Measurement of Thermomechanical Behaviour Under Transient Reverse Loading and Its Application to Advanced Alloy

Longhui Zhang[1a], David Townsend[2]

[1] Department of Engineering Mechanics, South China University of Technology, Guangzhou 510640, China

[2] Department of Engineering Science, University of Oxford, Oxford, OX1 3PJ, U.K.

[a]emlhzhang@scut.edu.cn & lhzhang.mechanics@gmail.com

Abstract. A bespoke reverse loading apparatus with real time strain monitoring and controlling capabilities is developed to measure the heat dissipation of metallic alloy under fast reverse loading, by taking CoCrNi alloy as a model material. The Taylor-Quinney coefficient (TQC) decreases during the initial strain hardening, while the subsequent kinematic hardening is associated with gradually constant TQC of about 50%, indicating the cyclic plastic work equally divided into heat and cold work stored in CoCrNi alloy.

Introduction

The last decade has seen the promising development of multicomponent alloys [1] with superior mechanical properties. A typical instance is the equal molar medium entropy alloy (MEA), which shows good ductility, the effectiveness in hindering the strain localization and the excellent fracture toughness in extreme conditions. Note that when the multicomponent alloy is plastically deformed, the temperature is changed due to the adiabatic heating effect. A central issue is the ratio of plastic energy converted into heat, a subject studied by Taylor and Quinney [2]. To the best of the authors' knowledge, the thermomechanical coupling effect and kinematic hardening of the multicomponent alloy during rapid reverse loading are yet to be understood.

Experimental Protocol

A dog-bone specimen was used, with a gauge length to diameter ratio of 3 mm-3 mm. Fig. 1a shows the initial microstructure of CoCrNi revealed by EBSD. The CoCrNi alloy presents an FCC structure with a grain size of about 150 µm. Fig. 1b schematically shows the bespoke reverse loading apparatus recently developed by Zhang and Townsend [3], with real time strain monitoring and controlling capabilities. The reverse loading tests were conducted by using a Zwick Z050 machine and a fast hydraulic Instron 8850 under displacement control mode at nominal strain rate of 10^{-3}/s and 10^{1}/s, respectively. For the tests using the Zwick machine, the Imetrum video extensometer tracked the engineering strain at a frame rate of 10 fps. The Imetrum system provided feedback to the Zwick Z050 machine to directly apply the reverse loading to the specimen. The reverse loading test on the fast hydraulic Instron was monitored by a high speed Photron camera at a frame rate of 10, 000 fps, and the engineering strain of gauge section was obtained from the image analysis by using the commercial DIC software Lavision Davis. Three different strain levels are considered, namely, low strain reverse (LSR), medium strain reverse (MSR) and high strain reverse (HSR). Details can be found in Ref. [4].

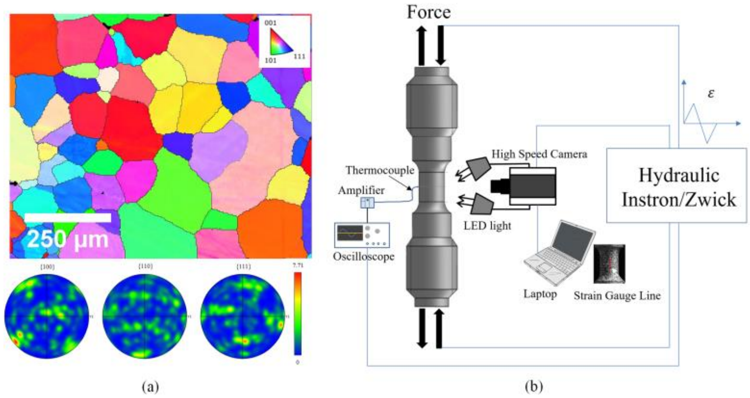

Fig.1 (a) Initial microstructure of CoCrNi alloy (b) Schematic of the bespoke reverse loading setup

Experimental Results

Fig. 2 presents the typical engineering stress, strain and temperature rise histories of the CoCrNi alloy subjected to the fast reverse loading at nominal strain rate of 10^1 /s. The material experiences rapid oscillation, which consists of tension-compression-tension reverse loading. The reversal deformation causes a noticeable temperature change. The temperature increases under the first tensile loading. A very slight step appears in the temperature rise during the unloading process. Assuming the adiabatic condition, the integration of the transient stress-thermal balance equation results in $\beta_{int}\int_0^{\alpha}\sigma d\varepsilon_p = \rho c_p \Delta T$,where β_{int} is the Taylor-Quinney coefficient. ε_p is the plastic strain, ρ is the material density, c_p is the specific heat and ΔT is the temperature

