International Journal of Plasticity 54 (2014) 113–131

Contents lists available at ScienceDirect

International Journal of Plasticity

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

An experimental analysis and modeling of the work-softening transient due to dynamic recrystallization

E.S. Puchi-Cabrera [a,b,c,*], M.H. Staia [a], J.D. Guérin [d], J. Lesage [c], M. Dubar [d], D. Chicot [c]

[a] School of Metallurgical Engineering and Materials Science, Faculty of Engineering, Universidad Central de Venezuela, Postal Address 47885, Los Chaguaramos, Caracas 1041, Venezuela
[b] Venezuelan National Academy for Engineering and Habitat, Palacio de las Academias, Postal Address 1723, Caracas 1010, Venezuela
[c] Université Lille Nord de France, USTL, LML, CNRS, UMR 8107, F-59650 Villeneuve d'Ascq, France
[d] UVHC, TEMPO EA 4542, F-59313 Valenciennes, France

ARTICLE INFO

Article history:
Received 5 August 2013
Available online 29 August 2013

Keywords:
Work-hardening rate
Work-softening rate
Flow stress
C–Mn steels
Dynamic recrystallization kinetics

ABSTRACT

The flow softening brought about by dynamic recrystallization (DRX) during the plastic deformation of metals and alloys under hot-working conditions is of a great practical significance for the computation of the loads, torques and power consumption required in industrial hot forming operations. The present communication reports the main results of an investigation that was carried out in order to analyze in detail the work-softening transient present on the flow curves of a C–Mn steel deformed in a wide range of temperatures and strain rates. The analysis of the experimental stress–strain curves allowed the description of the temperature and strain rate dependence of four important stress parameters: yield, critical, saturation and steady-state, by means of the Sellars-Tegart-Garofalo model (STG). Also, it has been possible to derive an expression for the time required to achieve 50% recrystallization as a function of the deformation conditions, as well as the computation of the Avrami exponent of the material. All this information has been subsequently employed in the description of the flow stress of the material as a function of deformation conditions. For this purpose, an original constitutive description in differential form, which combines a work-hardening and dynamic recovery term, described by the phenomenological equation earlier advanced by Sah et al. and an additional softening term, which involves the Avrami relationship, is proposed. The evolution equation that has been advanced is independent of strain. Therefore, it is shown that, in principle, it is possible to describe satisfactorily the evolution of the flow stress during transient loading conditions as a consequence of changes in strain rate or deformation temperature, regardless if the material undergoes DRX during such a transient. Contrary to many different models reported in the literature, the approach here proposed is independent of the peak parameters exhibited on the flow curves.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

In industrial forming processes conducted under hot-working conditions, the material undergoes extensive plastic deformation under variable conditions of deformation temperature and strain rate, which leads to the increase in its internal strain energy, mainly due to the increase in the dislocation density. Thus, in the course of plastic deformation under such conditions, different microstructural processes such as work-hardening, dynamic recovery (DRV) and dynamic recrystallization (DRX) could occur, which give rise to significant changes in mechanical properties and microstructure. Particularly, the

---

* Corresponding author at: Université Lille Nord de France, USTL, LML, CNRS, UMR 8107, F-59650 Villeneuve d'Ascq, France.
E-mail address: eli.puchi@univ-lille1.fr (E.S. Puchi-Cabrera).

0749-6419/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijplas.2013.08.011

List of symbols

Arabic symbols

A	material constant
A_c, A_s, A_{st}, A_y, A_z	material constants, s^{-1}
m_y, m_s	material constants
n_{Av}	Avrami exponent
R	universal gas constant, $J\ K^{-1}\ mol^{-1}$
Q_d	deformation activation energy, $J\ K^{-1}\ mol^{-1}$
Q_{DRX}	activation energy for DRX, $J\ mol^{-1}$
Q_c, Q_y, Q_s, Q_{ss}	activation energies, $J\ mol^{-1}$
t	recrystallization time, s
$t_{0.5}$	time for 50% recrystallization, s
T	absolute temperature, K
X_v	volume fraction recrystallized
Z, Z_c, Z_s, Z_{ss}, Z_y	Zener–Hollomon parameters, s^{-1}

Greek symbols

$\delta\varepsilon$	strain increment
ε	effective strain
$\varepsilon_{critical}$	critical strain for the onset of DRX
ε_r	relaxation strain
$\dot{\varepsilon}$	effective strain rate, s^{-1}
$\mu(T)$	temperature-dependent shear modulus, MPa
$\Delta\sigma$	flow softening due to DRX, MPa
σ	effective stress, MPa
σ_ε	flow stress corresponding to the work-hardening transient, MPa
σ_a	athermal stress, MPa
$\sigma_{critical}$	critical stress for the onset of DRX, MPa
$\sigma_y\ (T, \dot{\varepsilon})$	yield stress, MPa
$\sigma_{Sat.}\left(T, \dot{\varepsilon}\right)$	hypothetical saturation stress, MPa
σ_{ss}	steady-state flow stress, MPa
σ_{Hc}, σ_{Hs}, σ_{Hss}, σ_{Hy}	material parameters, MPa
θ	work-hardening rate, MPa
θ_0	athermal work-hardening rate, MPa

occurrence of DRX in materials with low to moderate stacking fault energy, would lead to the presence of a significant work-softening transient in the stress–strain curve, after the attainment of a peak stress, which could bring about an important decrease in the mean flow stress applied to the material during the forming operation.

The importance of including DRX into crystal plasticity models for broader applicability had already been pointed out by Neil and Agnew (2009), who had earlier incorporated the viscoplastic self-consistent (VPSC) polycrystal plasticity model advanced by Lebensohn and Tomé (1993), within the Marciniak–Kuczynski (M–K) approach for forming limit curve prediction of magnesium alloys.

In the past few years, a number of important theoretical advances and some experimental studies aimed at understanding and modeling the phenomenon of DRX in both ferrous and non-ferrous materials have been made. As an example, Busso (1998) proposed a visco-plastic constitutive theory for large deformations in order to describe the microstructural evolution due to DRX and grain growth processes, in materials with moderate to low stacking fault energy, when these are subjected to hot-working processes. The advanced model relies on scalar internal state variables (ISV) explicitly linked to mean dislocation spacing and average grain size, to describe the evolving microstructure. The onset of recrystallization is defined by means of a material instability criterion which depends on a critical mean dislocation spacing.

Other developments, such as that of Okuda and Rollet (2005) have been focused on the use of Monte Carlo simulation methods to study the grain growth behavior, including misorientation and mobility of a grain nucleus when particle pinning takes place in steels. Takaki et al. (2008, 2009, 2011), on the other hand, have focused on modeling DRX by means of a multi phase field approach, which involves the definition of each growing grain as a phase field, whereas the Kocks–Mecking equation is employed for determining the dislocation evolution. The combination of such equation with the phase-field simulation allows the estimation of the recrystallization effect.

Cram et al. (2009) have developed a physically based model for nucleation during discontinuous dynamic recrystallization (DDRX), which has been coupled with polyphase plasticity and grain growth models to predict the macroscopic stress and grain size evolution during straining. The model has been extended (Cram et al., 2012) to include the effect of solute on

Download English Version:

https://daneshyari.com/en/article/784417

Download Persian Version:

https://daneshyari.com/article/784417

Daneshyari.com