Enhancing Mechanical Properties of a Medium-Entropy Alloy by Regulating Mo Addition

Chang-Yu Hung[1,2]; Chenyang Li[3]; Martin Detrois[1]; Paul D Jablonski[1]; Wei Chen[3]; Stoichko Antonov[1]

[1]National Energy Technology Laboratory, 1450 Queen Avenue SW, Albany, OR 97321, USA; [2]NETL Support Contractor, 1450 Queen Avenue SW, Albany, OR 97321, USA;
[3]Department of Materials Design and Innovation, University at Buffalo, The State University of New York, Buffalo, NY 14260, USA

Research & Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

Motivation

Some multi-principal element alloys (MPEAs), including equiatomic, single-phase CrCoNi, and CrCoFeMnNi, are now widely recognized for their remarkable combinations of pronounced hardening rates, high ductility, and exceptional fracture toughness at room and cryogenic temperatures. To push the limit of hardenability of the medium-entropy alloy, the strategies associated with local lattice distortion or stacking fault energy (SFE) reduction that promote complex heterogeneity and defect dynamics require further investigation.

Objectives

The purposes of this study are to (1) further enhance the mechanical properties of a typical medium-entropy NiCoCr with alloying Mo, and (2) understand the strengthening mechanism for the Mo-added medium-entropy alloys.

Approaches

A series of MPEAs with nominal composition of $Ni_{35}Co_{35}Cr_{30-x}Mo_x$ (x value in atomic ratio, x= 0 (DT1), 5 (DT2), and 10 (DT3)) were designed. Uniaxial tensile tests and loading-unloading-reloading (LUR) were carried out to understand the effect of alloying Mo. The microstructure of as-annealed and interrupted tensile samples were investigated with electron microscopes.

As-Annealed Microstructure

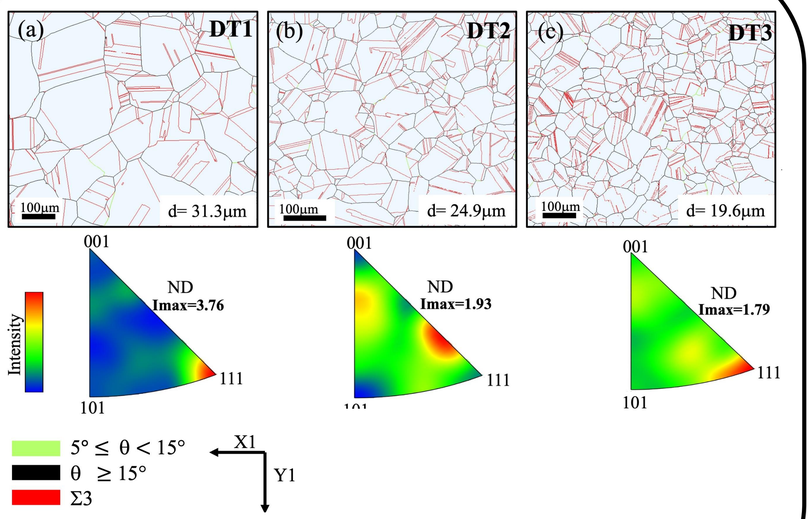


Figure 1: Electron backscatter diffraction (EBSD) grain boundary maps of full-recrystallized samples of (a) DT1, (b) DT2, and (c) DT3.

Mechanical Properties and Microstructure

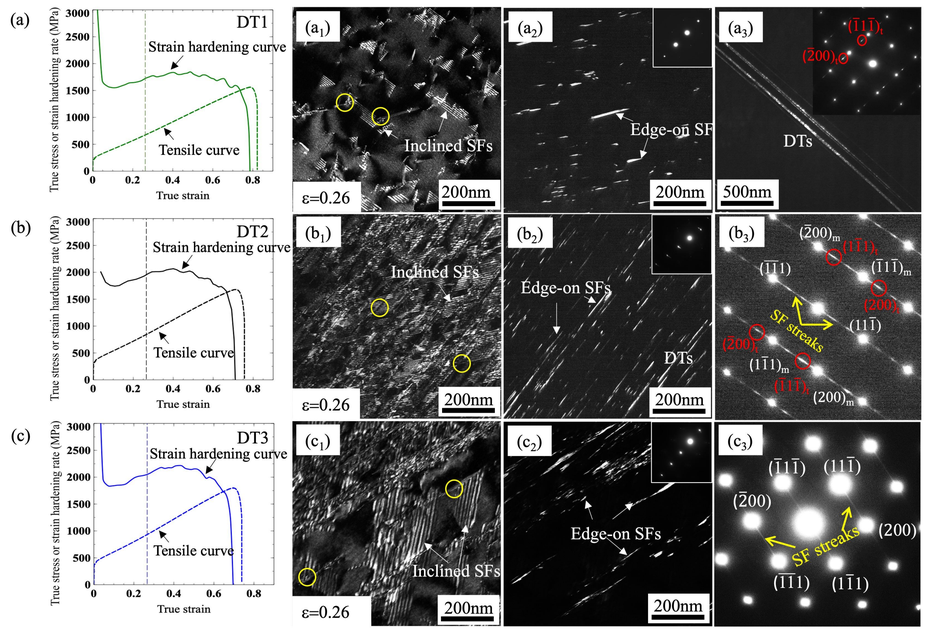


Figure 2: (a-c) True stress-strain curves, strain-hardening curves, and deformation microstructure of DT1-DT3. Inclined and edge-on stacking faults were indicated with arrows. The selected area electron diffraction patterns with streaks and extra spots correspond to SFs and deformation twins.

