Failure and damage evaluation of HDPE pipes

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Abstract

In this paper, we chose HDPE pipes as a material for our study. On the one hand, we leaded a new approach of failure analysis and prediction using new models. They are obtained through a modified version of the stress controlled unified theory that includes materials' properties in addition to what is provided by Miner linear model. On the other hand, burst pressures calculations are done according to many theories and formulas that exist in the literature such as the formula of Faupel. Moreover, we compared a theoretical model to an experimental one. The theoretical model is using the burst pressures obtained from the Faupel formula. The experimental one is using the burst pressures obtained through experimental static tests done for HDPE pipes with variable depths of groove notches.

Furthermore, we established a mathematical model capable to estimate the damage of thermoplastic HDPE pipes, using burst pressures calculated originating from the Faupel's model proposed for metals. This model is based on the modification of the Faupel formula by introducing the pressures characterizing the HDPE pipes. This model has shown good accuracy and concordance with the experimental results.

Keywords: *thermoplastic polymer; burst pressure; damage models; HDPE pipes*

1. Introduction

The over costs generated by the production losses, which are a direct result of manufacturing problems, convinced many users to be deeply concerned about the policy of quality, they have to adopt, to check the conformity of the existing products in the market. For that reason, many visits and audit missions are organized to the manufacturers' factories to check the technical conformity of the produced materials according to the international codes. That's why, this kind of users' mobilization engages the manufacturers in a dynamic of change in order to fit the technical specifications and answer the customers' requirements. This engagement is possible by making the right tests which guarantee the quality of their product in the market.

Moreover, the damage of HDPE pipes is usually due to thickness reduction by abrasion, chemical attack, weakening by sunlight UV radiation, defects in materials during the preparation or during extrusion. It degrades the reliability of the installation and cause a reduction of the piping lifetime. Failures such as leaks, ruptures or burst can lead to serious accidents in the pressure piping systems. That's why we need to determine the probable damages of a pressure HDPE pipe.

Furthermore, the codes are dealing with damage occurrence by using linear systems such as the MINER methods. But the damage occurrence seems very complex, regarding the number of parameters and the non-linearity of the systems. The unified theory is dealing with such systems and gives a simplified method to quantify the cumulative damage through static tensile tests.

In the next steps of this paper, we are proposing a simplified approach, for damage assessment, using FAUPEL burst pressure formula and experimental tests done over HDPE pipes with variable groove depths. The experimental results are compared to the calculated ones through the combination of the unified theory and FAUPEL formula.

2. Theory

2.1. Burst Pressure Formulas

Many theories have been developed to predict the fracture of pressure cylinder by determining the limit charges. These theories are dealing with the internal pressure. HILL in 1950, FAUPEL in 1953, KLEVER in 2006, ASSER in 2009 and finally DNV in 2010. In ours works, we are interested in the damage calculation based on the burst pressure variable through the simplified formula of FAUPEL.

2.2. Damage evaluation

In our paper, we adopted a modified approach based on the static damage and unified theory of Bui-Quoc [5]. It was developed by replacement of cyclic preloading by creating artificial damages (notches) and replacing stresses by pressures. For that reason, we took a life fraction defined by the ratio of thickness fluctuation over the thickness (Δe/e). Where e is the thickness of the studied pipe.

The static damage is expressed as bellow:

$$D = \frac{1-\gamma_e}{1-\gamma_{ec}} = \frac{1-\frac{P_{ur}}{P_u}}{1-\frac{P_a}{P_u}} \quad (4)$$

The final expression of the damage is given by:

$$D = \frac{\beta}{\beta + (1-\beta)\left[\dfrac{\dfrac{P_{ur}}{P_0} - \dfrac{P_{ur}}{P_u}}{\dfrac{P_{ur}}{P_0} - 1}\right]} \qquad (5)$$

However, Chaboche [6] has proposed a model based on the remaining lifetime to failure. This model shows that the level of fatigue preloading, assimilated to the notches in our case, influences the residual lifetime. The expression of the static damage based on the time to failure is given by:

$$D = 1 - \frac{t_R'}{t_R} \qquad (6)$$

Where $t_{R'}$ is the residual life, for the same loading, giving rise to life t_R for the undamaged material. The limit conditions supposed to be true are:

D = 0: if the specimen has not been subjected to any preliminary damage (when $t_{R'} = t_R$).

