

Advanced Modeling of Plasticity of Linepipe Steels with Anisotropic Texture and Complex Loading History

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ABSTRACT

Modern linepipes can have highly anisotropic properties from manufacturing processes aimed at improving strength, toughness, and weldability. The anisotropy may have a significant effect on pipe integrity, including buckling and collapse resistance. Accurate material models are required to understand this effect. In this paper, Taylor's polycrystal plasticity model is introduced to study the anisotropy evolution during pipe forming and construction. The crystal plasticity model is physically realistic and the measured texture is used to model the anisotropy. The capability of the model in simulating material anisotropy and plasticity evolution under cyclic strains is demonstrated using an X100 material as an example.

KEY WORDS:

Linepipe integrity; anisotropy; Taylor's crystal plasticity; reel-lay.

INTRODUCTION

Modern linepipe steels made by thermo-mechanically controlled rolling (TMCP) can have significant anisotropic plastic properties due to the textures created in the rolling process. The transverse strains induced by pipe manufacturing, such as UOE, can further modify the material properties through the Bauschinger effect. In addition, the construction and service conditions, such as offshore pipe-laying by reeling and service strains from frost heave and thaw settlement, can impose cyclic plastic strains. The strain history affects mechanical properties in both longitudinal and transverse directions.

The evolution of the anisotropic plastic properties is important to many aspects of pipeline integrity. For example, the collapse resistance to external pressure and buckling resistance to bending are sensitive to the cross-section ovality and stress-strain properties of the pipes. The changing of the ovality during cyclic loading, on the other hand, is also affected by the evolution of the plastic properties. The accurate prediction of the material property evolution in all directions is beneficial and critical to the precise estimation of the load carrying capacity of the linepipes with complex loading histories, especially under biaxial loadings. For this purpose, more representative material models rather than the isotropic model are required to simulate pipe

behavior.

The conventional anisotropic hardening and kinematic hardening based phenomenological plasticity models, although are simple to use, have certain limitations. There exist many anisotropic models among which the simplest and the most widely used is the Hill's (1948) quadratic anisotropic model. There are also many non-quadratic anisotropic models such as, Barlat and Lian (1989) and Hill (1990, 1993). The non-quadratic models gave a better representation of the shape of yield surface, but require more effort in tuning the model parameters. On the other hand, the anisotropic models can be used only for monotonic loadings. To simulate material behaviors under cyclic loading and loading-path change, kinematic hardening model is often used. One of the most well-established kinematic models is the nonlinear isotropic/kinematic hardening model (Armstrong and Frederick, 1966; Mahbadi and Eslami, 2006) in which the yield surface translates in the stress space (kinematic component) and changes size (isotropic component) in terms of some internal variables (such as backstress and equivalent plastic strain) that characterize the stress/strain history. The pipe forming procedures therefore are needed to accurately determine the internal variables of the materials in the post-manufacturing state.

Liu and Wang (2006) applied nonlinear isotropic/kinematic hardening model to represent the anisotropy of linepipe steels and to study the effect of material's anisotropy on pipe buckling resistance. Although the analyses showed the model works reasonably well for some linepipe steels, a better model which accounts for both material anisotropy and kinematics is highly needed. In recent years, some new models combining the Hill's quadratic anisotropic hardening model with the kinematic hardening model have been developed (Wu 2002 and Martinez and Brown 2005). However, due to the phenomenological nature, tedious experiments must be conducted in order to collect all the information required to tune the model parameters.

The anisotropy of linepipe steels resulting from rolling is mainly caused by the so-called texture, i.e., the preferred orientations of grains. During cold working, the large plastic deformation can also change grain orientations and therefore modify material anisotropy. Numerous research work has been done to model the behavior of the individual grains and their interactions based on theories of dislocations in crystals. Among them, the rate-dependent Taylor-type polycrystal plasticity model (Taylor and Elam, 1925; Taylor, 1938) is