Materials Science & Engineering A 597 (2014) 415–421

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Temperature and grain size dependent plastic instability and strain rate sensitivity of ultrafine grained austenitic Fe–14Cr–16Ni alloy

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ARTICLE INFO

Article history:
Received 11 December 2013
Accepted 4 January 2014
Available online 10 January 2014

Keywords:
Austenitic Fe–Cr–Ni alloy
Ultrafine grain
Temperature
Plastic instability
Strain rate sensitivity

ABSTRACT

In this study temperature and grain size dependent plastic instability and strain rate sensitivity (SRS) were investigated for coarse grained (CG) and ultrafine grained (UFG) austenitic Fe–14Cr–16Ni alloys. As tensile testing temperature increased from 20 to 200 °C, UFG alloys exhibited much more prominent decrease of uniform strain compared with CG counterparts. Transmission electron microscopy (TEM) analysis of deformed UFG alloys revealed temperature dependent evolution of microstructures. Through grain refinement, the SRS of Fe–14Cr–16Ni alloy increased and activation volume decreased, which may be related to the interactions of dislocations with grain boundaries. The SRS of UFG alloys exhibited greater temperature dependence than CG alloys.

1. Introduction

Nanocrystalline (NC) and ultrafine grained (UFG) metallic materials have applications as structural materials due to their enhanced mechanical strength [1–4] and improved corrosion [5,6] and radiation resistance compared to bulk coarse grained (CG) counterparts [7–9]. A majority of NC and UFG metallic materials typically exhibit degraded ductility mainly due to diminished dislocation activity within fine grains [10,11]. Several mechanisms have been proposed to delay plastic instability for these fine grained metallic materials with a target to achieve enhanced work hardening capability, including promoting the accumulation of dislocations, deformation-induced phase transformation and deformation twinning [12]. A bimodal distribution of grain size appears to effectively improve ductility of UFG metals as fine grains (<300 nm) impart high strength whereas coarse grains (1–3 μm) provide strain hardening capability by sustaining significant dislocation activity [13,14]. Deformation-induced martensitic phase transformation improved the ductility of UFG Fe–Cr–Ni–Mo alloy [15]. Nanotwinned microstructure in fcc metals provides a combination of high strength and ductility [16,17].

Strain rate sensitivity (SRS) is an important parameter to determine the rate-controlling deformation mechanisms of metals. Grain size has significant effect on the SRS of metals. UFG and NC Cu [18], Ni [19] and Al [20] show a higher SRS value (m) than their CG counterparts. Reduction in m values with decreasing grain size observed in bcc Fe and Ta [18,21] was attributed to significant increase of athermal component of the flow stress and insensitive grain size dependent thermal component.

There are few temperature and grain size dependent studies on SRS and deformability of UFG or NC metals and alloys. Canadinc et al. [22] performed compressive jump tests on ferritic interstitial-free steel and reported greater SRS in UFG microstructure than in CG counterparts. Temperature also plays an important role on the strain rate dependent deformation behaviors of metals. Wang et al. [23] showed that the SRS of NC Cu is more temperature dependent than that in CG Cu. Interaction of mobile dislocations with grain boundaries (GBs) was believed to be the dominant rate-controlling mechanism in NC Cu. For conventional CG austenitic 304 SS, strain-induced austenite-to-martensite phase transformation rate dominates deformation behaviors at low temperatures, -80 to 25 °C, and the magnitude of SRS was proportional to transformation rate. At higher temperatures, slip took over and the corresponding SRS values decreased with increasing strain [24,25].

In this paper, we report on temperature and grain size dependent plastic instability and variation of SRS of UFG austenitic Fe–14Cr–16Ni alloy studied by strain-rate jump tests, and corresponding deformation mechanisms are discussed.

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http://dx.doi.org/10.1016/j.msea.2014.01.003

