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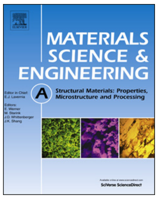

Serration behavior and microstructure of high entropy alloy CoCrFeMnNi prepared by powder metallurgy

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ABSTRACT

The equiatomic CoCrFeMnNi high entropy alloy prepared by powder metallurgy has homogenous chemical composition and microstructure. The mechanical properties of the CoCrFeMnNi high entropy alloy at the strain rates (1×10^{-4} s^{-1} to 0.1 s^{-1} and 1×10^{3} s^{-1} to 3×10^{3} s^{-1}) and the temperature (298 K, 673 K and 1073 K) were investigated. Results indicate that the yield strength of the CoCrFeMnNi high entropy alloy is in the range of 350–700 MPa, increasing sensitively with increasing the strain rates, especially at a high strain rate (larger than 1×10^{3} s^{-1}). The serration behavior of the high entropy alloy is observed on the flow stress curves of the alloy deformed at a low strain rate of 1×10^{-3} s^{-1} and the high strain rates (1×10^{3} s^{-1} to 3×10^{3} s^{-1}). Influences of the strain rate and the temperature on the serration behavior of the CoCrFeMnNi high entropy alloy are discussed.

1. Introduction

High entropy alloys, called solid solution alloys, contain at least five major elements in equal or near equal atomic percent [1]. The equiatomic CoCrFeMnNi high entropy alloy owns a single-phase solid solution with the face-centered-cubic (FCC) structure. Many researchers present rising interest on the mechanical behavior and the application of the CoCrFeMnNi high entropy alloy [2–7]. The strength of the CoCrFeMnNi high entropy alloy is relatively low in as-cast state, only around 200 MPa [7]. High entropy alloy are commonly prepared by arc melting, mechanical alloying, laser cladding, and spark plasma sintering [8–14]. The compositional segregation of elements and brittle intermetallic are inevitable in the high entropy alloy ingots prepared by vacuum arc melting [14–16]. Powder metallurgy is an efficient way to prepare a high strength CoCrFeMnNi high entropy alloy with homogeneous compositions and microstructures [15]. Powders can be completely combined in a short time so that the microstructure without coarsening [17], and the extremely fast cooling rates can also refine the microstructure. In addition, the compositional segregation can be avoided and the single phase can be stabilized with this fast cooling rates [18].

A row of sharp or tooth-like projections appear on flow stress curves of solid materials are called serration behavior by Zhang et al. [8]. The serration behavior in the plastic regime of the CoCrFeMnNi high entropy alloy has been observed in both compressive and tensile tests [7,16,19–22]. Zhang et al. [8] summarized that serrations observed in the high entropy alloys during the compressive tests at the strain rate of 1×10^{-3} s^{-1} seemed to be greater than those at strain rate of 1×10^{-4} s^{-1} or 10 s^{-1}, and were more visible than those at elevated temperatures. Serration behavior is supposed to associate with Cottrell atmosphere interaction with moving dislocations, slip band, and dynamic strain aging, i.e. the dynamic breakaway / locking of dislocations from / by mobile solute atoms at intermediate temperatures [23–26]. Otto et al. [16] reported that serrations were commonly attributed to dynamic dislocation pinning and breakaway, such as dynamic strain aging. Yasuda et al. [23] presented that serrations may cause by dynamic strain aging and closely related to the solute atmosphere around moving dislocations or stacking faults. Chen et al. [27] applied self-similar random process and chaotic behavior to explain the mechanism of serration behavior. Serrations in other traditional alloy had also been investigated. For example, the serration behavior of dual phase steels at various temperatures and strain rates between 1×10^{-3} s^{-1} and 1 s^{-1} had been studied Bayramin et al. [28]. The results suggest that the serrations can be linked to a periodic microstructural feature. In addition, Portevin-Le Chatelier (PLC) effect [29–33], defined as continuous serrated yielding in stress–strain curve in certain ranges of temperature and strain rate, is another method to explain the serration behavior of the high entropy alloy. The critical strain of the Portevin-Le Chatelier

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Table 1
Chemical composition of the *CoCrFeMnNi* high entropy alloy.

