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Replication of liner collapse phenomenon observed in hyperbaric type IV hydrogen storage vessel by explosive decompression experiments

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ABSTRACT

An experimental design based on representative sample is described in order to reproduce the detachment and deformation of the inner polymer layer (called liner) of hyperbaric hydrogen storage vessels during the emptying step. It is the first step of a better understanding of the mechanisms involved in the creation of a liner collapse. Results showed that a hydraulic testing machine fitted with a pressure hydrogen chamber enables to create a liner collapse on small samples by explosive decompression experiments. Tomographic observations have revealed that the collapse appears at the polymer liner/composite interface in areas that are not sufficiently bonded, nor consistently. Determination of liner collapse amplitudes, assessed by tomography, has underlined that, under some specific conditions, the deformation of the liner is permanent even when hydrogen has completely desorbed from the sample. In addition to liner collapses, composite cracks were also highlighted.

Introduction

Hydrogen is increasingly considered as an alternative to traditional energy sources like oil and natural gases. It offers several advantages such as the absence of greenhouse gas emission and quasi-infinite source. However, hydrogen storage remains a major issue for a large-scale use. There are several ways to store hydrogen such as liquid storage tanks [1,2], metal hydrides [3,4], polymer and composite foams [5]; nowadays the most promising technology is the use of high pressure gaseous hydrogen vessel [6,7]. The last generation of these vessels - known as type IV – is composed of a polymer liner assembled with a metallic boss and fully wrapped with carbon fiber-thermoset resin composite [8,9]. The composite material provides mechanical strength to the structure [10] and its thermo-mechanical behavior is rather well documented in literature [11–15] whereas the plastic liner ensures gas tightness. Therefore, type IV vessels can answer to most of the technological issues due to their light weight and the

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possibility to reach high pressure. Usually, the pressure inside the vessel is above 350 bar and can reach 700 bar for on-board application. These vessels are submitted to many emptying/filling cycles during which the liner, confined in the composite shell, undergoes complex loadings combining bending and biaxial compression induced by the internal pressure. Moreover, the liner undergoes a hydrostatic loading, not only because of the confining gas pressure but also because of stresses from thermal gradient, generated by hydrogen gas compression and decompression during the emptying/filling steps. Besides, the gas solubility can induce damage (degradation process) or local changes of material properties. It is well established that some gases have the ability to dissolve in polymers or elastomers which are environment-sensitive materials. Thus, the molecular mobility is strongly affected by the penetration of small molecules which can act as plasticizers [16] and in some cases cause damage like void formation, bubble, surface blistering or dilation [17–20]. Indeed, if they are not confined, these materials absorb gas and swell until the external pressure is removed. Thus, the dissolved gas is no longer in pressure equilibrium and can generate important mechanical damages. For example, some authors have shown that elastomers with low cross linking level tend to form bubbles whereas those highly crosslinked crack [21,22]. Regarding semi-crystalline polymers, damages caused by explosive decompression were already observed [18,23–25], but it is still difficult to match degradation mechanisms to test conditions or materials characteristics as the initiation mechanism is not well understood and may not be unique for each family of materials.

These many type of stresses can cause, depending on operating conditions, the detachment and the permanent deformation of the liner like it is shown in Fig. 1. The liner collapse is a phenomenon already described in literature for oil and gas pipes and some models have been developed in order to predict its appearance in terms of pressure differential [26–29] but it remains a very schematic approach. Regarding hydrogen pressure vessel, the origin of the liner collapse has not been yet explained. This is mainly due to the difficulty to perform hydrogen pressure experiments because of the potential hydrogen explosiveness and the embrittlement mechanisms on many metals [30–32]. Collapse appears during the draining step [33] in such a way that this phenomenon can be compared to an explosive decompression or blistering, both of which have already been reported for oil pipes [24].

The understanding of the cause of the collapse will enable to optimize the design of future tanks generations and the use of current and future composite vessels. A first step to a better understanding of the origin of the liner collapse is to reproduce this phenomenon on specimens. Nevertheless, due to the important cost of type IV vessels and the difficulty to work at high hydrogen pressure, bringing about a liner collapse presents several technical locks. So, the aim of the present study is to develop a laboratory experiment for mechanical testing under pressurized hydrogen in order to reproduce, at a laboratory scale, a liner collapse on representative test samples. These latter are composed -like in hyperbaric type IV hydrogen storage vessel- of an assembly of thermoplastic polymer and composite plates bonded together by an epoxy based adhesive. Explosive decompression experiments were conducted thanks to a tensile testing machine equipped with a high pressure chamber. Once samples were fully saturated with hydrogen, they were submitted to fast decompression. Damages caused in the sample after gas decompression were assessed from computational tomography analysis.

Experimental

Materials and samples

Representative samples are composed of a 2 mm-thick composite material layer on which is fixed, on both sides, a 1 mm-thick molded sheet of polyamide 6 liner. Material layers are bonded together by an epoxy based adhesive. These flat

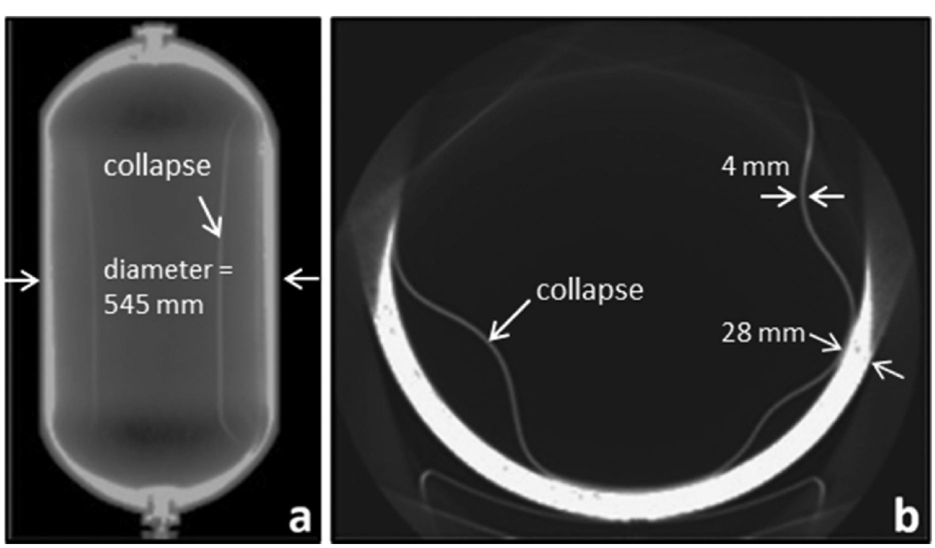

Fig. 1 – Tomographic views of a hyperbaric type IV hydrogen storage vessel with a collapsed liner: (a) parallel and (b) perpendicular to vessel axis.