Effect of Cr Element on Microstructure and Mechanical Properties of $Ti_8Zr_6Nb_4V_5Cr_x$ Lightweight High Entropy Alloys

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Abstract: $Ti_8Zr_6Nb_4V_5Cr_x$ (x = 0, 1, 2, 3, 4 at.%) lightweight high entropy alloys with different additions of Cr were prepared and effects of Cr on phases, microstructure and mechanical properties were investigated. Results show that $Ti_8Zr_6Nb_4V_5$ lightweight high entropy alloy is composed of BCC phase and BCC2 phase, while $Ti_8Zr_6Nb_4V_5Cr_x$ alloys by addition of Cr are composed of BCC phase and C15 Laves phase. Dimensional size of BCC phase first increase and then decrease with increasing Cr content, while volume fraction of C15 Laves phase first decreases and then increases with increasing Cr content. It is noteworthy that dimensional size of BCC and C15 Laves phases are refined when the Cr content is 4 at.%. Moreover, density of $Ti_8Zr_6Nb_4V_5Cr_x$ alloys by adding varying Cr content increases slightly, and strength of the alloys increases significantly. Compressive strength of LW-Cr2 alloy with Cr content of 2 at.% reaches the highest of 2326.3 MPa. LW-Cr1 alloy shows excellent comprehensive mechanical properties with compressive strength of 1963.8 MPa and fracture strain of 23.51%. Addition of Cr is playing a significant role in enhancing the mechanical properties of $Ti_8Zr_6Nb_4V_5Cr_x$ lightweight high entropy alloys.
Keywords: lightweight high entropy alloys; phases; microstructure; refinement; mechanical properties

1 Introduction
High entropy alloys exhibit excellent properties for its distinctive structure, such as high strength [1], high hardness [2], thermal stability [3], oxidation resistance [4], etc. With the development of green economy, there is a great demand for lightweight materials in the fields of aviation, aerospace and transportation. Lightweight high-entropy alloys (LHEAs) have been given a special position. Researchers have gradually developed a strong interest in research of LHEAs. Generally, density of LHEAs is less than 7 g/cm^3, and such relatively low density provides important significance for research. Compared with traditional alloys, LHEAs possess excellent mechanical properties like higher specific strength/hardness, excellent corrosion resistance, higher temperature oxidation resistance, etc.

2 Experimental procedure
$Ti_8Zr_6Nb_4V_5Cr_x$ button type ingots were prepared by vacuum arc melting in high purity argon atmosphere. X-ray diffractometer (XRD) of type D8 ADVANCE was utilized to test phase composition and structure for LW-Crx alloys. Microstructure and morphology of LW-Crx alloy were characterized by scanning electron microscopy (SEM) with model Zeiss SUPRA55. Compression test of the specimens was conducted by MTS 370 universal mechanical property testing machine at room temperature. Three measurements were made to avoid accidental errors.

3 Result and discussion
Figure 1 shows X-ray diffraction analysis for $Ti_8Zr_6Nb_4V_5Cr_x$ LHEAs (x = 0, 1, 2, 3, 4 at.%). Results show that $Ti_8Zr_6Nb_4V_5$ (LW-Cr0) alloy is solid solution alloy consisting of two BCC phases, which are BCC+BCC2 dual-phase structure. Notably, BCC2 phase disappears in the alloy with addition of 1 at.% Cr, and new diffraction peaks appear at 2θ of 34.85° and 72.92°, which are characteristic diffraction peaks of C15 Laves phase. It indicates that addition of Cr changes phase composition of LW-Cr0 alloy and leads to phase transformation from BCC2 phase to C15 Laves phase. LW-Cr1, LW-Cr2, LW-Cr3 and LW-Cr4 Cr-containing alloys consist of the main BCC phase and C15 Laves phase.

