International Journal of Plasticity 27 (2011) 328–351

Contents lists available at ScienceDirect

International Journal of Plasticity

journal homepage: www.elsevier.com/locate/ijplas

Non-quadratic Kelvin modes based plasticity criteria for anisotropic materials

Rodrigue Desmorat [a,*], Roxane Marull [a,b]

[a] LMT-Cachan, ENS Cachan/UPMC/CNRS/PRES UniverSud Paris, 61 avenue du président Wilson, 94235 Cachan Cedex, France
[b] Snecma Villaroche, Rond-point René Ravaud - Réau, 77550 Moissy-Cramayel, France

A R T I C L E I N F O

Article history:
Received 16 October 2009
Received in final revised form 20 May 2010
Available online 10 June 2010

Keywords:
Kelvin modes
Yield criterion
Anisotropic materials
Cubic symmetry
CMSX2 superalloy

A B S T R A C T

Novel (non-quadratic) plasticity criteria based on Kelvin modes are formulated here for anisotropic materials. As an example, such a macroscopic criterion is applied with success to the case of FCC nickel-base single crystals. Indeed, relying on the cubic symmetry of the material, the Kelvin decomposition of elasticity tensor easily allows for the definition of an objective and loading independent criterion. The criterion identification is performed from different loading cases for CMSX2 single crystal superalloy. Tension–torsion yield surfaces at room temperature and yield stress dependence on crystal orientation are modeled. The Kelvin modes based criterion is compared to experimental data, to Hill and Barlat and coworkers macroscopic criteria and to Schmid law predictions. The results show that a simple three-parameter yield function built thanks to von Mises equivalent Kelvin stresses accounts for a satisfying plasticity criterion for such alloys.

Non-quadratic norm $\|\cdot\|_a$ plasticity framework is addressed. Intrinsic generalizations of Hershey–Hosford criterion are proposed for cubic material symmetry.

© 2010 Elsevier Ltd. All rights reserved.

1. Introduction

Plasticity of anisotropic materials is often difficult to model. It has nevertheless an important role in forming processes (Hill, 1950; Barlat et al., 1991, 1997; Karafillis and Boyce, 1993; Lademo et al., 1999; Yoon et al., 2000; Bron and Besson, 2004), when dealing with failure modes (Wu et al., 2003; Boumaiza et al., 2006) or for specific materials such as aeronautics single crystal superalloys (Nouailhas and Culie, 1991; Zamiri et al., 2007; Zamiri and Pourboghrat, 2010).

In macroscopic models, the plastic behavior is described by means of a convex yield surface that evolves during plastic deformation. The first anisotropic yield function was proposed by Hill (1948) for orthotropic materials. From the beginning, Hill has pointed out the limitations of his famous criterion and has extended it into a more general power function of degree n in plane stress conditions (Hill, 1950),

$$f = \sum_{p+q+r\leqslant n} A_{pqr}\sigma_{11}^{p}\sigma_{22}^{q}\sigma_{12}^{r} - 1 < 0 \rightarrow \text{elasticity} \tag{1}$$

where the powers p, q, r are positive or zero integers, with $p + q + r \leqslant n$ and with the necessary existence of r even when 1 and 2 are the principal axes of orthotropy. Non-quadratic yield functions have recently regained interest (Aretz et al., 2007; Banabic et al., 2003; Soare et al., 2008), for instance when tension–compression asymmetry has to be taken into account (Cazacu and Barlat, 2004; Hu, 2005).

* Corresponding author.
E-mail address: desmorat@lmt.ens-cachan.fr (R. Desmorat).

0749-6419/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijplas.2010.06.003