D = 1: if the specimen is failed (when $t_{R'}=0$).

3. Experimental methodology

3.1. Burst pressure test

We created artificial damages by creating notches of variables depths and then we evaluated the damage for each depth. For this reason, we are using an HDPE pipe of 5.8 mm of thickness, 63 mm external diameter and a length of 400 mm. The used HDPE material is a PE100 with a nominal pressure of 16 bars (PN 16).

The burst test has been done in a burst pressure tester using a feeding, flow controlled, water pump, figure 1. To conduct the test, we prepared the specimen and put it in the hydraulic end caps. Then, we link it to the high pressure hose and put it in the burst basin, using water with controlled temperature until burst, figure 2.

(a) (b)

Figure 1. The used equipments (a) Closed pipe with end caps (b) Burst pressure control panel with a pressure sensor, pressure display and the pump control.

(a) (b)

Figure 2. (a)Burst test of an undamaged HDPE pipe (b) Burst test of a notched HDPE pipe.

3.2. Tensile test

The used machine, Figure 3, works under the EN12201 code and can handle a force of 5 KN and a moving speed of 100 m / s. After we had completed all the tensile tests, we recorded the traction curves in the machine's onboard computer.

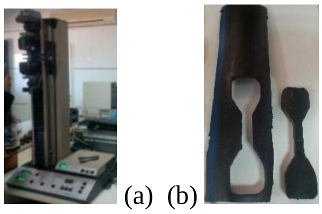

Figure 3. Hounsfield traction machine 5 KN (b) Cutting of HDPE pipe

4. Results

4.1. Experimental model

We got all the burst pressures for the undamaged and the notched pipes as shown by the figure 6. The obtained pressures have been represented in function of the life fraction as shown by the figure 4

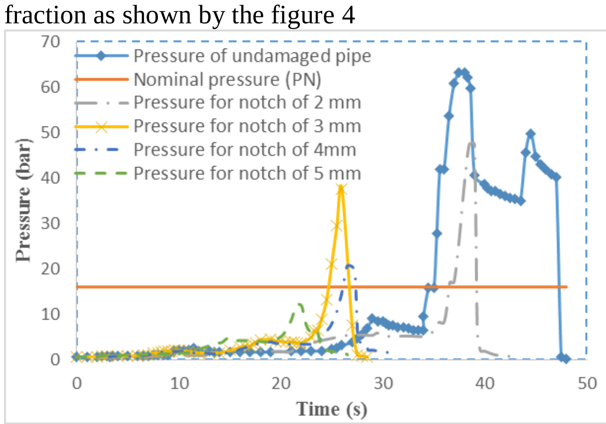

Figure 4. Example of Burst pressures evolution for the undamaged and the notched pipes

From the curves above, we notice that the behavior of the undamaged pipe is totally different from the notched pipes ones.

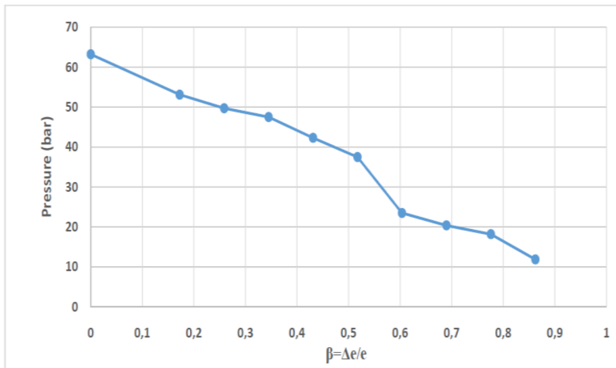

Figure 5. Burst pressures evolution in function of the life fraction.

The evolution of the pressure decreases considerably with the augmentation of the life fraction and then the notch depth, figure 5.

To assess the damage of the studied HDPE pipes, we used the three models presented in the introduction of this work. We get the curves of the damage as shown in the figure 6.

