MODELING OF THE ELASTO-PLASTIC BEHAVIOR OF HSLA X140 STEEL: EFFECT OF PRE-STRAIN AND TRIAXIALITY

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Abstract

In this work, a comprehensive experimental campaign is conducted to investigate the effect of pre-strain on the mechanical properties of X140 steel used in high performance threaded connections. Mechanical tests are used to characterize the plastic and fracture behavior of the material. Smooth tensile (ST), notched tensile (NT), plane strain (PE) and shear tests (STC) were performed. Cyclic tension-compression tests are used to characterize kinematic hardening. Initially qualified as isotropic, this material showed an anisotropic behavior after undergoing a pre-strain expansion as its plastic flow becomes loading direction dependent. This pre-strain effect is well reproduced using a phenomenological modeling combining isotropic and kinematic hardening contributions with a Hosford's criterion.

Introduction

Threaded high grade steel connections with a metal-to-metal seal known as premium connections, used in many industrial applications related to the exploitation of energy, are reliable solutions for maintaining the tightness and structural strength under extreme conditions. The two parts of these seamless connections are pre-deformed, one in expansion (Box part) and the other in contraction (Pin part). This work addresses the development of a predictive elastoplastic behavior model for the high-grade steel (X140) threaded connections, considering the effect of pre-strain and triaxiality.

Material

The as-received material studied is a high strength steel with X140 grade. The chemical composition is reported in Table 1. The material has a martensitic microstructure.

Table 1 : Chemical composition of X140 (wt%).

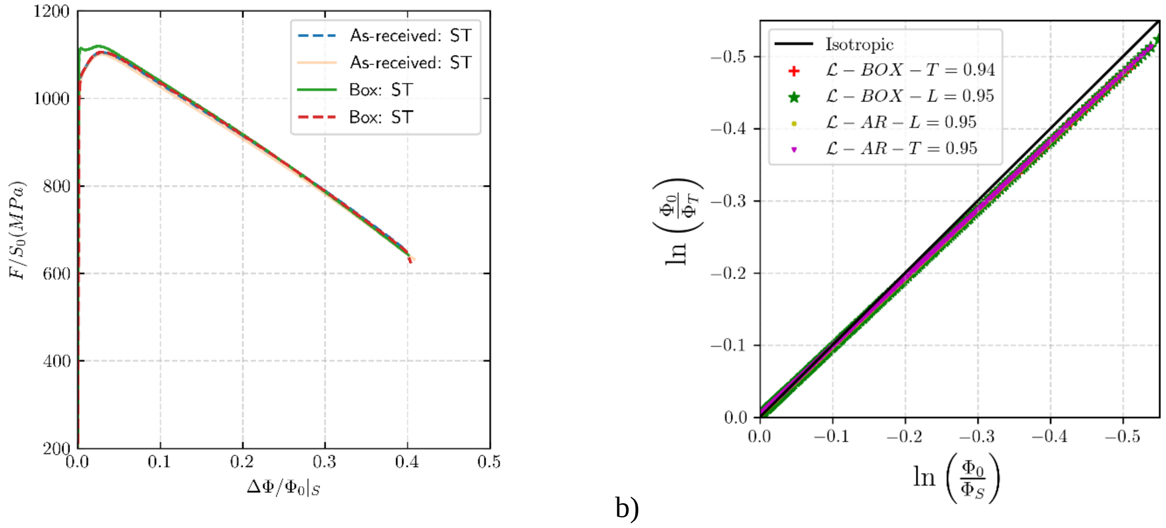
C	Cr	Mn	Mo	Other
0.26	1	0.5	0.5	V,Nb,B,Al,Ti,S

Testing procedure

The experimental work was conducted on a material extracted from the tube in the non-threaded zone the connection (as-received material), and from the Box part in the connection (pre-strained material). Tensile tests were performed on smooth bars (ST), notched specimens (NT) and plane strain (PE) specimens. These specimens were taken in both longitudinal (L) and transversal (T) directions of the connection. The tests were conducted at room temperature on an MTS servohydraulic machine with an axial strain rate of $10^{-4}s^{-1}$, the tests were controlled with a mechanical extensometer. Tension-compression shear tests (STC) were performed on a dedicated loading device, (Bouvier et al., 2006). A precise metrology was performed for each specimen using an optical profilometer. This metrology is particularly important as it allows to consider the post-machining tolerances and to determine the value and the position of the minimum diameter on the specimen. Plastic anisotropy is characterized on smooth and notched specimens using a setup with two cameras to measure radial contractions along the thickness S-direction of the tube and the direction perpendicular to S. This non-contact measurement technique allows the local tracking of post-striction mechanical behavior, (Shokeir et al., 2022). It is based on a continuous acquisition to synchronously record the force, the machine displacement, the axial extensometer, and the images of the working area of the specimen.

Results

Figure 1-a) shows the nominal stress as a function of radial contraction curves for tensile tests performed along L and T directions. High strength and ductility are observed in both directions: Ultimate Tensile Strength UTS ≅ 1200 MPa and a necking coefficient Z ≅ 66% are recorded for the as-received material. Despite low Uniform Elongation (UE=6%), the material has a high reserve of ductility after necking which is well tracked using ET technique. Measurements along the two directions (L and T) are remarkably close. In addition, the measured Lankford coefficients are close to 1 as shown in *Figure 1*-b). The pre-strained material flow stresses depend on the loading direction. In fact, the flow stress in the T loading direction, which corresponds to the pre-straining direction, is the highest. It is also observed in *Figure 1*-a) a reduction of the uniform elongation. This behavior is characteristic of a mixed isotropic/kinematic hardening effect evidenced by performing strain (loading)-path changes. Moreover, no effect of the pre-strain is observed on the ductility of the material. The effect of triaxiality is also studied using axisymmetric notched specimens and shear samples. The experimental database covers a stress triaxiality range from 0 to 1.4. It has been recorded a reduction in the material ductility as the triaxiality increased.



a) b)

Figure 1 : (a): Comparison between the nominal stress versus radial contraction stress curves for ST specimens from as-received material and pre-deformed material (Box). (b) Lankford coefficients for ST specimens from as-received material and pre-deformed material (Box)

A Hosford's yield criterion with a combined isotropic/kinematic hardening is employed to describe plastic behavior. Tension-compression shear tests and cyclic tension-compression tests are used to characterize kinematic hardening. Plane strain tests are used to characterize the shape parameter of the Hosford's yield surface. An inverse analysis is used to adjust all material parameters. The identification strategy deployed shows a good agreement between experimental and simulated macroscopic and local responses (post-necking strain).

References

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