structural relaxations of polyurethane matrix which add a viscous component to the elastic component. In a third time, plateau plastic region, cell edges buckle and membranes are tore by excessive deformations. The cell plans are collapsed by shearing until total densification[3].

Just after removed samples from water, the mechanical properties losses are the same for all immersion time upper than characteristic time for diffusion in REV, i.e. a decrease of elastic modulus and a decrease of stress of anelastic yield. These degradations combine the water molecules acting as plasticizer (participate in hydrogen bonding) and the changes in segment length distributions induce by hydrolysis on the polyurethane matrix.

Peak deconvolutions of ATR-FT-IR spectra, performed on small cubic samples to ensure that the chemical degradation of polyurethane matrix is not controlled by diffusion, have allowed identifying a linear increase of primary amide and carboxylic acid concentrations appears with the ageing time. These species formed are hydrolysis products of urea/urethane and ester groups which lead to chain scissions in hard and soft segments micro-domains[4].

Drying process of samples at room temperature and relative humidity of 50%, allows to remove certain amount of free and bonded water which are diffused and to assess the reversibility of physical and mechanical properties. The chemical degradation induces a linear decrease of elastic modulus and of stress anelastic yield.

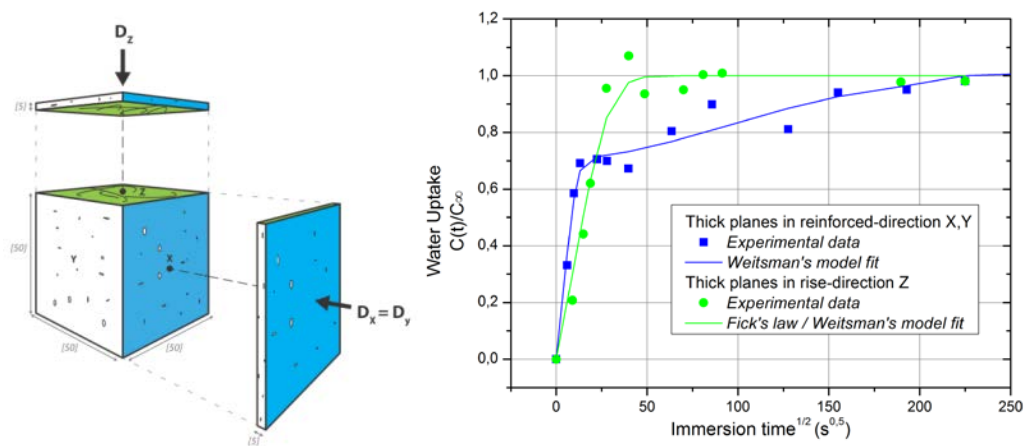


Figure 1: Water uptake in R-PUF thick plates immersed at room temperature, in rise direction (Z - green) and in fibers direction (X - blue and Y - white) fitting with Fick's law and Weitsman's model.

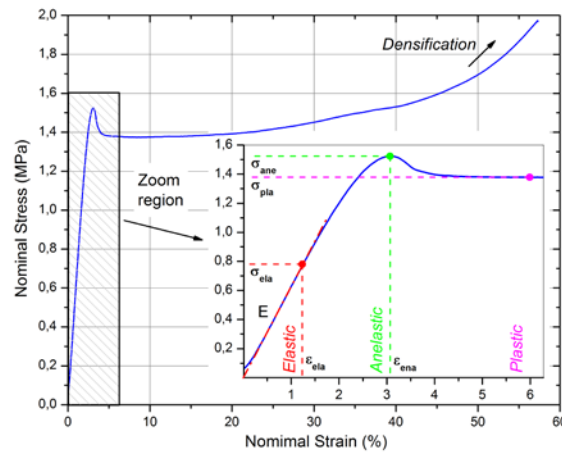


Figure 2: Uniaxial compression stress-strain curve of R-PUF REV in rise direction (strain rate 5mm/min).

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