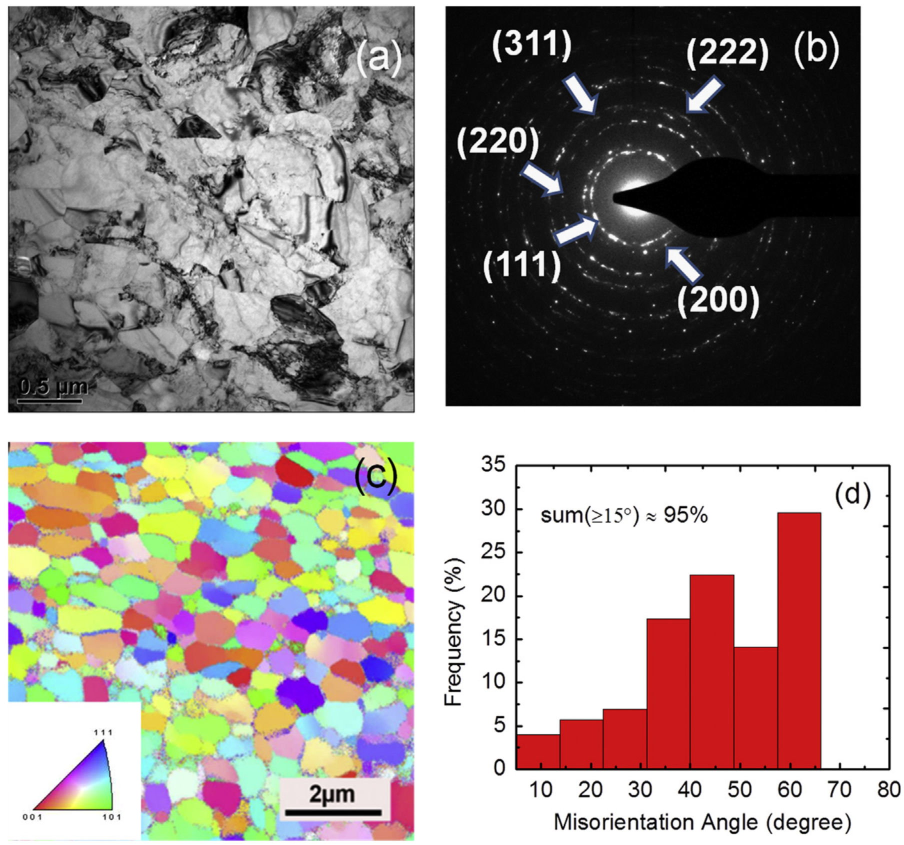

Fig. 1. (a) Bright field TEM image of UFG Fe–14Cr–16Ni alloy with an average grain size of ~400 nm, produced by route Bc at 500 °C for 8 passes. (b) Selected area diffraction (SAD) pattern of UFG Fe–14Cr–16Ni alloy, indicating that fcc austenite is the predominant phase (c) EBSD micrograph of the UFG alloy [26]. (d) Statistical distribution of misorientation angles shows primarily high angle grain boundaries.

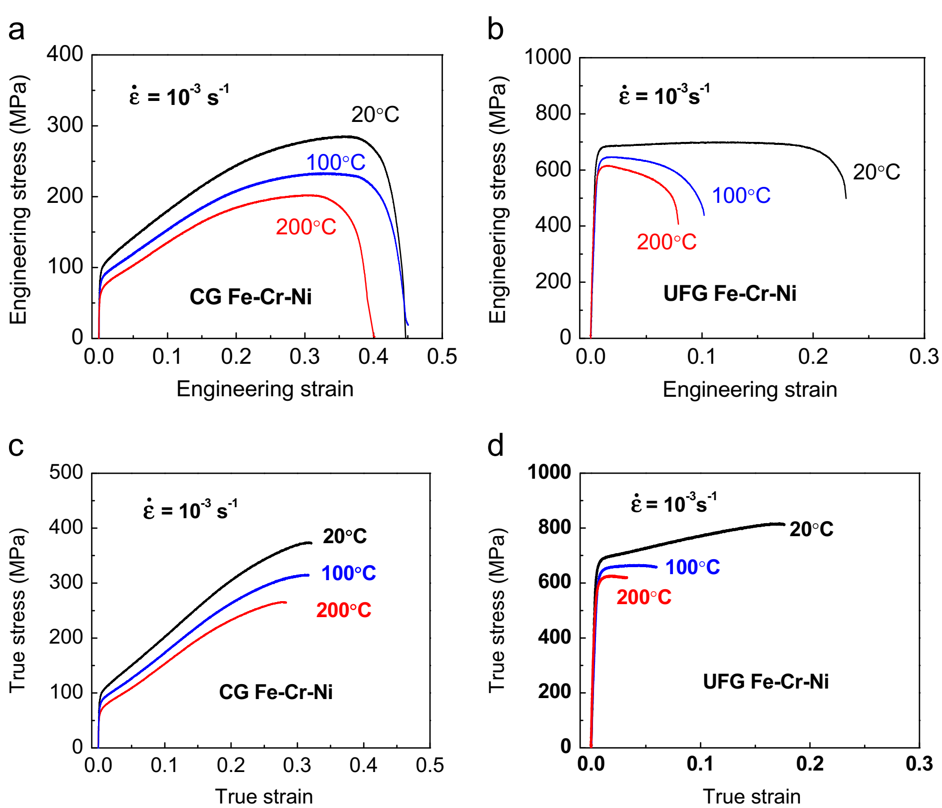

Fig. 2. Engineering stress–strain curves at constant strain rate of 1×10^{-3} s^{-1} at 20, 100 and 200 °C for (a) CG and (b) UFG Fe–14Cr–16Ni alloy. Both yield strength and total elongation reduced as temperature increased from 20 to 200 °C. Compared with CG sample, the reduction of total elongation was more significant in UFG specimens at 200 °C. (c–d) The converted true stress–true strain curves for CG and UFG alloys.