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A procedure to determine the tangential true stress-strain behavior of pipes

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ABSTRACT

Determining the tangential mechanical properties of a tube is essential for simulation of various manufacturing processes that involve the use of a tubular geometry. The aim of this study is to develop a procedure to determine the tangential true stress-strain behavior of pipes. For this purpose a modified ring test setup is proposed consisting of a ring specimen loaded with two separate D-blocks. Using a finite element model, an optimized ring specimen geometry is obtained. The optimized ring specimen exhibits uniform tangential distribution in the gauge region of the specimen and necking occurs consistently at the center of the gauge length. It is found that friction has a substantial effect on the mechanical response of the ring test for which two different setups to reduce friction are proposed. One using lubricated D-blocks (DB) and one using lubricated D-blocks with needle roller bearing (RB). Assisted by the FE model, the friction during the experiment is account for and a data analysis procedure to determine the tangential stress-strain curve of the pipe is proposed. It is found that the results using this procedure show very good agreement with previously published results.

1. Introduction

Various manufacturing processes require detailed knowledge of the tangential mechanical behavior of pipes to obtain proper designs and evaluations of the final product. One such process commonly employed in the petroleum industry is the Solid Expandable Tubular Technology (SETT) [1–3]. It is a cold working process in which a tubular casing is expanded radially by pushing a conical mandrel axially into the tube to obtain a desired radial permanent expansion. The technology enables mono-diameter casing, which is being used to replace the conventional multi-diameter telescopic casing configuration used in oil wells. This is achieved by expanding multiple tubes of a certain diameter in the well resulting in a rather uniform diameter throughout the well hole providing a larger downhole diameter than the conventional telescopic configuration, hence resulting in an increased rate of oil production. However, to assess the mechanical integrity of the tube being expanded such that to select an appropriate tubular steel grade, it is of paramount importance to know the tangential stress-strain behavior of the tube.

According to ASTM A370 [4], the tensile properties of pipes is to be determined from a specimen cut in the axial direction. Alternatively, ASTM A370 specifies a method to determine the transverse properties of pipes by cutting a circumferential strip from the pipe, flatten it and tensile test it. The work hardening from the flattening steps alters the transverse behavior considerably and the result will not represent the tangential true stress-strain curve of the pipe. Crone et al. [5] conducted a study to determine the effect of flattening the specimen on the tested mechanical properties of the pipe and concluded that flattening has a large effect on the experimental results.

The material testing standard ASTM D2290 [6] specifies the split-disc test method to determine the tangential yield and tensile strength of thermoplastic pipes. The specimen is a ring cut from the pipe and is loaded with two half discs, which are inserted internally in the ring specimen and are pulled apart with a tensile testing machine. Kaynak et al. [7] used this method to study the effect of the filament winding process parameters on the tangential tensile strength of continuous fiber reinforced epoxy composite tubes, in Ref. [8] the influence of defects on the tensile strength of glass fiber reinforced composite pipes was studied with this testing method

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and in Ref. [9] the effect of aging of HDPE plastic pipes on the failure strain was investigated. Though the method is found efficient in determining the tangential strength and failure strain of the pipes, it does not provide a way to determine the full tangential stress-strain curve nor does it quantify the effect of friction between the disks and the ring specimen.

Few researchers [10–12] have addressed this issue in the past and made attempts to experimentally measure the tensile transverse properties of pipes. Arsene et al. [11] addressed the importance of the ring specimen geometry in view of the effect of bending on the test results. They performed finite element analysis and used a notched ring specimen with three die inserts to load the ring specimen to overcome the issue with bending involved in the classical ring test, as recommended in the international standard ISO 8495-8496 [13]. Wang et al. [10] conducted a study to determine the transverse properties of tubular products and proposed a modified split-disc experimental setup, which uses D-blocks. The contact between the D-blocks and the internal surface of the ring specimen will mimic the internal pressure experienced in a pipe. However, the reason to why the selected ring specimen geometry is used is not given. Friction between the D-blocks and the specimen is considered negligible, which is justified by the use of lubricated thin Teflon sheets in-between the D-blocks and the specimen. However, this assumption was not confirmed and no attempts were undertaken to quantify its effect on the mechanical response of the ring test. Most recently Dick and Korkolis [14] conducted a thorough investigation on the mechanics of the ring hoop tension test (RHTT) and found that the friction can have a large effect on the uniaxial stress state in the specimen.

This study addresses some of the aforementioned shortcomings of previous ring test setups and presents a novel testing and evaluation method for determining the tangential stress-strain behavior of pipes. The first part of the work presents an optimization study to find an optimum ring specimen geometry aided by the use of the finite element method (FEM). The second part presents the experimental setup and the means used to minimize the friction effects involved in the experimental setup and the third part provides a data analysis procedure and the determination of the tangential true stress-strain curve of a pipe.