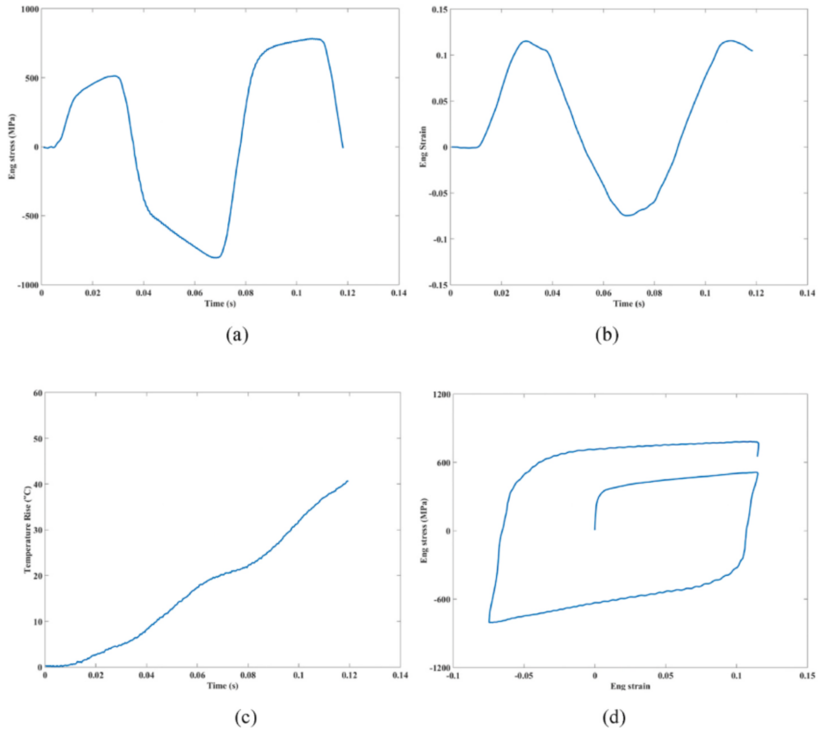

Fig. 2 Typical engineering stress-strain-temperature rise histories

rise up to an accumulated plastic strain value α. Fig. 3a shows the value of TQC is far away from 0.9 throughout the reverse loading process. The initial strain hardening of CoCrNi alloy is accompanied by the reduction of TQC, while the subsequent kinematic hardening stage is accompanied by the gradual constant TQC of about 0.50, indicating the plastic energy equally divided into heat and cold work stored in the CoCrNi alloy. Considering the stored energy of cold work and the corresponding microstructural change, the intragranular misorientation was evaluated using kernel average misorientation (KAM) in Fig. 3b. The abundant dislocation activities substantiate the capability of dislocation storage in the microstructure and then the strain-hardening ability during the reverse loading. This confirms the latent energy (cold work) definitely remains in the CoCrNi alloy during reverse loading.

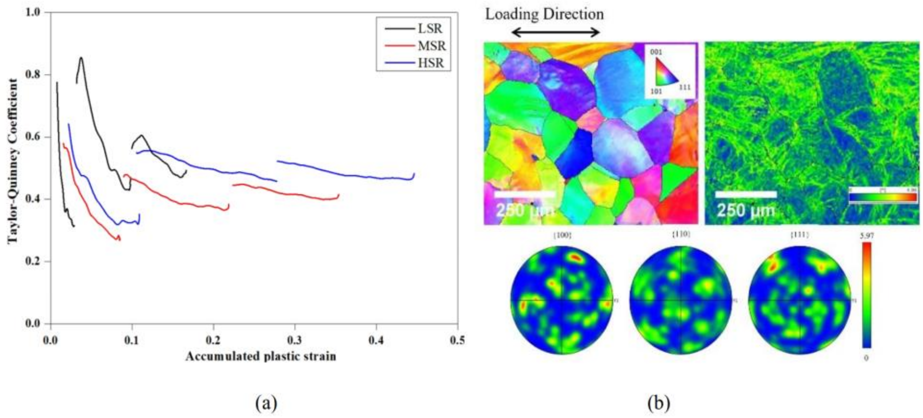

Fig. 3 (a) TQC under fast reverse loading (b) EBSD maps of the CoCrNi after MSR loading.

Conclusion

The deformation of CoCrNi alloy under transient reverse loading is associated with thermomechanical coupling. Except for the initial strain hardening with the decrease of TQC, the present thermomechanical measurements clearly show that the heat generation and the latent energy contribute almost equally to the fast reverse plastic deformation of CoCrNi alloy.

References

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