Fracture of Pipelines and Cylinders Containing a Circumferential Crack

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Abstract

This study is concerned with the problem of a pipe containing a part-through or a through circumferential crack. First, the stress intensity factors for an internal or an external circumferential surface crack in a pipe are obtained. The main objective here is to give the necessary theoretical information for the treatment of subcritical crack growth process. Next the problem of a through crack in the presence of large scale plastic deformations is considered. The crack opening displacement (COD) is used as the main parameter to analyze the fracture instability problem and to correlate the experimental results. In the analytical part of the study Reissner's shell theory and an elastic or elastic-plastic line spring model are used to formulate the problem. The experiments were performed on 20-inch diameter X60 line pipes. A 0.025-inch wide starter notch was introduced to the pipes which were then subjected to cyclic loading under four point bending. The limited data obtained from the fatigue tests give the expected result, namely that the crack propagation rate in pipes may be predicted from the baseline data obtained from simple specimens provided the stress intensity factors for pipes are calculated with sufficient accuracy. The ductile fracture results show that the technique based on the asymptotic behavior of COD may be quite useful in determining a conservative estimate of the fracture instability load.

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1. Introduction

This report presents the theoretical and the experimental results of a four year study on the fracture of circumferentially cracked pipelines and relatively thin-walled cylindrical containers. The research was sponsored by the U.S. Department of Transportation, Research and Special Programs Administration, Office of University Research. It was part of a coordinated DOT program in which the National Bureau of Standards and Johns Hopkins University were the other participants.

The primary objective of the research program was (*a*) to identify the possible modes of fracture failure in pipelines and in relatively thin-walled cylindrical containers containing various types of initial circumferential flaws, (*b*) to review and develop appropriate fracture criteria and to carry out the necessary analytical investigations which may be applied to various phases of fracture failure in circumferentially cracked pipes and containers, and (*c*) to design and perform an experimental research program in order to test the validity of the related analytical models.

1.1 Fracture Mechanics Approach

Depending on the thermo-mechanical behavior of the material and the nature of applied loads and environmental conditions, in the design of pipelines, tank cars, and a variety of other pressurized containers, it is often necessary to consider fatigue or corrosion crack propagation and fracture among the possible modes of failure. This requires, in addition to the application of standard failure theories specified by the existing design codes, the treatment of the problem of acceptance and safety from the viewpoint of fracture mechanics. In using this approach the flaws or certain types of imperfections which may initially exist in the material are treated as "cracks." These initial flaws which may have the potential of growing into a macroscopic fatigue or corrosion fatigue crack are generally weld defects (such as slag inclusions, excessive or inadequate weld penetration, incomplete fusion, gas pockets, arc burns, etc.), notches caused by possible initial misalignment during