Elements	*Co*	*Cr*	*Fe*	*Mn*	*Ni*
(at%)	19.80	21.40	20.10	19.40	19.30

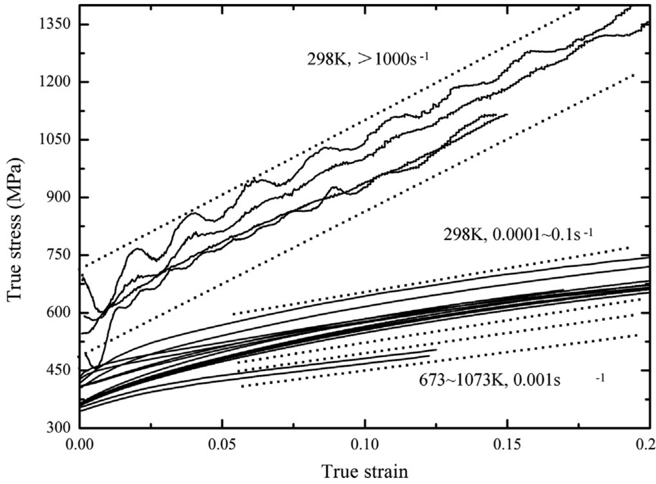

Fig. 1. True stress vs. true strain curves of the CoCrFeMnNi high entropy alloy obtained in compressive tests as function of temperature and strain rate.

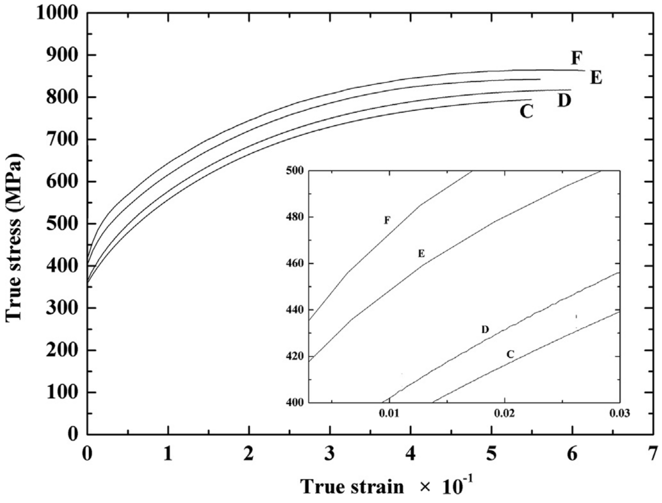

Fig. 2. The strain rate (1×10^{-4} s^{-1}, 1×10^{-3} s^{-1}, 0.05 s^{-1} and 0.1 s^{-1}) effects on the serration behavior at ambient temperature. The representative inset shows magnified figure of the stress-strain curves.

effect marks the boundary between stable and unstable flow. Fu et al. [26,30,34] proposed two mechanisms for the normal and inverse behavior of the critical strain for the Portevin-Le Chatelier effect. Therefore, the mechanism for the serration behavior of the equiatomic CoCrFeMnNi high entropy alloy is yet unclear.

In the present study, we focus on the equiatomic CoCrFeMnNi high entropy alloy prepared by powder metallurgy. The compressive tests were performed at a wide-range of strain rates and temperatures to explore the plastic deformation and related serration behavior. The aims of the paper are as follows: (1) to investigate the mechanical properties of the powder metallurgy CoCrFeMnNi high entropy alloy; (2) to report the microstructure of the serration behavior of the powder metallurgy CoCrFeMnNi high entropy alloy deformed at high strain rate; (3) to discuss the strain rate and temperature effects on the serration behavior of the CoCrFeMnNi high entropy alloy.

