Effect of Al Content on Microstructure and Mechanical Behavior of As-CastNi35(CoCr)62-xAlxTi3High-Entropy Alloys

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Abstract: The effects of different Al content on the microstructure and mechanical properties of$Ni_{35}(CoCr)_{62-x}Al_xTi_3$ high entropy alloys (HEAs) were studied and analyzed. The results show that the microstructure of the alloys is the FCC main phase and a small amount of the B2 phase. And the mechanical properties of the alloys also change, yield strength and tensile strength at room temperature increase, while the plasticity becomes worse.

Keywords: High entropy alloy, Microstructure,B2 phase,Mechanical properties

1 Introduction (Bold, 10 pt., Arial)

EquiatomicCoCrNi is one of the typical HEAs characterized by a single FCC solid-solution phase, exhibiting a disappointing yield strength, which typically falls below 450 MPa at room temperature[1-3].Lu et al [4]investigated $NiCoCrAl_x$ (x = 0-30, at.%) alloy by adding Al elements, the results showed that the solid solution strengthening of Al element and the formation of hard BCC phase promotes the strengthening of this alloy system, and the FCC+BCC dual-phase can significantly enhance the CoCrNiHEA.Previous studies proved that by adding Al and Ti elements and adjusting their proportion, the strength of alloys can be greatly improved, while ensuring that the reduction of plasticity is within the acceptable range, resulting in HEAs with excellent mechanical properties [5]. In this paper, Al and Ti elements were selected as alloying elements, and the effects of Al content on phase composition, microstructure, and mechanical properties of $Ni_{35}(CoCr)_{62-x}Al_xTi_3$HEAs were studied systematically.

3 Experimental procedure

Three designed HEAs ingots with the nominal chemical composition $Ni_{35}(CoCr)_{62-x}Al_xTi_3$ (x=7, 10, 12, denoted by Al_7, $Al_{10,}$ and Al_{12} HEAs, respectively) were synthesized by vacuum arc-melting with high-purity metals (purities above 99.9 wt. %) in a water-cooled copper mold.

Phase constitutions of three studied HEA samples were identified, using a X'Pert Pro (PANalytical) X-ray diffractometer (XRD) with Cu Kα radiation (λ = 0.154 nm). The morphology and microstructure were characterized by a Zeiss Sigma 500 scanning electron microscopy (SEM) operating at 15 kV equipped with a backscattering electron detector (BSE).

A Zwick/Roell Z020 universal testing machine was employed to conduct the tensile test at ambient temperature to investigate mechanical properties of studied alloys.

2 Result and discussion

Phase constitution and microstructure

Fig. 1 shows the XRD patterns of Al_7, Al_{10} and Al_{12} HEAs under as-cast. As can be seen, the main diffraction peaks of Al_7 HEA are identified as a single FCC phase (based on the typical lattice of (111), (200) and (311) for the FCC structure). While the BSE images (Figs. 2(a) and (b)) clearly indicate the presence of a few second phase in Al_7-HEA, the diffraction peaks of the secondary phase in Al_7-HEA cannot be discovered may due to its too small volume fraction. When the addition of Al increases to 10, the diffraction peaks corresponding to (100) and (110) can be distinguished demonstrating the formation of the $L1_2$ precipitates and B2 secondary phase, therefore the Al10-HEA primarily consists by the FCC matrix with B2 secondary phase and $L1_2$ precipitates occupied in it. The existence of diffraction peaks corresponding to the ordered BCC structure suggests that the content of Al element is related to the phase transformation from the FCC structure to B2 structure. The Al_{12}-HEA, as with Al_{10}-HEA, consists of the FCC major phase, B2 secondary phase, and ordered $L1_2$ precipitates within the FCC matrix. It worth noting that the number of diffraction peaks for the B2 structure is significantly increased compared to the Al_{10}-HEA, which indicates the increment of the B2 secondary phase volume fraction.

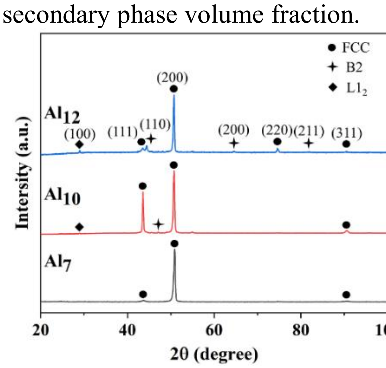

Fig.1. XRD patterns of the Al_7, Al_{10} and Al_{12} HEAs.