2. Optimization of the ring specimen

Most of the attempts [6,10,11,15,16] to determine the tangential stress-strain behavior of pipes have used a similar specimen configuration consisting of a ring cut from the pipe with a gauge section manufactured to localize the necking location. Preliminary experiments were conducted following the experimental setup, specimen geometry and testing method in Ref. [10]. The difference was in the choice of material. In Ref. [10] a low-carbon hot-rolled steel tube with outer diameter 95.25 mm and thickness 2.2 mm was used whereas in this study an aluminum alloy Al 6063-T5 tube was used. The Al 6063-T5 material was delivered in 200 mm long seamless tubes with outer diameter of 60 mm and wall thickness of 3 mm. For all tests necking occurred in the transition between the large radius and the gauge length, as shown in Fig. 1, rather than at center of the gauge length. This indicates that the specimen could be subjected to non-uniform tangential stresses, bending and frictional forces between the D-block and the ring specimen. In order to develop a validated method to determine the tangential stress-strain behavior of pipes, an optimum ring specimen configuration need to be chosen. As there are no standards outlining the specimen dimensions for such tests a study to optimize the ring specimen configuration is motivated.

The specimen selected for the optimization is a ring specimen, as shown in Fig. 2, for which the application of a tensile load

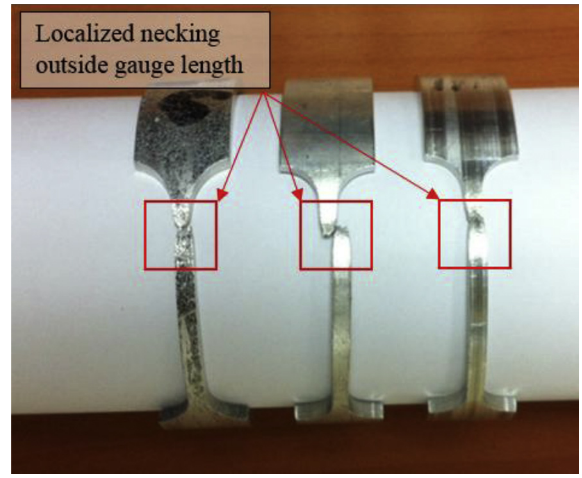

Fig. 1. Failed ring specimens using RHTT (Ring Hoop Tension Test) test method outlined in Ref. [10].

through the D-blocks mimics the internal pressure experienced in pipes. The objective of the optimization study is to obtain a specimen configuration for which necking appears within the gauge length of the specimen and for which a uniform tangential stress state is achieved within the gauge length while accounting for the effect of friction between the D-blocks and specimen. In Fig. 2 the geometry of the specimen is shown, which has an initial specimen thickness $t_0 = 3$ mm, specimen outer diameter $D = 60$ mm, initial width of reduced gauge section $w_0 = 3$ mm, fillet radius $\rho = 6$ mm and a specimen width of 15 mm. The three optimization parameters to be addressed are the gauge length as given by angle α,

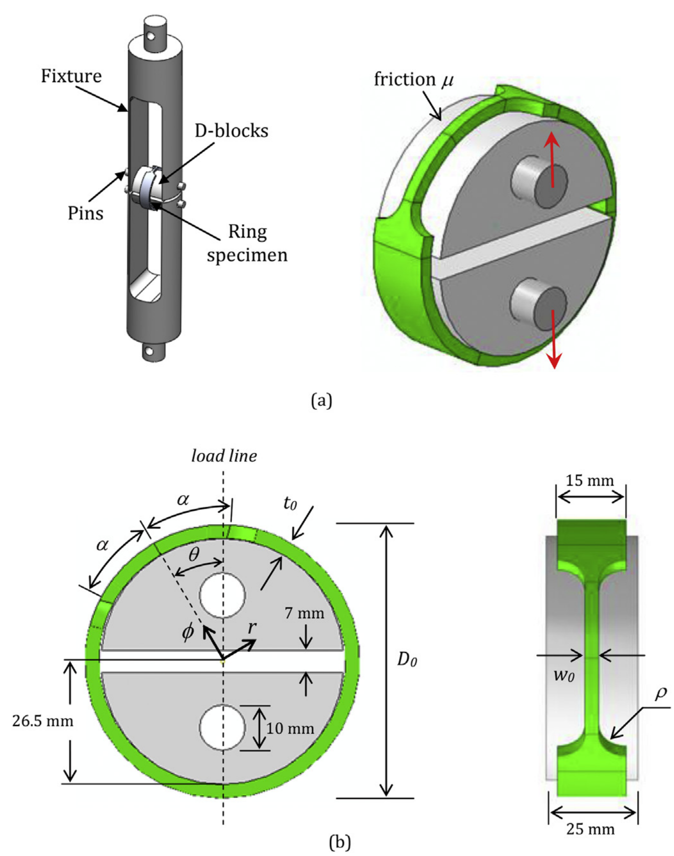

Fig. 2. (a) Test setup and (b) configuration of the ring specimen.