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Effect of aging treatment on microstructure and mechanical properties of $Al_{0.5}CoCrFeNi\ B_{0.2}$ high entropy alloy

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ABSTRACT

$Al_{0.5}CoCrFeNiB_{0.2}$ high-entropy alloy was prepared by vacuum arc melting. The as-cast alloy was heat treated for 10 h at 1000!to investigate the effects of aging on the microstructure and tensile properties. The as-cast and aged alloy exhibit simple FCC and bcc solid solution phases. The as-cast alloy consists of dendrite and interdendrite, where granular-liked and stringer-shaped phases appear. After the aging treatment, needle-liked phase precipitated in dendrite, which grown with stringer-shaped dissolution. The aging treatment can improve the tensile property of the alloy obviously.

KEYWORDS

High-entropy alloy;
Aging treatment;
$Al_{0.5}CoCrFeNiB_{0.2}$ alloy;
Mechanical property.

INTRODUCTION

Traditionally, alloys have been designed to have one or two element as their main component for primary properties and with other minor elements incorporated for deûnite microstructure and properties, such as in the cases of ferrous, aluminum, titanium, and magnesium alloys. Recently this paradigm has been broken by high entropy alloy developed by Yeh et al[1,2]. High entropy alloy are defined as alloys with n ($5 \leq n \leq 13$) principal elements each having an atomic percentage between 5 and 35 at. pct[2]. Some studies[3-5] found that high entropy alloy may possess simple solid solution structure and excellent properties.

Now most of high entropy alloys were consisted of metallic elements. In order to improve the mechanical properties of the alloys, some non-metallic elements may incorporate in high entropy alloy[6-8]. For example, Hsu[8] studied the effect of boron addition on the wear resistance and high-temperature compression strength of CuCoNiCrAl0.5Fe Alloy. Their results show that the wear resistance and high-temperature compression strength were significantly enhanced by the formation of boride in the alloys. But the alloys with boride were less tough. Our previous work on the effect of boron addition on the tensile mechanical properties of $Al_{0.5}FeCoNiCr$ alloy also show that boron addition increased tensile strength, but decreased ductility obviously[9]. In the traditional alloys, the microstructure and mechanical properties of a cast ingot are well known to be markedly affected by homogenization, hot working and cold working. Therefore heat treatment may be used to improve the mechanical properties of high entropy alloys similarly. Therefore, the purpose of this study is to investigate the effect of aging treatment on microstructure and mechanical properties of $Al_{0.5}CoCrFeNi\ B_{0.2}$ alloys.

EXPERIMENTAL PROCEDURES

Alloy ingots with nominal composition of $Al_{0.5}CoCrFeNi\ B_{0.2}$ high entropy alloy were prepared by vacuum arc melt casting in high-purity argon atmosphere with a water-cooled copper crucible. Elemental metal with purity higher than 99 wt% were used as raw materials. The chemical homogeneity was realized by repeated melting at least four times. Samples cut from the ingot were aged at 1000! for 10h, and then quenched in water. Microstructure analyses, phase identification, and mechanical measurements were then carried out on the as-cast and aged specimens. The crystal structure was identified by X-ray diffractometer (XRD, D/max Ultima III) with Cu Ka radiation scanning from 40° to 100° in 2θ at a scanning rate of 4°/min. The microstructure and chemical composition were examined using optical microscope (OM, XJZ-6A) and scanning electron microscopy (ESEM, Philips-FEI XL30) equipped with an energy dispersive spectrometer (EDS). Room temperature tensile properties were tested on a CMT-6104 testing machine with strain speed of $4\times10^{-4}s^{-1}$ and the fracture morphology was observed by scanning electron microscopy (SEM, JEOL-JSM 6380LV).

