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Fatigue life prediction and damage modelling of High-density polyethylene under constant and two-block loading

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Abstract

An experimental analysis for determining the fatigue strength of HDPE-100, under constant and variable amplitude loading is presented. Further, the cumulative fatigue damage behavior for HDPE-100 was experimentally investigated. First, The S–N curve was obtained to establish the fatigue life of The HDPE-100 subjected to constant stress amplitude. Secondly, the Cumulative fatigue damage was estimated by different cumulative model such as Miner rule, damage stress model and Energy model (Damage energy model). Comparison between predictions and experimental results showed different trends depending on the prediction model used.

Keywords: polyethylene; Cumulative damage; Fatigue damage; viscoelastic behavior; Two-block loading

1. Introduction

The fatigue behavior of polymers is gaining more and more importance in the study of materials, such interest dictated by the increasing use of polymers in complex applications, and this as a direct consequence of their advantages like technical performance and of course their relatively low cost [1]. High density polyethylene (HDPE) is one of the most used in industry because of the diversity of its applications and the multiple benefits it provides over conventional materials.

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This material is extensively used in water and gas distribution systems. This latter has provided cheaper solutions in the industry of pipes constituents and network, from manufacturing to exploitation, through installation and maintenance.

Nomenclature

DEM	Damage energy model
DSM	Damage stress model
Nri:	number of cycles to failure for level i under σ_i
Ui	the work transferred to the specimen for the solicitation of amplitude σ_i applied for ni cycles.
Wi:	total work transmitted to the specimen at the time of fatigue failure.
W_{edi}	energy due to damaged stress
W_i	energy due to the applied stress
W_u	energy due to the ultimate stress of the material
W	energy density
σ_{edi}	Damage stress
σ_i	Applied stress
σ_u	Ultimate stress
σ	Stress
ε	Strain

The tube system into service is subject to internal pressure or to external forces that vary in magnitude and frequency. The repetition of these fluctuating loads, generates responses that differ depending on the type of loading [2]. Such cyclic loads cause cumulative damage and cracks that can contribute to rupture of the pipe system [3]. It is important to make clear that these polymeric pipes have a problem that needs special consideration. Experience has shown that low stress may cause rupture of the pipe in relatively short service time, especially if the loading is cyclic [4]. It is probable that the problems of material fatigue under cyclic loading are associated with the presence of intrinsic defects during the manufacturing process. Such defects can lead to pipe rupture, causing economic and human losses. This will have direct consequences on the durability of the whole system [5].

Until now, Industrial laboratory carries out hydrostatic tests to pipes. Such tests provide information on material resistance to monotonic loads, but give no information on the behavior of the material under cyclic loading. Even, if stresses are lower than those considered in the design step [6, 7].

The aim of this paper is to determine the fatigue strength of HDPE-100 material, and analyze its fatigue behavior by characterizing and determining its life curve. Based on the experimental results, we propose to examine and evaluate some cumulative damage models proposed for metallic materials, such as a Miner's rule, damage stress and the energy (damage energy) model. Predictions of different models were carried out. Then, they are compared to experimental results.

2. Material and experimental procedure

2.1. Tensile tests

Specimen tests were cut directly from HDPE pipe in the longitudinal direction [8, 9]. Cylinder sections were cut axially and transversely by a guillotine cutter. A total of 60 fatigue specimens and 10 tensile specimens were machined by the CNC machine Mill 55 (EMCO- Concept Mill). The geometry and dimensions of the specimens are shown in Figure 1.