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Ratcheting and wrinkling of tubes due to axial cycling under internal pressure: Part I experiments

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ABSTRACT

Under compression, pressurized tubes thick enough to deform plastically buckle into an axisymmetric wrinkling mode. The wrinkle amplitude is initially small but with persistent compression grows inducing a gradual reduction in axial rigidity and eventually causing a limit load instability, which is followed by collapse. The onset of buckling and collapse can be separated by a strain level of a few percent. This work investigates whether a tube that develops small-amplitude wrinkles can be subsequently collapsed by persistent axial cycling. Part I presents the results from a set of experiments on super-duplex tubes with D/t of 28.5 loaded as follows. A tube is pressurized and then compressed into the plastic range to a level that initiates wrinkling. It is then cycled under stress control about a compressive mean stress while the pressure is kept constant. The combined loads cause simultaneous ratcheting in the hoop and axial directions as well as a gradual growth of the wrinkles. At some stage the amplitude of the wrinkles starts to grow exponentially with the number of cycles N leading to localization and collapse. The rate of ratcheting and the number of cycles to collapse depend on the initial compressive pre-strain, the internal pressure, and the stress cycle parameters all of which were varied sufficiently to generate an adequate data base. Interestingly, in all cases collapse was found to occur when the accumulated average strain reached the value at which the tube localizes under monotonic compression. A shell model coupled to a specially calibrated plasticity model that can reproduce the biaxial ratcheting exhibited in the problem are presented in Part II. The model is first evaluated by comparison to the experiments and then used to study parametrically cyclic loading histories seen in buried pipelines.

1. Introduction

Offshore pipelines often carry hot hydrocarbons at a certain internal pressure. If such a line is trenched, buried or anchored it can simultaneously develop axial compression due to the axial constrain. The operating pressures and temperatures are often high enough to plastically deform the line (Klever et al., 1994; Di Vito et al., 2010) and potentially exceed the critical buckling stress causing the line to wrinkle (see Paquette and Kyriakides, 2006; Kyriakides and Corona, 2007). Mild wrinkling is benign, but at higher strain levels the amplitude grows leading eventually to collapse by localization of the wrinkles. Imperfections due to small misalignments at girth welds, heat-affected regions around the welds, hard spots at connections with other equipment, etc., can all enhance the onset of wrinkling. During a lifetime of 20 to 30 years, pipelines experience several startup and shutdown cycles (~hundreds). A question arises as to whether wrinkles formed as a result of such stress risers can grow (ratchet) due to this cycling and if so what are the consequences. In preceding publications we showed that stress controlled cycling that leads to compressive material ratcheting interacts with wrinkles causing them to grow. Experiments performed showed that persistent cycling does indeed eventually lead to collapse of the tube (Jiao and Kyriakides, 2009a,b, 2010 hither to referred to as J&K [09,10]). In the present work we consider similar cyclic histories but in the presence of a constant internal pressure that leads to simultaneous axial and hoop strain ratcheting.

In the way of setting the problem up let us first review plastic buckling under compression and internal pressure. Paquette and Kyriakides (2006) revisited the problem by conducting compression experiments on pressurized super-duplex 2507 tubes with D/t values of 39.8 and 28.3. They showed that the general features of plastic buckling under axial compression and internal pressure are similar to those of pure axial loading reported in Bardi and Kyriakides (2006) and Bardi et al. (2006). Fig. 1 shows a comparison of two monotonic compressive responses recorded using tubes with $D/t = 28.5$ and the same material as that used in the present study. The first was compressed in the absence of pressure while the second at an internal pressure of $P = 0.49P_o$ ($P_o = \sigma_o t/R$ – yield pressure). Starting with the zero pressure case, compression yields

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