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Investigation of subsequent viscoplastic deformation of austenitic stainless steel subjected to cyclic preloading

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Abstract

This paper investigates the effects of cyclic preloading on the subsequent viscoplastic deformation. A series of experiments such as the subsequent creep, subsequent stress relaxation, and cyclic loading with strain rate changes after cyclic preloading were conducted with Type 304 stainless steel at room temperature. The cyclic proportional and non-proportional loadings were conducted as cyclic preloadings. Tension-compression loading was chosen as the cyclic proportional loading, and circular and cruciform loading as the cyclic non-proportional loading. The experimental results showed that the subsequent deformation changes with the number of cycles of cyclic preloading. The differences in the subsequent deformation were examined by transmission electron microscopy (TEM). The observations suggest that changes in the dislocation structure depending on the number of cycles of cyclic preloading affect the subsequent viscoplastic deformation.

Keywords: Creep; Dislocations; Stress relaxation; Cyclic loading; Viscoplastic material; Electron microscopy; Mechanical testing

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1. Introduction

Recently, extensive research on the subsequent deformations of materials subjected to preloading has been carried out. The stress reversal Bauschinger effect, i.e., the difference in yield stress in tension and compression, is a well known subsequent deformation. This phenomenon must be considered for a precise modeling when forming sheet metals and considering subsequent springback predictions (Chun et al., 2002a,b; Yoshida et al., 2002; Yoshida and Uemori, 2002; Chung et al., 2005; Lee et al., 2005a,b). Mollica et al. (2001) developed a general three dimensional model, which can reproduce the stress–strain response at loading reversals and can be applied to more general changes in loading direction. Deformation induced anisotropy, which leads to different subsequent deformations depending on the loading direction has also been investigated (Ishikawa, 1997; Ishikawa and Sasaki, 1998; Kalidindi, 2001; Yao and Cao, 2002; Tuğcu et al., 2002; Garmestani et al., 2002; Wu, 2002; Chiang et al., 2002; Geng et al., 2002; Wu et al., 2003; Kowalczyk and Gambin, 2004; Tsakmakis, 2004; Häusler et al., 2004; Bron and Besson, 2004; Vincent et al., 2004; Cazacu and Barlet, 2004; Kuwabara et al., 2005; Wu et al., 2005; Barlet et al., 2005). Kalidindi (2001) reviewed and summarized models of anisotropic strain hardening and deformation textures in low stacking fault energy fcc metals and reported a new approach in modeling the deformation behavior of the materials. Garmestani et al. (2002) presented a crystal plasticity based modeling framework for the evolution of anisotropy in Al–Li alloys. Loadings with stain path changes are also an important issue in subsequent deformation (Hiwatashi et al., 1997, 1998; Kuwabara et al., 2000; Hoc and Forest, 2001; El-Danaf et al., 2001). Hiwatashi et al. (1997) developed a model based on the microstructure and simulated deformation due to the loading with a strain-path change. Hoc and Forest (2001) conducted plane strain tests followed by uniaxial tensile tests on IF-Ti steel to determine the hardening law.

To explain the macroscopic deformation mechanisms from a microscopic point of view micro/meso scopic observations have been conducted in recent decades (Doong et al., 1990; Jiao et al., 1995; Christ et al., 1995; Feaugas, 1999; Bocher et al., 2001; Gan et al., 2002; Zisman et al., 2002; El-Madhoun et al., 2003; Jia and Fernandes, 2003; Lopes et al., 2003; Haddou et al., 2004; Trivedi et al., 2004; Zuev et al., 2004). Christ et al. (1995) showed the effect of dislocation arrangements on subsequent fatigue tests. Bocher et al. (2001) showed that the overstrengthening due to non-proportional loadings is related to the development of heterogeneous substructures. Zisman et al. (2002) examined a shear microband formed in mild steel after an orthogonal strain-path change. El-Madhoun et al. (2003) concluded that the cellular dislocation structures are low energy structures and that they govern the plastic hardening behavior of commercial purity polycrystalline aluminum.

Extensive researches on the viscoplastic deformations of austenitic stainless steel have been presented (Krempl, 1979; Kujawski et al., 1980; Yoshida et al., 1989). However, there are few studies on the subsequent deformations after preloading and the microscopic observations.