Microstructures and Mechanical Properties of a new high entropy alloy

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1. Introduction

As is known to all, conventional alloys have been designed to have one or two principal elements with only minor additions of other elements to modify their properties. Generally, adding small amounts of alloying elements is necessary to improve performance or to obtain some special properties [1, 2]. According to traditional experience, too many alloying elements will inevitably lead to the formation of brittle intermetallic compounds, which have greatly limited the development of traditional alloys. However, the appearance of a new class of alloys since 1995, this traditional concept was broken. These alloys have been named as high entropy alloys because the atomic scale mixing entropies are higher than traditional alloys. High entropy alloys generally contain five to thirteen principle elements with each concentration between 5 and 35 at.% [3-5]. Up until now, it has been demonstrated that this explored alloys are feasible to be synthesized, processed and analyzed contrary to the misunderstanding based on traditional experiences. High entropy alloys tend to predominantly consist of simple solid solutions (face-centered cube-FCC, body-centered cube-BCC or mixed) due to high configurational entropy of mixing. Moreover, there are many opportunities in this field for academic studies and industrial applications [6, 7]. Recent developments in the field of high entropy alloys have revealed that they have versatile properties like: ductility, toughness, hardness and corrosion resistance [8-13].

The aim of this paper is to study the microstructures and mechanical properties of a new high entropy alloy, FeCrNiMnAl system. In this high entropy alloy, the cost of alloy elements is lower than that of high entropy alloys studied today. Microstructural analysis and mechanical properties of the FeCrNiMnAl alloy were performed using the as-cast alloy samples.
2. Experimental Procedure

High-purity (at least 99.9%) powders of the constitutive elements were used as the starting materials, which were melted and processed in an electromagnetic suspension furnace. The melting process was developed in the water-cooled copper shell, sample cooling rate being almost instantaneous. The produced ingot’s shape was cylinder with a diameter of 150 mm and height 50 mm. The chemical composition of the FeCrNiMnAl high entropy alloy is presented in Table 1 and reveals the equiatomic percentage for this composition.

| Element | Fe | Cr | Ni | Mn | Al |
|---------|----|----|----|----|----|
| Wt%     | 26 | 21 | 24 | 18 | 11 |
| At%     | 20 | 20 | 20 | 20 | 20 |

The specimens for microstructural characterization and mechanical testing were cut from the produced ingot using an electric discharge machine. Microstructures of samples were examined by optical microscopy (OM, Axiover 200MAT, Zeiss) and X-ray diffractometer (XRD, D/max-2500/PC, Rigaku). The samples for OM and XRD were mechanically ground, polished and etched using 10% nital. The Vicker’s hardness was measured using a 5 kg load.

3. Results and Discussion

The microstructures of the as-cast alloy sample in low and high magnifications under the optical microscope are shown in Fig. 1(a-c). It can be seen from the figures that the microstructure of the as-cast FeCrNiMnAl high entropy alloy sample is composed of the main phase which is a solid solution with a dendritic structure evenly distributed in the high entropy alloy as can be observed in Fig. 1a.

![Fig. 1 OM images of the as-cast FeCrNiMnAl high entropy alloy sample at the magnifications of (a) 100×, (b) 200× and (c) 500×.](image-url)
Fig. 2 shows the X-ray diffraction pattern of the as-cast alloy sample. The diffraction peaks can be assigned to (110), (200), (211), (220) diffractions, respectively, which represents the typical character of a crystalline body-centered cubic (BCC) phase. Obviously, there is no other distinct diffraction peaks in the as-cast high entropy alloy except BCC peaks.

Hardness is the property of a material that shows the ability to oppose to an action of permanent shape change when a compressive force is applied. The hardness values for a high entropy alloy are a good indicator of an improvement in mechanical properties. The hardness value for the as-cast FeCrNiMnAl high entropy alloy was determined after a series of 20 measurements along the diameter of the sample and the mean value was calculated. There was no large variation in the hardness values measured along the lines. The hardness mean value for the sample was 422 HV5.

4. Conclusion
The high entropy alloy FeCrNiMnAl is a new alloy which was successfully obtained and characterized. Analyzing the as-cast FeCrNiMnAl high-entropy alloy with optical microscopy it is observed that this alloy forms a dendritic structure. The as-cast FeCrNiMnAl high-entropy alloy is single BCC structures. Results for hardness test show that medium value for high entropy alloy FeCrNiMnAl is 422 HV5.

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