Amplification of Back-Stress Hardening with Mo Addition

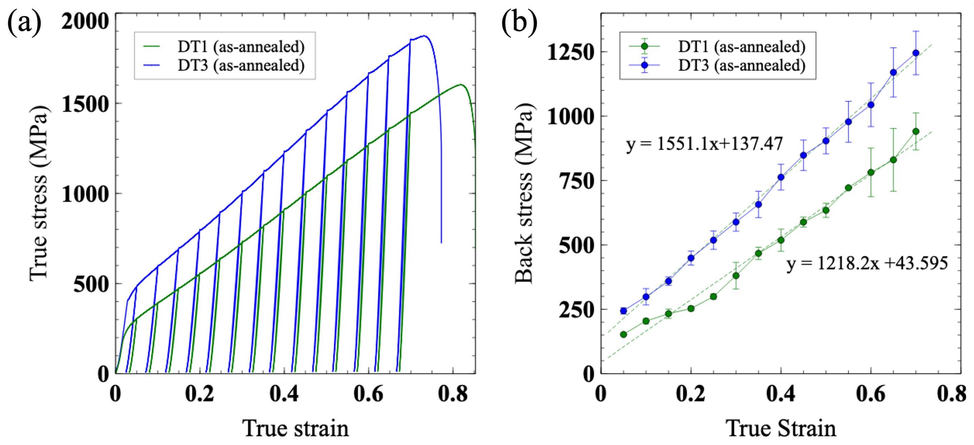


Figure 3: (a) The loading-unloading-reloading curves of DT1 and DT3; (b) the curves of calculated back stress for DT1 and DT3.

Discussion

SFE Calculation

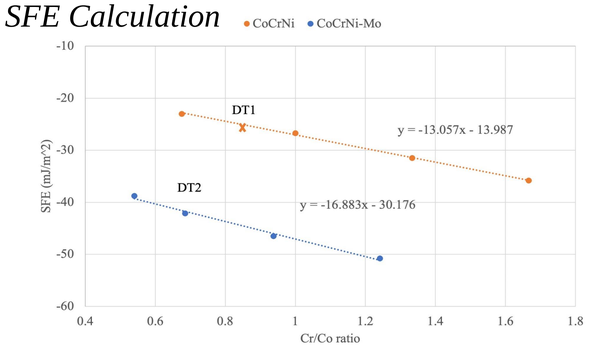
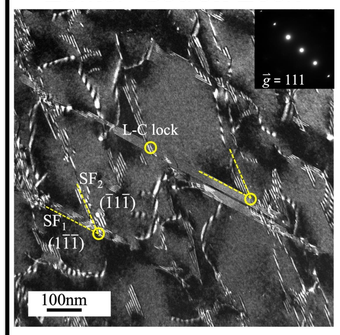


Figure 4: Stacking fault energy calculation based on composition around DT1 and DT2.

Lomer-Cotrell Lock



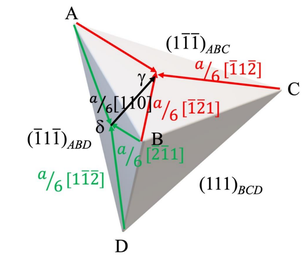


Figure 5: A transmission electron microscopic micrograph with a corresponding Thompson Tetrahedron illustrates the formation of sessile dislocation by SF intersection.

$$\begin{cases} DB_{ABD} \rightarrow D\delta_{ABD} + \delta B_{ABD} \\ CB_{ABC} \rightarrow \gamma C_{ABC} + B\gamma_{ABC} \end{cases} \rightarrow \delta B + B\gamma \rightarrow \delta\gamma$$

Conclusions

(1) Alloying addition of Mo not only effectively delays the grain growth, but also strongly improves the mechanical properties. 10 at% Mo alloyed in DT3 improves the yield strength by 85% with only ~10% decrease in fracture elongation.

(2) The increase in yield strength appears to be related to severe lattice distortion caused by the large atomic radius of Mo, while the high ductility can be mainly ascribed to the SFE reduction with Mo that promotes formation of sessile dislocation at SFs intersection.

Acknowledgements: This work was performed in support of the U.S. Department of Energy's (DOE) Fossil Energy and Carbon Management Advanced Energy Materials Research Program executed through the National Energy Technology Laboratory (NETL) Research & Innovation Center's Advanced Materials Development Field Work Proposal.