Nano Particles Reinforced and Directional Solidification in High Entropy Alloys

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Abstract: Nano-precipitation strengthening is an extremely effective method for enhancing the mechanical properties of metallic materials, significantly improving their strength, toughness, and wear resistance. Directional solidification techniques provide a valuable means to control the crystal growth rate and orientation of high-entropy alloys, making them an essential tool for studying the solidification process of these alloys and enriching related theories. This paper systematically presents the recent research progress and key achievements of our research team in the areas of composition design, material preparation, phase formation mechanisms, crystal growth patterns, and strengthening mechanisms of high-entropy alloys. Through the exploration of various compositional combinations, we propose a composition design strategy based on valence electron concentration, revealing the relationship between the microstructure and macroscopic properties of the alloys. Furthermore, we delve into the mechanisms by which nano-precipitates influence the mechanical properties of the materials. These studies not only provide a theoretical foundation for the application of high-entropy alloys but also offer guidance for future material design and optimization.

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1 Introduction

Nanoparticle is an efficient approach for enhancing alloys' strength [8-12] because of the interaction of dislocations with nanoparticles based on the report of Beyerlein et. al [11], which is readily implementable in 3D printed alloys. Nevertheless, the mechanical heterogeneity between the precipitates and surrounding matrix generally causes stress-strain concentration at their interfaces and triggers microcrack nucleation, resulting in ductility loss [13-15]. To overcome the strength-ductility trade-off dilemma in precipitation strengthened alloys, coherent precipitates with a crystal lattice almost the same as that of the surrounding matrix, can be introduced through alloy design and heat treatment [14-16]. This strategy has been demonstrated in certain alloys, e.g., maraging steels [13] and complex concentrated alloys (CCAs) [17], to achieve a gigapascal strength with a large tensile ductility, yet its application is limited due to the delicate alloy design and thermo-mechanical processing.

2 Experimental procedure

The casted samples were prepared by induction melting of a mixture of pure metals (purity>99%) in a high-purity argon atmosphere and then casting into a water-cooled copper crucible. The microstructure was characterized using a Zeiss Sigma 300 field emission scanning electron microscope (SEM) operated at 20 kV with an energy dispersive spectrometer (EDS)

3 Result and discussion

Fig. 1a displays the SEM images of the CoCrCuMnNi HEA. It was found that the produced CoCrCuMnNi HEA has a typical dendrite crystal structure. Fig. 1b shows an image of the dendrite and inter-dendrite zones. Some plate-strip precipitates were observed in the inter-dendrite zone.

Fig. 1c shows an image of the inter-dendrite zone with a high magnification. A mass of nanometer precipitates was found in the inter-dendrite zone. An image of the dendrite zone with high magnification is presented in Fig. 1d. In the dendrite zone, many nanometer precipitates were also observed.

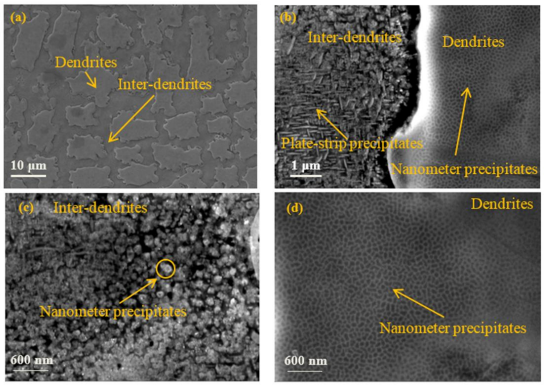

Fig. 1 Microstructure of the CoCrCuMnNi HEA by SEM

4 Conclusion

It should be emphasized that we have not only developed a CoCrCuMnNi HEA in the current work, but our study also sheds light on developing HEAs with remarkable mechanical properties. Furthermore, some main conclusions are drawn.

1. The CoCrCuMnNi HEA is composed of two FCC phases. A large amount of nanometer precipitates (5–50 nm in size) and domains (5–10 nm in size) are found in the inter-dendrite and dendrite zones.

2. This CoCrCuMnNi HEA prepared by vacuum arc melting exhibits excellent mechanical properties. The obtained tensile yield and the ultimate tensile strengths are about 458 MPa and 742 MPa, respectively, and the corresponding elongation is approximately 40%. This HEA has a mechanical response almost identical to those of the single-phase Fe20Mn20Ni20Co20Cr20 HEA (grain-refined) and the dual-phase Fe50Mn30Co10Cr10 HEA (as-homogenized), the two most suc cessful HEAs to date.
3. The enthalpy of mixing between Cu and Co, Cr, Mn, or Ni is higher than that between any two of Cr, Co, Ni, and Mn elements, which is the key factor for the separation of Cu from the CoCrCuMnNi HEA.

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