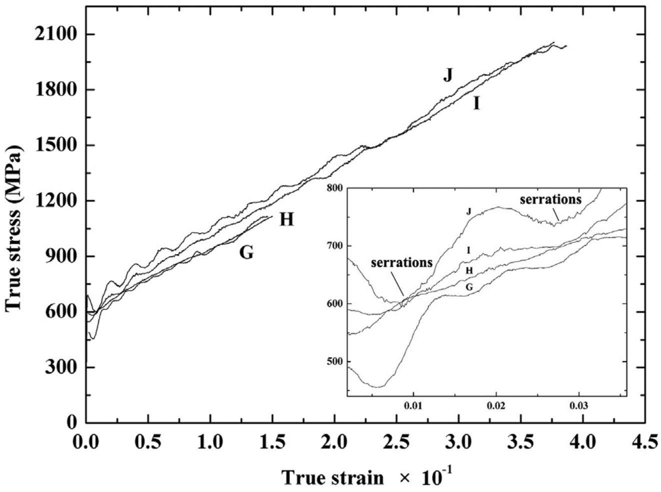

Fig. 3. The strain rate (1200 s^{-1}, 1260 s^{-1}, 2710 s^{-1} and 2800 s^{-1}) effects on the serration behavior at ambient temperature. The representative inset shows magnified figure of the stress-strain curves.

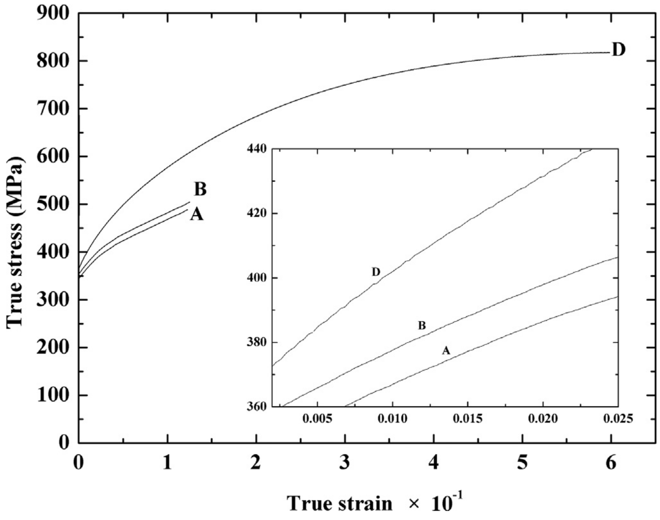

Fig. 4. The temperature (298 K, 673 K and 1073 K) effects on the serration behavior at the given strain rate of 1×10^{-3} s^{-1}. The representative inset shows magnified figure of the stress-strain curves.

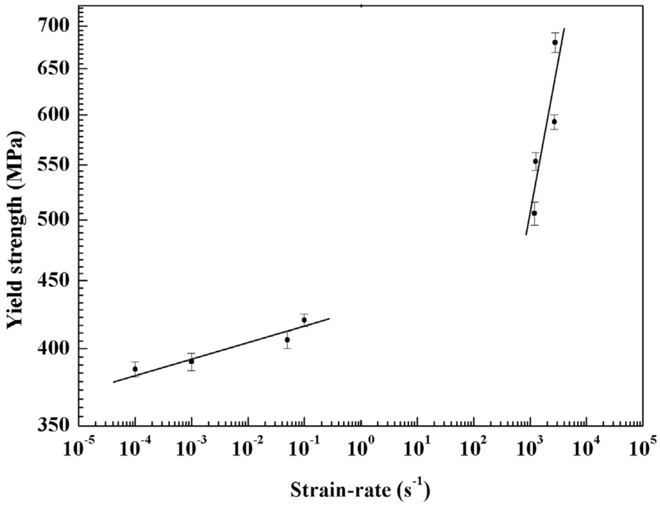

Fig. 5. The yield strength vs. strain rate curves of the CoCrFeMnNi high entropy alloy. This plots the logarithm to base 10 of the values on the axis.