Improvement in the Mechanical Properties of $AlNbTiVCrNi_{1.5}$ High Entropy Alloys Containing Alloyed C

Fangdong Xu, Dezhi Chen*, Ruirun Chen
National Key Laboratory for Precision Hot Processing of Metals, Harbin Institute of Technology, 150001, China
*Corresponding address: Heilongjiang Province, Harbin City, Nangang District, 92 West Dazhi Street
*Corresponding e-mail: chendezhi383@163.com

Abstract: Lightweight high entropy alloys with various Ni and C contents were prepared by vacuum arc melting. The cooperative effects of Ni and C additions on the phase formation, microstructure and mechanical properties. The results shows that The Ni1.5 (AlNbTiVCr) 98.5-xCx (at. %) high entropy alloys are composed of BCC matrix phase, TiC phase, C14 Laves phase, and a small amount of C15 Laves phase. The microstructure of alloys is a typical dendritic structure, with TiC distributed between the dendrites and needle like C14 Laves phase dispersed within the dendrites. The addition of C increases the mechanical properties of alloys first and then decreases. Ni1.5AlNbTiVCrC1 alloy shows the best mechanical properties, and its compressive strength and fracture strain are 1968.1 MPa and 13.7 %, respectively. The improvement in mechanical properties of lightweight high entropy alloys is attributed to solid solution strengthening and second phase strengthening.

Keywords: Lightweight high entropy alloys, Laves phase, Microstructure, Mechanical properties

1 Introduction

The lightweighting of materials is a research focus, as lightweight materials can reduce carbon emissions [1]. Traditional lightweight alloys have reached their development limit due to their poor room temperature strength, low melting point, and high cost. In high entropy alloys, multiple alloying elements tend to form solid solution structures rather than intermetallic compounds [2]. Therefore, the excellent performance of high entropy alloys has attracted a large number of researchers' favor. The emergence of the concept of high entropy alloys has brought new ideas to the design of lightweight alloys. Lightweight high entropy alloys have achieved rich research results in composition design [3]. For example, $AlNbTiVCrNi_{1.5}$ high entropy alloy has the low density and good strength [4]. In order to further improve its room temperature mechanical properties, the $Ni_{1.5}$ (AlNbTiVCr) $_{98.5\text{-}x}C_x$ alloys were designed and the phase formation, microstructure and mechanical properties were investigated.

Experimental procedure

Five lightweight high entropy alloys were prepared by vacuum arc melting. Each ingot is repeatedly melted 6 times to ensure the uniformity of chemical composition. Preparation of block shaped samples with dimensions of 8mm × 8mm × 8mm using wire cutting for subsequent phase identification and microstructure observation. Scanning electron microscope (SEM, TM4000) with the energy dispersive spectrometry (EDS). X-ray diffraction (XRD, Empyrean) was used to identify crystal structure. The compression samples dimensions are φ4 mm×6 mm. The compression test was conducted on an AGXplus test equipment with the compression rate of 0.5 mm/min.

2 Result and discussion

Fig. 1 shows the XRD results of Ni1.5 (AlNbTiVCr) $_{98.5\text{-}x}C_x$ alloys, where TiC diffraction peaks gradually appear after the addition of C element. Analysis shows that the phase structure after the simultaneous addition of Ni and C is B2, TiC, C14 Laves phase. The increase in C content leads to an increase in the diffraction intensity of the (110) main peak, while the diffraction intensity of TiC and C14 Laves phases decreases. The diffraction intensity of B2 phase gradually increases. Fig. 2 shows the microstructure of the alloy, from which three different contrasts can be observed. Based on the XRD results and previous work analysis, the gray matrix phase is B2 solid solution, the white phase is C14 Laves phase, and the black phase is TiC phase. The increase in C content leads to an increase in the area fraction of TiC. The white needle like C14 Laves phase and the black TiC phase are distributed between the dendrites. There is the most negative mixing enthalpy between C and Ti, which preferentially combines to form TiC.

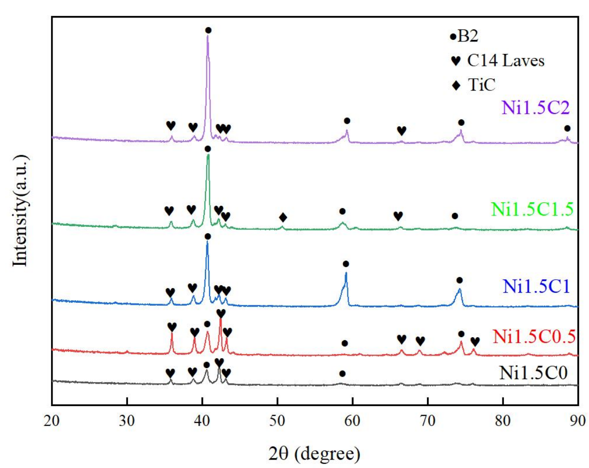

Fig. 1 XRD patterns of Ni1.5 (AlNbTiVCr) 98.5-xCx alloys.