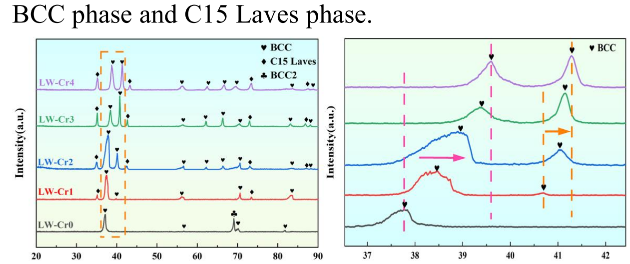

Fig. 1 X-ray diffraction analysis of Ti8Zr6Nb4V5Crx LHEAs
(a) XRD patterns; (b) Diffraction peaks of BCC phase

Figure 2 shows SEM-BSE images of $Ti_8Zr_6Nb_4V_5Cr_x$ LHEAs (x = 0, 1, 2, 3, 4 at.%). Results show that LW-Cr0 alloy is composed of two phases, and the two phases of LW-Cr0 alloy without addition of Cr are a bright phase enriched with both Ti and Nb (much lower than Ti) elements and dark phase enriched with Zr and depleted with V. Both the bright and dark phases are BCC structures (called BCC and BCC2, respectively), which is consistent with results of XRD analyses. Figures 2(b)-(e) show microstructures of Cr-containing alloys LW-Cr1, LW-Cr2, LW-Cr3 and LW-Cr4, respectively. It is obviously that the four alloys are composed of two phases, they are bright phase enriched with both Ti and Nb (much lower than Ti) elements and dark phase enriched with Zr, Cr, and V (Zr at.% > V at.% > Cr at.%) elements. The bright phase is the main phase with disordered BCC (same as LW-Cr0) structure and the dark phase is the ordered CrZrV-type C15 Laves phase. Addition of Cr into $Ti_8Zr_6Nb_4V_5$ LHEAs leads to phase transformation from BCC2 phase to C15 Laves phase, which is consistent with XRD analysis.

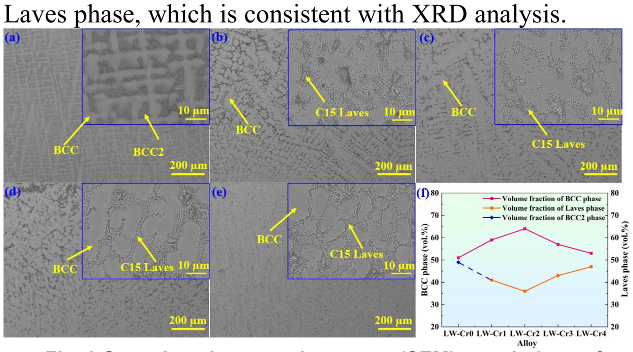

Fig. 2 Scanning electron microscopy (SEM) morphology of Ti8Zr6Nb4V5Crx LHEAs
(a) LW-Cr0; (b) LW-Cr1; (c) LW-Cr2; (d) LW-Cr3; (e) LW-Cr4; (f) Volume fraction of BCC phase and Laves phase

Compressive tests show that compressive strength and fracture strain of the alloys is significantly affected by Cr. Compressive strength of LW-Cr0, LW-Cr1 and LW-Cr2 alloys are 1743.4MPa, 1963.8MPa and 2326.3MPa, respectively. Fracture strain of alloys decreases and then increases with addition of Cr. LW-Cr1 alloy exhibits excellent overall properties with compressive strength of 1963.8MPa and fracture strain of 23.5%. Density of $Ti_8Zr_6Nb_4V_5Cr_x$ LHEAs is quite close to the theoretical results, and both of them decrease slightly with increase of Cr content. Actual density of LW-Cr0 alloy is 6.06 g/cm^3, and that of LW-Cr4 alloy is increased to 6.21 g/cm^3.

Table 1 Comprehensive properties and density of Ti8Zr6Nb4V5Crx LHEAs

LHEAs	Compressive strength (MPa)	Compressive strain (%)	Density (g/cm^3)
LW-Cr0	1743.4	29.6	6.06
LW-Cr1	1963.8	23.5	6.13
LW-Cr2	2326.3	14.8	6.15
LW-Cr3	1975.2	15.4	6.19
LW-Cr4	1787.3	16.2	6.21

.

Conclusion

(1) $Ti_8Zr_6Nb_4V_5$ (LW-Cr0) LHEA is composed of BCC and BCC2 with volume fraction of 51% and 49%, respectively. After addition of Cr, BCC2 is transformed into C15 Laves.
(2) Compressive strength and yield strength of LW-Cr*x* alloy first increase and then decrease with addition of Cr. Compressive strength and yield strength of the LW-Cr2 alloy reaches maximum of 2326.3 MPa and 2046.1 MPa, respectively.
(3) Fracture strain of LW-Cr*x* alloys decreases and then increases with addition of Cr. Ductility decrease of alloys is related to formation of brittle C15 Laves phase. Fracture strain of LW-Cr4 alloy is greatly increased to 16.2% for the grain refinement.

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