To further investigate the microstructure evolution and phase transformation, macro and micro BSE (as shown in Fig.2) were employed. Three studied samples all contain the FCC matrix (bright region) and the B2 secondary phase (dark region) in grain interiors. However, the proportion of the B2 secondary phase in Al_7, Al_{10} and Al_{12} HEAs is different, it can be distinctly seen from the BSE images in Fig. 2 that the volume fraction of the B2 secondary phase increases with the increment of the Al addition in these studied HEA system, which is consistent with the XRD results in Fig. 1. The volume fractions of the B2 secondary phase in the Al_7, Al_{10} and Al_{12} HEAs are measure to be ~0.7%, ~5.6% and ~14.0% by ImageJ software, respectively. In addition, some precipitates are visible in the B2 secondary phase of three studied HEAs. The precipitates in the B2 secondary phases of Al_7-HEA exhibit a needle-like structure and are interspersed with each other, nevertheless the precipitates of Al_{10} and Al_{12}HEAs are cubic or spherical particles discretely distributed in the B2 secondary phases. Moreover, some uncertain particles discontinuously located in the boundaries of the B2 secondary phases. The specific structure of precipitates in the B2 secondary phases and uncertain particles located in the boundaries need to be combined with high-end characterization methods for in-depth analysis.

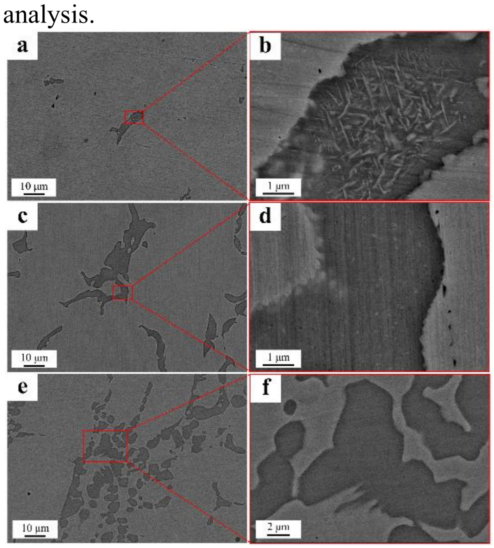

Fig.2. SEM images of the Al_7, Al_{10} and Al_{12} HEAs.

Mechanical properties

The mechanical properties are demonstrated by representative tensile engineering stress-strain curves of the three studied alloys at ambient temperature in Fig. 3.

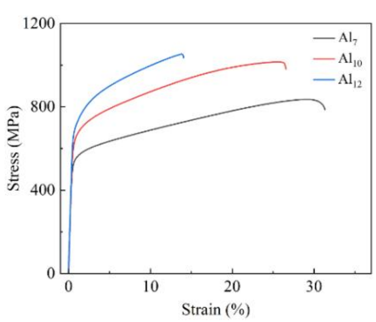

Fig.3. Engineering stress-strain curves of the Al_7, Al_{10} and Al_{12} HEAs at ambient temperature.

The Al_7-HEA represents a moderate yield strength ($\sigma_{0.2}$) of ~531 MPa, and a good ultimate tensile strength (σ_{UTS}) of ~836 MPa with an excellent total elongation of ~32.1%.The strength of the Al_{10}-HEA has a significant improvement, the values of the yield strength and ultimate tensile strength increase to ~639 MPa (~20.4%) and ~1016 MPa (~21.5%), respectively, while the ductility of the Al_{10}-HEA decreases to ~25.4%. The Al_{10}-HEA shows a further increase in strength and decrease in ductility, with the $\sigma_{0.2}$ of the Al_{10}-HEA reaching ~683 MPa (~8.6%), the σ_{UTS} of the Al_{10}-HEA reaching ~1053 MPa (~3.6%). Although the enhancement in strength of the Al_{10}-HEA is slight, the ductility critically deteriorates, the total elongation dramatically decreases to ~13.6% (46.5%). It can draw a conclusion that the strength of the studied alloy system improves with the increment of the Al content, while the ductility becomes worse.

4 Conclusion

With the increase of Al content, the microstructures of the studied alloys change. Both the size and volume fraction of the B2 phase show a significant increasing trend. Meanwhile, the mechanical properties of the studied alloys also change, the strength increases with the Al content, while the plasticity decrease. Therefore, it can be concluded that the Al element promotes the formation of the B2 phase, which improves the strength of alloys, but results in a loss of plasticity simultaneously.

Acknowledgments

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