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Description of yield surface evolution using a convected plasticity model

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ABSTRACT

The convected plasticity model proposed by Wu (2003a,b, 2005, 2007), making use of convected coordinate system, is applied to discuss the evolution of yield surface. It is shown that this constitutive model is capable of describing all experimentally observed features of subsequent yield surface: isotropic hardening, kinematic hardening, distortion, and rotation of yield surface. The rotation of yield surface in 3D stress space has not been much discussed in the literature, but recent experiments at National Taiwan University (Sung et al., 2011) have shown that it is an important property of subsequent yield surface. In particular, the rotation of subsequent yield surface is pre-strain path dependent. It does not rotate, when the pre-strain is tensile; but the yield surface rotates about the axial stress axis when the pre-strain is torsional.

1. Introduction

It is well-known that the evolution of yield surface includes isotropic expansion or contraction, translation, and distortion of the yield surface. However, in a recent experimental study of our laboratory at National Taiwan University, we found that the rotation of subsequent yield surface was also an important feature of yield surface evolution (Sung et al., 2011). Rotation of yield surface had been previously observed and reported in the literature. But, they were all related to non-proportional paths, including segments of straight lines, in the two-dimensional stress space. In our experiments, we observed yield surface rotations in the three-dimensional stress space even in the cases of proportional loading paths. This effect has never been reported in the literature.

We conducted experiments in the three-dimensional stress space by applying combined axial force, torque, and internal pressure to thin-walled tubular specimens. Denoting the axial direction by z and the circumferential direction by θ, the axial normal stress is denoted by σ_{zz}, the hoop stress by $\sigma_{\theta\theta}$, and the shear stress by $\sigma_{\theta z}$. In the experiments, the yield surfaces were determined based on an equivalent offset strain of 17.68μ. We found that with torsional pre-strains the yield ellipsoid rotated clockwise about the σ_{zz} axis, but, with reversed torsional pre-strains, the yield ellipsoid rotated in a reversed direction about the σ_{zz} axis. On the other hand, when the specimens were subjected to axial pre-strains, yield ellipsoids did not rotate. Therefore, the rotational behavior of yield surface is pre-strain path dependent and a constitutive model of plasticity should include a way to account for rotation of the yield surface.

Most researchers use models of plasticity referred to space-fixed Cartesian coordinate system (The Eulerian formulation). In this formulation, the infinitesimal element under consideration is space-fixed, and materials flow in and out of the element. The constitutive equations of this case include yield function, flow rule, hardening rules, and loading/unloading condition. The hardening rules can include rules for isotropic hardening, kinematic hardening, and/or distortion. A way of accounting for the rotation of yield surface was proposed by Kurtyka and Zyczkowski (1985, 1988, 1996). Considering Ilyshin's five dimensional space, these authors used a moving system of coordinates translated and rotated with respect to the original system. There were 25 quantities in the rotation tensor with only ten of them being independent. This rotation tensor could be applied to any non-proportional loading, but, only two-dimensional cases were considered in the examples. This approach was subsequently applied by Vincent et al. (2004). Using a different approach, Dafalias (2000) proposed the notion of plastic spin as a constitutive ingredient necessary to address the question of the rotation of anisotropic axes. Following this approach, anisotropy axes were related by Choi et al. (2006) to the constitutive spin by a co-rotational rate. In this way, the rotational hardening could change the anisotropy axes of the yield function. The theory was applied to the two-dimensional stress space. Other studies of non-proportional loading in the two-dimensional stress space were carried out by Yoon et al. (1995), Losilla and Tourabi (2004) and Rousselier et al. (2009, 2010). No examples using the aforementioned two approaches have been found in the literature that

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