metals

Editorial

High-Entropy Alloys (HEAs)

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1. Introduction and Scope

High-entropy alloys (HEAs) [1,2] loosely refer to multi-principal-element solid solution alloys due to their high configurational entropy, in contrast to traditional alloys, which focus on the edge or corner of phase diagrams with one principal component. The unique compositions and the resulting attractive properties of HEAs have stimulated growing research interest due to scientific curiosity and potential industrial applications [3,4]. In order to balance the properties for targeted applications, the microstructure of HEAs can be a single phase or multiphases, and traditional physical metallurgy principles have been applied to develop a variety of HEAs, including high-entropy stainless steels, high-entropy superalloys, high-entropy refractory alloys, high-entropy light-weight alloys, high-entropy oxides, high-entropy metallic compounds, etc. However, great challenges still remain in the fundamental understanding of HEAs formation and their properties, and potential high-performance HEAs are yet to be explored. This special issue is meant to collect contributions from authors working in the various fields of HEAs to timely disseminate the rapid progress in this fascinating and expanding class of advanced materials.

2. Contributions

The composition/processing/microstructure/properties relationship plays the central role in the physical metallurgy of HEAs. The $Al_xCoCrFeNi$ (x denotes molar ratios) [5,6] HEAs represent an optimal combination of high strength and good ductility, and accordingly have been widely studied in the literature. Indeed, in this special issue, most papers focus on the microstructure evolution and mechanical properties of $Al_xCoCrFeNi$ HEAs. Hou et al. [7] studied deformation behavior of $Al_{0.25}CoCrFeNi$ HEA with a single face-centered cubic (FCC) phase after cold rolling and subsequent recrystallization annealing at 1100 °C for 10 h, and determined the yield strength as a function of grain size, sample thickness and flow stress. Zhang et al. [8] studied the hot deformation behavior of as-cast and homogenized $Al_{0.5}CoCrFeNi$ HEAs during isothermal compression as a function of temperature and strain rate. They found that the homogenized alloy has a better hot workability than as-cast alloy, and the flow stress in a homogenized state was always higher than that in an as-cast state under the same deformation conditions. Ma et al. [9] studied the morphological evolution of the body-centered-cubic (BCC)/B2 phases in $Al_xCoCrFeNi$ (x = 0.41, 0.57, 0.74, 0.92, 1.12, and 1.33) HEAs. They found that the BCC/B2 coherent morphology is closely related to the lattice misfit between these two phases: A weave-like morphology induced by the spinodal decomposition forms at lower Al contents, and spherical disordered BCC precipitates form within the ordered B2 matrix at much higher Al contents. Addition of Ti to the $Al_xCoCrFeNi$ HEAs can increase the mechanical strength due to strong attractive cohesion between Ti and Co, Cr, Fe, and Ni, while promoting formation of intermetallics. Lindner et al. [10] reported formation of four main phases in a mixed solid solution as well as intermetallic phases in $Al_xCoCrFeNiTi$ (x = 0.2, 0.8, and 1.5).

Refractory NbTiVZr HEA is ductile, and adding Al could improve the strength and oxidation resistance. Yurchenko et al. [11] reported formation of C14 Laves and Zr_2Al-type phases when annealing at 1200 °C while additional intermetallics form at 800 °C and 1000 °C in Al_xNbTiVZr (x = 0, 0.5, 1, and 1.5). Developing high-strength low-density HEAs is extremely important for transportation and defense industries, and Kumar and Gupta [12] provided a timely review that summarized density, microstructure, mechanical properties (yield strength, peak stress, and fracture strain), and manufacturing of light-weight HEAs that primarily consist of elements Mg, Li, Al, Ti, and Zn, in combination with Si, Sc, Zr, V, Cu, Nb, V, Fe, etc. To explore their potential applications for dynamic deformation during high speed impacts, Geantă et al. [13] did virtual testing of composite structures consisting of AlCoCrFeNi HEA and carbon steel plates using different joining processes. They found that the composite structures obtained by welding and brazing have good continuity and rigidity, and accordingly demonstrate the best ballistic behavior.

Environmental properties are also important for HEAs since structural materials are inevitably used in corrosive and oxidizing environments. Butler and Weaver [14] systematically investigated the oxidation behaviors of $Al_x(CoCrFeNi)_{100-x}$ (x = 8, 15, 30) HEAs in the as-cast and annealed states, and concluded that these alloys display good oxidation resistance at a parabolic oxide growth rate constants (k_P) corresponding to those expected for Group II and Group III Ni–Cr–Al alloys. Shi et al. [15] reviewed the effects of environments, alloying elements, and processing methods on the corrosion resistance of HEAs. They concluded that the formation of the homogeneous protective oxide film such as Cr_2O_3 enhance pit corrosion resistance, while additions of Al and/or Cu reduce corrosion resistance due to phase transformation as well as the elemental segregation. Additional methods to improve corrosion resistance include anodic treatment, addition of Mo, and addition of the inhibitors.

Multicomponent amorphous alloys (so-called metallic glasses) resemble HEAs in many ways [16], but one key difference is that metallic glasses are always metastable or instable at any temperature, from thermodynamic and kinetic points of view. In contrast, HEAs can be equilibrium phases (e.g., at high temperatures), but will become unstable or metastable at lower or cryogenic temperatures although phase transformations may be inhibited by frozen diffusion at low temperatures. Wu et al. [17] showed that two amorphous coatings ($Fe_{49.7}Cr_{18}Mn_{1.9}Mo_{7.4}W_{1.6}B_{15.2}C_{3.8}Si_{2.4}$ and $Fe_{40}Cr_{23}Mo_{14}C_{15}B_6Y_2$) exhibit lower penetration depth, higher elastic recovery, and lower wear volume than the substrate, indicating the excellent wear resistance of the coatings, due to the high hardness and high hardness/elastic modulus ratio. Zhong et al. [18] studied the serrated-flow behavior of a multicomponent amorphous $Pd_{77.5}Cu_6Si_{16.5}$ alloy under uniaxial compression at the strain rates 2×10^{-3}, 2×10^{-4} and 2×10^{-5} s^{-1}. They observed that the elastic energy density displays a power-law distribution at the strain rate of 2×10^{-3} and concluded that the self-organized critical behavior emerges with increasing strain rates.

3. Conclusions and Outlook

Nine papers in this special issue focus on the physical metallurgy of high-entropy crystalline alloys, including two papers that review light-weight HEAs and their corrosion properties. The other two papers report the wear behavior and serration flow of multicomponent amorphous alloys. They only represent a small fraction of the wide spectrum of diverse HEA research. Other important research areas on HEAs include: Accelerating HEA design using combinatorial approach, developing computational thermodynamic and kinetic databases using the CALPHAD (an acronym for Calculations of Phase Diagrams) method, first-principles prediction of structural, electronic, magnetic, thermodynamic, kinetic, environmental, elastic and plastic properties, developing high-performance HEAs for critical environments (such as high temperatures, high pressure, high strain rates, irradiation, corrosion and oxidation), developing novel functional HEAs, etc. As a matter of fact, there is no limit in applying the concept of HEAs to all materials (metals, semiconductors, ceramics, polymers, etc.) for improved properties with reduced cost, and we hope that this special issue on HEAs will draw more interest in this fascinating area from academia and industries, and spark innovative ideas towards developing next-generation high-performance materials.

Conflicts of Interest: The author declares no conflict of interest.

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