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Influence of ageing in the failure pressure of a GFRP pipe used in oil industry

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ABSTRACT

This paper is concerned with the influence of ageing in the failure pressure of a glass fibre reinforced polymer (GFRP) pipes used for oil and gas transport. Burst tests were performed on pipes submitted to accelerated ageing combining hydraulic pressure and temperature (1 MPa and 80 °C). An alternative method, which does not require the immersion in a water bath or other fluid bath, was adopted for the ageing of the specimens. The experiments show that the burst pressure can be strongly affected by the ageing period. Tensile tests also have been performed, showing a brittle-elastic behaviour. For this particular composite, the stiffness of the tensile specimen is not significantly affected by the ageing time, but the ultimate tensile stress (UTS) is affected by the ageing time. A methodology to obtain analytic estimates of both UTS and failure pressure for a given ageing time is proposed. In order to obtain a lower bound of the failure pressure at a given operation time, besides the pipe geometry, it is only necessary to know the UTS of the composite obtained in a minimum of three tensile tests performed at different ageing times. The prediction error is less than 0.8% for the UTS and is less than 25% for the failure pressure.

1. Introduction

Fibre reinforced polymer-matrix composites have been extensively used in various engineering applications such as aeronautic, aerospace and marine industries due to their advantages compared to conventional metallic materials. In chemical, petrochemical and oil and gas industries, glass fibre reinforced polymer (GFRP) pipes are particularly interesting to convey fluids which are commonly aggressive to most of metals and alloys, avoiding corrosion problems. However, during the service life, GFRP pipes may be exposed to aggressive environmental conditions, resulting in degradation of material properties. In this paper, the definition adopted for ageing is the modification of the microstructure of the composite such that the same loading process performed in the same environment at different times, gives different mechanical responses. The degradation due to ageing mechanisms may significantly reduce the service-life of composite structures. Ageing can be induced by different factors such as temperature, moisture and UV radiation, and can cause pronounced changes in modulus, strength, and ultimate strain and can be at elevated temperatures.

Many studies regarding the effects of ageing factors on mechanical properties of composites can be found in the literature [1,2]. In particular, studies concerning the influence of hot water immersion and moisture on the mechanical properties of fibre reinforced composites such as in [3–19]. Moisture and temperature accelerate the ageing process and could reduce the mechanical

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performance of fibre, matrix and especially the fibre/matrix interface [3–13]. Interfacial stress components can be induced if the thermal expansions of fibre and matrix are different. The degradation of fibre reinforced polymer materials in hydrothermal conditions can derive from hydrolysis (chemical ageing induced by irreversible changes) or swelling and plasticization from the physical ageing induced reversible changes [14–16]. Yang et al. [17] investigated how water absorption and hydrothermal ageing influenced fibre surface on GFRP. Soykok et al. [18] studied how fastened joints of glass/fibre epoxy composites are influenced by hot water immersion. The influence of water ageing on the mechanical properties of flax and glass fibre reinforced composites was investigated by Assarar et al. [4]. The effect of water immersion effects in composites with different types of matrices was studied by Dell'Anno and Lees [19]. It is a consensus of almost all researchers that hot water ageing has a negative impact on mechanical characteristics of fibre reinforced composite materials.

Despite the corrosion resistance of GFRP pipes, there are few papers about the effect of ageing on the failure pressure of pipes used in oil and gas industry [8–10]. Although the study of ageing in such kind of composite is not new, the adequate prediction of the strength of an arbitrary GFRP pipe at a given time in a given environment is still an open area of research. Assessing the integrity of aged GRFP pipelines is particularly important in the oil and gas industry, since in many situations it is important to decide whether operation must be immediately stopped or if it is safe to wait until the next scheduled maintenance stop. Rodríguez et al. [9], performed a failure analysis of a GFRP pipe for oil transport including the chemical degradation process that attack the fibre–matrix interface reducing the mechanical performance. Zhang et al. [10] investigated the failures of an anticorrosion plastic alloy composite pipe after several years of usage.

The present study is concerned with the influence of ageing in the failure pressure of glass fibre reinforced polymer (GFRP) pipelines. Initially, the objective was basically to use an alternative ageing methodology in samples of a particular kind of GRFP pipe used in oil and gas industry to check how the UTS is affected by the ageing process. This testing methodology does not require the immersion in a water bath or other fluid bath and is described in [20,21]. The ageing methodology consists of long term hydrostatic tests performed in GFRP pipes filled with water at 80 °C and a constant internal pressure of 1.0 MPa (2, 4 and 6 months). Such conditions were selected to simulate the long life operation conditions in pipelines in the petroleum industry units. It is important to remark that it is not an easy task to perform long-term hydrostatic tests with water at constant pressure at elevated temperatures (about 30 °C below the glass transition temperature). The pressure control is also very important, since very small variations of temperature may induce huge pressure oscillations ([21,22]). The hydrostatic specimens were provided directly by the manufacturer and were tested as received. After the ageing process, tensile tests were performed using specimens manufactured from the aged pipes. These tests showed that the variation of the stiffness of the tensile specimens is negligible, despite the ageing time, while the ultimate tensile stress is affected. The ultimate tensile strength decreases asymptotically to a limit value. An analytic expression was proposed to predict the UTS for any given ageing time. The model predictions of the UTS were in very good agreement with experimental results with a maximum relative error of 0.8%.

After each ageing period, and before the fabrication of the tensile specimens, a burst test was performed. The experiments show that the failure pressure can be strongly affected by the ageing period. Differently than for metallic materials that can be welded, it is difficult to fabricate composite specimens for hydrostatic burst testing at elevated temperatures. Besides the temperature control, the main challenge is to have end closures with the necessary strength to assure that the failure will occur in the middle portion of the specimen. Flanges are bonded at the extremities and it is important to observe that the tests were performed with water at 80 °C (fluid temperature close to the glass transition temperature). It is not an easy task to bond polymer parts at this temperature. This fact motivated to extend the study in order to propose a simplified methodology to obtain a preliminary analytic estimate of the failure pressure of an aged pipe without the need of hydrostatic testing. This approach for thin-walled pipes is somewhat similar to the proposed successfully in [20,21,23,24] to predict the failure pressure of thin-walled metallic pipes.

In order to obtain a lower bound of the failure pressure at a given operation time, besides the pipe geometry, it is only necessary to know the elastic properties of the composite and the ultimate stress obtained in three tensile tests performed with different ageing times. The results of the model predictions of the burst pressure for different ageing times are compared with experiments, showing a reasonable agreement, with a maximum relative error below 25%. This methodology is a preliminary step for assessing the integrity of aged GFRP pipelines, not requiring the use of numerical codes and not even hydrostatic testing.

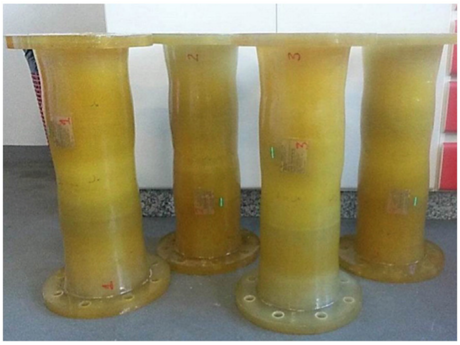

Fig. 1. GFRP pipe flanged pipe segments.