FAILURE ANALYSIS OF POLYETHYLENE GAS PIPES

KAMEL CHAOUI*1, RABIA KHELIF2, NASSEREDDINE ZEGHIB3 AND ALAA CHATEAUNEUF4

1 LR3MI, Mechanical Engineering Dept., Badji Mokhtar University, BP 12, Annaba, 23000, Algeria; 2 LaMI – IFMA, Université Blaise Pascal, Campus de Clermont-Ferrand, BP 265, 63175 Aubière Cedex, France; 3 LR3MI, Mechanical Engineering Dept., Badji Mokhtar University, BP 12, Annaba, 23000, Algeria; 4 LGC – UBP, Complexe Universitaire des Cézeaux, Université Blaise Pascal, BP 206, 63174 Aubière Cedex, France

Abstract: Natural gas transmission and distribution industry is using pipes of different origins to transport hydrocarbons under pressure. The use of polymeric material such as polyethylene (PE) made it possible to achieve significant profits in construction times and installation costs. However, some catastrophic failures took place for various reasons. The objective of this study is to highlight the various mechanisms of rupture of PE pipes in service and in laboratory conditions. It is clear that at least two mechanisms control PE pipe failures based on results cumulated in operating conditions. They are nominally ductile and brittle mechanisms respectively characterizing short and long-term failures. Several laboratory tests are used to extract design data for long-term failure-type prediction based on stress and time to failure relationship. It remains difficult to assess the relation between creep and fatigue loadings on the one side. On the other side, the manufacturing process of the test specimens (extruded pipes and compression molded sheets) influences considerably the obtained performance for viscoelastic materials subjected to working conditions. When analyzing different results, it is found that there is a certain correlation between failure times under both constant and fluctuating loading patterns and moreover, fatigue can be used as an accelerating agent of brittle fracture which normally occurs in the long-term span and under low load levels. Brittle-to-ductile transition is studied under fatigue crack propagation mode using an energy criterion. It is found that the approach leads to critical energy rates of 211 and 695 J/m² for brittle and ductile regimes respectively. The brittle fracture damage zone is characterized by a single craze made up by locally drawn fibers and dispersed

*To whom correspondence should be addressed; e-mails: chaoui@univ-annaba.org and chaoui_k@yahoo.fr

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voids whereas ductile rupture is rather dominated by highly yielded material and significantly transformed matter as observed under polarized-light microscopy. PE mechanical behavior is affected by several factors including the state of residual stresses and the morphological variances induced by the extrusion process and subsequent cooling. As a result, there is a crystallinity increase from inner to outer layers of the pipe. The assessment of PE pipe failure mechanisms is to contribute to a better understanding of effects of other external chemical agents such as solvents in degrading the pipe overall resistance.

**Keywords:** polyethylene pipe, failure, fatigue, creep, damage zone, brittle, ductile

1. **Introduction**

Polyethylene (PE) resins are processed into pipes and fittings on a large scale to construct water and natural gas transmission and distribution networks. As shown in recent statistics [1], more than 22,000 km of PE pipes constitute the Algerian medium pressure gas network and all newly installed gas distribution systems around the country are exclusively made of PE because of its relatively low cost, ease of installation and maintenance, and long-term durability against environmental degradation; these properties made it a real alternative to metallic systems. Despite the large acceptance of PE pipes as an economic alternative, safety and reliability remain basic issues, especially for long-term brittle-like failure and accelerated stress corrosion cracking in both water and gas mains. Many studies have been carried out to highlight various behavioral aspects of both medium density polyethylene pipes (MDPE) and high density polyethylene pipes (HDPE) in terms of service lifetime [2], mechanical characterization [3], structure relationship [4], failure mechanisms [5], pipe joining [6], and environmental effects [7].

To a certain extent, it is possible to control the mechanical properties of semicrystalline polymers by morphology management [8] during processing operations. Substantially improved Young’s moduli and tensile strengths have been obtained in shear-controlled orientation in injection-molded and high-pressure injection-molded HDPE because of the appearance of highly oriented structures. Quasi-static mechanical testing of HDPE processed by shear-controlled orientation in injection molding exhibited an improvement of 59% in the flexural modulus in comparison with the mechanical performance of conventional injection-molded specimens. The search for homogeneous geometrical dimensions in terms of the diameter and wall thickness, which are represented by the Standard Dimension Ratio (SDR is the ratio between the outside pipe