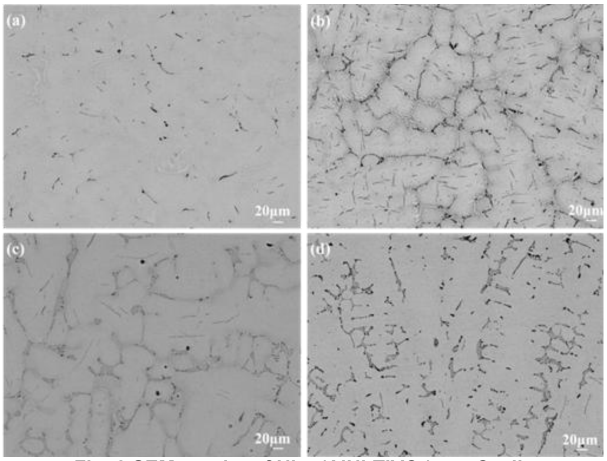

Fig. 2 SEM results of $Ni_{1.5}$ (AlNbTiVCr) $_{98.5-x}C_x$ alloys.

The distribution of phases is first controlled by melting point and composition, and then the distribution of white needle like C14 Laves phase and black TiC phase depends on grain boundary wetting. The distribution of phases during solidification and cooling mainly depends on grain boundary wetting. The maximum solid solubility of C in Ni is 2.7mol%, and the maximum solid solubility of Ti in Ni is 13.9mol%. Therefore, after the formation of Ni Ti and C-Ti metal compounds, the remaining C will exist in free form within the microstructure of the alloys.

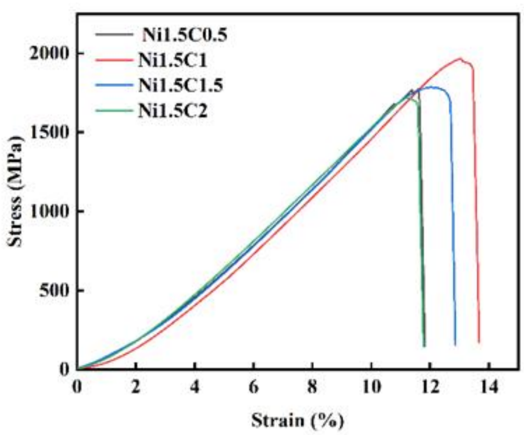

Fig. 3 Compressive stress–strain curve of Ni1.5(AlNbTiVCr)98.5-xCx HEAs.

As shown in Fig. 3, the compressive strength of the alloy gradually increases with the increase of C content. When the C content increases from 0.5 to 1, the compressive strength of the alloy increases from 1776.2 MPa to 1968.1 MPa, and the fracture strain increases from 11.8% to 13.7%. At this point, the mechanical properties of the alloy are optimal. The addition of C causes a slight decrease in the density of the alloy. The maximum density in this combination of gold is 5.75 g/cm^3, and the minimum density is 5.71 g/cm3. As the C content continues to increase, the compressive strength and fracture strain of the alloy decrease. The compressive strength decreases from 1787.3 MPa in Ni1.5C1.5 alloy to 1720.4 MPa in Ni1.5C2 alloy, and the fracture strain decreases from 12.9% in Ni1.5C1.5 alloy to 11.8%.

3 Conclusion

The $Ni_{1.5}$(AlNbTiVCr) $_{98.5-x}C_x$ high entropy alloys are composed of BCC matrix phase, TiC phase, and C14 Laves phase. The microstructure is a typical dendritic structure, with TiC distributed between the dendrites and needle like C14 Laves phase dispersed within the dendrites. The Ni1.5C1 alloy with the best mechanical properties in this combination of gold has a compressive strength of 1968.1 MPa and a fracture strain of 13.7%.

4 Acknowledgments

This work was supported by the National Key Laboratory for Precision Hot Processing of Metals, Harbin Institute of Technology (6142909230101), the Heilongjiang Postdoctoral Fund (LBH-Z23132) and the China Postdoctoral Science Foundation (2023TQ0099).

References

[1] Buluc, G, Florea, I. Investigation of FeNiCrWMn - a new high entropy alloy. 3rd International Conference on Modern Technologies in Industrial Engineering (ModTech), 2015:6.

[2] Hirotada Hashimoto. Synthesis of Li-Mg-Al-Ti based lightweight high entropy alloys by mechanical alloying and investigation of conditions for solid solution formation. Journal of Alloys and Metallurgical Systems, 4 (2023):100037.

[3] Abayomi Adewale Akinwande. Tribological performance of a novel 7068-aluminium/lightweight-high-entropy-alloy fabricated via powder metallurgy. Materials Chemistry and Physics, 15 (2023) 128207.

[4] Hirth J P and Loathe J. Theory of dislocations, 2nd ed. John Wiley & Sons, New York, 1982: 764.

[5] Fangdong Xu. Lightweight and high hardness $(AlNbTiVCr)_{100-x}Ni_x$ high entropy alloys reinforced by Laves phase. Vacuum, 213 (2023) 112115.