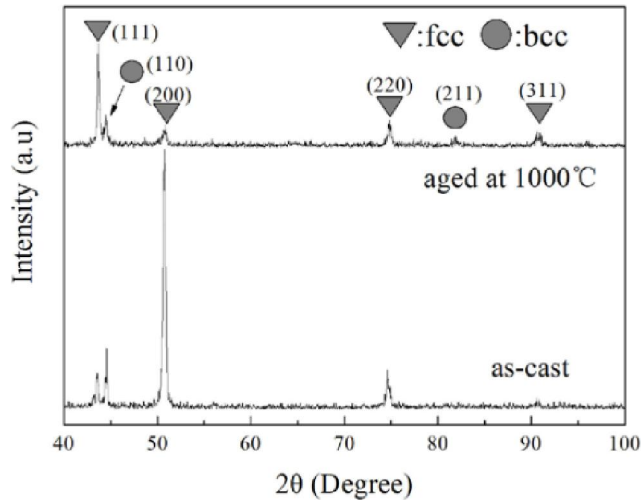

Figure 1 : XRD patterns of the as-cast and aged $Al_{0.5}CoCrFeNi\ B_{0.2}$ alloys

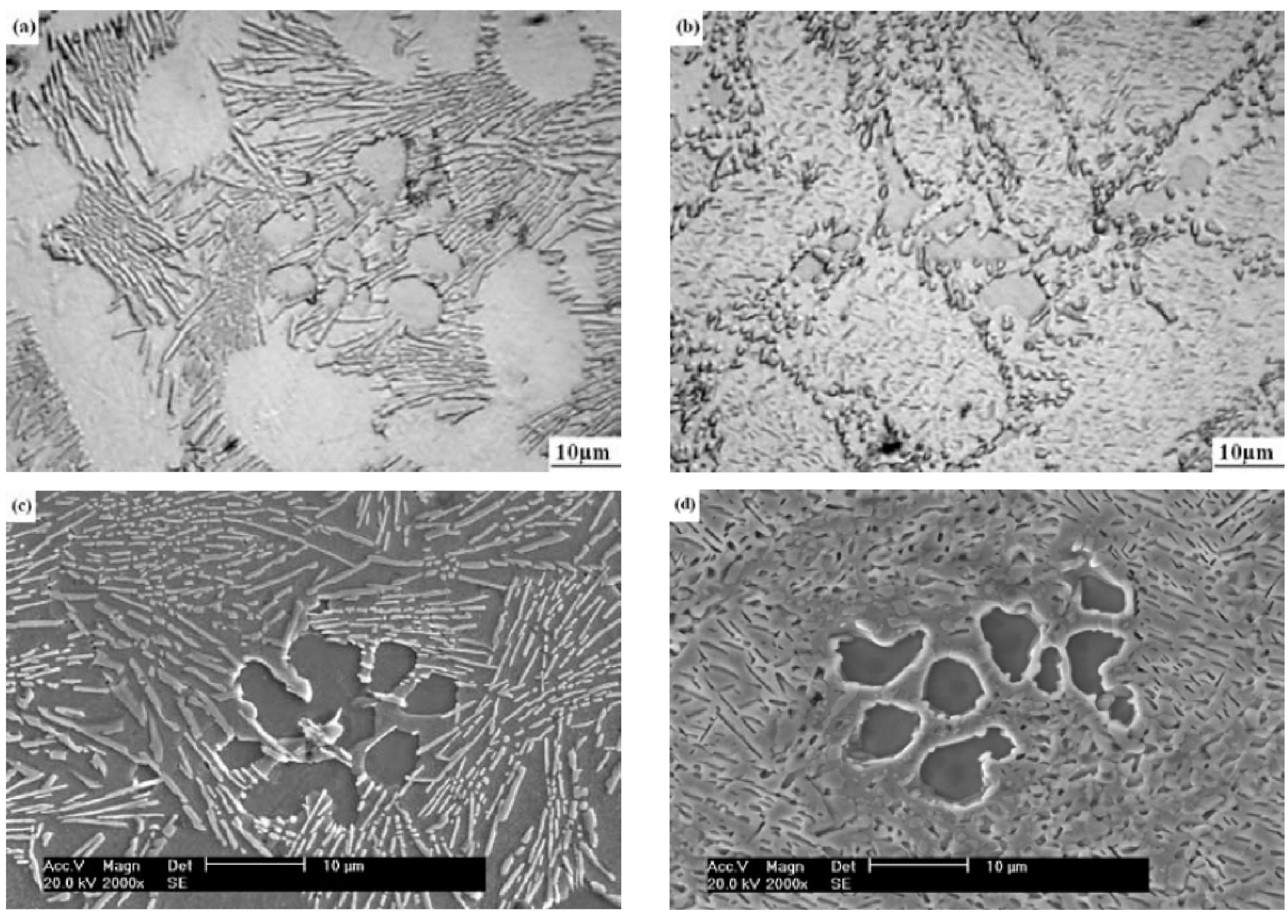

Figure 2 : Microstructures of the as-cast and aged $Al_{0.5}B_{0.2}CoCrFeNi$ alloys: (a) as-cast (OM), (b) aged at 1000 °C (OM),

TABLE 1 : Chemical compositions of the as-cast and aged $Al_{0.5}CoCrFeNi\,B_{0.2}$ alloys

Alloy	Position	Al	Co	Cr	Fe	Ni	B
	Nominal	10.64	21.28	21.28	21.28	21.28	4.26
as-cast	Dendrite	10.71	22.88	19.54	21.92	21.57	3.38
	Stringer-shaped	2.17	10.68	59.01	16.35	5.36	6.43
	Granular-liked	26.4	18.26	8.24	14.46	28.72	3.92
aged at 1000°C	Dendrite	7.64	24.65	19.34	24.88	21.05	2.44
	Needle-liked	8.75	24.53	18.64	25.61	21.23	1.24
	Granular-liked	30.68	16.6	5.48	12.07	33.87	1.3

RESULTS AND DISCUSSION