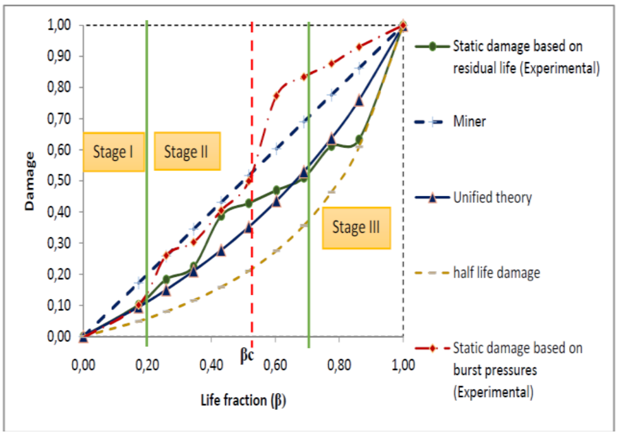

Figure 6. Evolution of the static damages in function of the life fraction [1]

From the curve above, we concluded that the three damages are acceptable to represent the damage of HDPE pipes. All of them show clearly the critical life fraction around 52% which is equivalent to a maximum of thickness loss of 3 mm for an initial thickness of 5.8 mm.

4.2. Theoretical model

The theoretical formulas of Faupel [7] can be corrected according internal pressure behavior parameters. The approximate corrected model is given by the equation (7):

$$P = \frac{2}{\sqrt{3}}\sigma_y\left(2-\frac{\sigma_y}{\sigma_{UTS}}\right)\ln\left(\frac{D_0}{D_i}\right)\bullet\alpha$$

(7)[2]

Where:

$\alpha = (P_m/P_r)$ is a parameter depending on the studied material

P_m and P_r are respectively the maximum pressure and the rupture pressure for an HDPE pipe as shown in the figure 7.

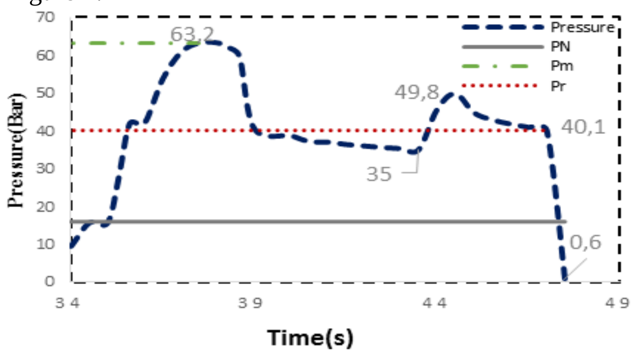

Figure 7. Pressure evolution in function of the time [2]

Figure 8.

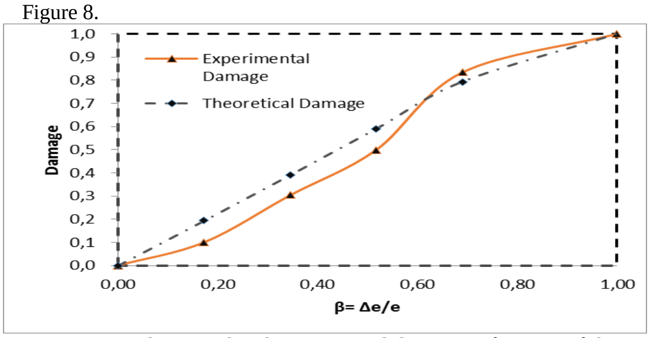

Figure 9. Theoretical and experimental damage in function of the life fraction [2].

The evaluated damage in both the cases, theoretical and experimental, shows satisfactory and reliable results. So we can check the burst pressure limits just by doing theoretical calculations and correcting the model based on the parameters obtained from the burst of an undamaged HDPE pipe[2].

4.3. Validation

To validate these models ,in another part of our work we evaluated the damage through a combined theory using the unified theory and burst pressure equation for the steel P265GH and A36 used in pressure vessel's equipment [3], [4].

5. Conclusion

By using the results of this work we can build up a solid maintenance strategy and make the work with HDPE pipes safer and easier. Besides, the proposed simplified approaches allow clients and industrials companies to assess the damage based on static tests only, without doing any dynamic tests. Moreover, they can be a tool that can help them to do quick checks or launch audit mission to the manufacturers' factories for HDPE pipes' quality control and conformity check regarding the codes.

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