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Ratcheting and wrinkling of tubes due to axial cycling under internal pressure: Part II analysis

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ABSTRACT

Part I presented a set of experiments in which pressurized tubes were cycled axially under stress control about a compressive mean stress. This loading history causes biaxial ratcheting involving compressive axial strain and expansion of the diameter of the tube. The compressive strain in turn induces the initiation and growth of axisymmetric wrinkles. Persistent cycling resulted in localization of the wrinkles and collapse. In Part II the problem is first modeled as a shell with initial axisymmetric imperfections while the biaxial ratcheting of the material is modeled using the Dafalias–Popov two-surface nonlinear kinematic hardening model. It is demonstrated that when suitably calibrated this modeling framework reproduces the prevalent ratcheting deformations and the evolution of wrinkling including the conditions at collapse accurately for all experiments. The calibrated model is then used to evaluate the ratcheting behavior of pipes under thermal-pressure cyclic loading histories experienced by axially restrained pipelines.

1. Introduction

In Part I we reported results from a series of experiments involving axial cycling of tubes under internal pressure. The SAF2507 tubes tested had D/ts of about 28.5, the pressure levels ranged from 0 to 0.6 P_o and the axial stress cycle parameters were varied. In most cases the tubes were pressurized to the chosen level and then compressed into the plastic range inducing small amplitude wrinkles to the test section. The specimens were subsequently cycled axially by prescribing stress cycles with a compressive mean stress. The cycling results in a gradual shortening of the test section (axial strain ratcheting) while the internal pressure induces ratcheting of the hoop strain. As was the case for the corresponding un-pressurized problem studied in J&K [09,10],[I] the axial ratcheting causes a gradual growth of the wrinkles which eventually leads to the collapse of the tube.

In Part II we extend the axisymmetric shell formulation developed in J&K [09,10][I] to the pressurized case. The elastoplastic behavior of the material under cyclic loadings is again modeled using the two-surface nonlinear kinematic hardening model of Dafalias and Popov (1975, 1976) with the modifications put forward in Hassan et al. (1992) and Hassan and Kyriakides (1994a,b). The biaxial ratcheting places new challenges on the model, which must be addressed. The formulation is first evaluated by simulating the experiments. Once its veracity is proven it is used to study the effects of cyclic loading histories representative of the buried pipeline problems outlined in the Introduction of Part I.

2. Analysis

2.1. Formulation

Plastic buckling of long circular cylinders under combined axial compression and internal pressure was addressed in Paquette and Kyriakides (2006)[I] (see also Bardi et al., 2006[I]). J&K [09,10][I] adopted an axisymmetric version of this formulation, coupled it to a cyclic plasticity constitutive model and used them to simulate the initiation and evolution of wrinkling in tubes cycled axially under stress-control. The present formulation follows along the lines of those in J&K [09,10][I] but is extended to include the internal pressure. Axial cycling under internal pressure results in simultaneous ratcheting in the axial and circumferential directions. This places additional demands on the two-surface kinematic hardening model used in J&K [09,10][I] requiring the conduct of additional material tests, which are described in Appendix A.

The problem is idealized as a thin-walled circular cylindrical shell with mid-surface radius R, wall thickness t and length $2L$, which is pressurized, compressed and cycled in the same manner as in the experiments. The aim here is not to reproduce the experimental set up exactly but rather to develop a model that will allow us to study the behavior of a long pipeline. In Part I it was

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[I] Refers to references figures and tables that appear in Part I.

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