Figure 1 shows the XRD patterns of the as-cast and aged $Al_{0.5}CoCrFeNi\,B_{0.2}$ high entropy alloys. As can be seen in Figure 1, the as-cast alloy exhibits simple face-centered cubic (fcc) and body-centered cubic (bcc) solid solution phases, and the number of phases is not affected by aging treatment.

Figure 2 shows microstructures of the as-cast and aged $Al_{0.5}B_{0.2}CoCrFeNi$ alloys. Typical dendrite and interdendrite structures are observed in the as-cast alloy. Granular-liked and stringer-shaped phases can be seen in the interdendrite. However, the microstructure morphology varies obviously for the alloy aged at 1000°C for 10h. After aging treatment, stringer-shaped phase mainly dissolved. And the dendrite grown, which further precipitates fine needle-liked phase.

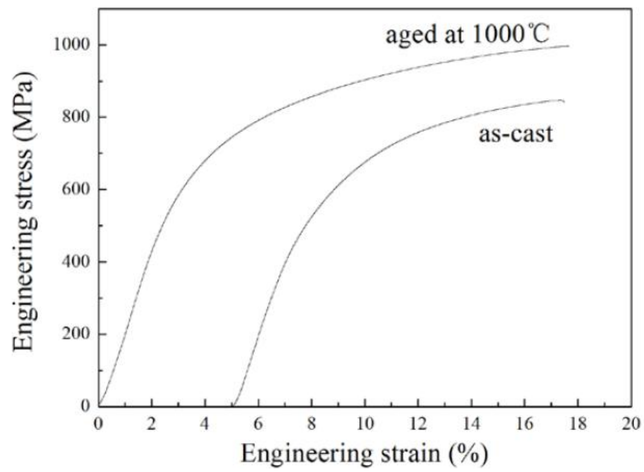

Figure 3 : Room-temperature tensile curves of the as-cast and aged $Al_{0.5}CoCrFeNi\,B_{0.2}$ alloys

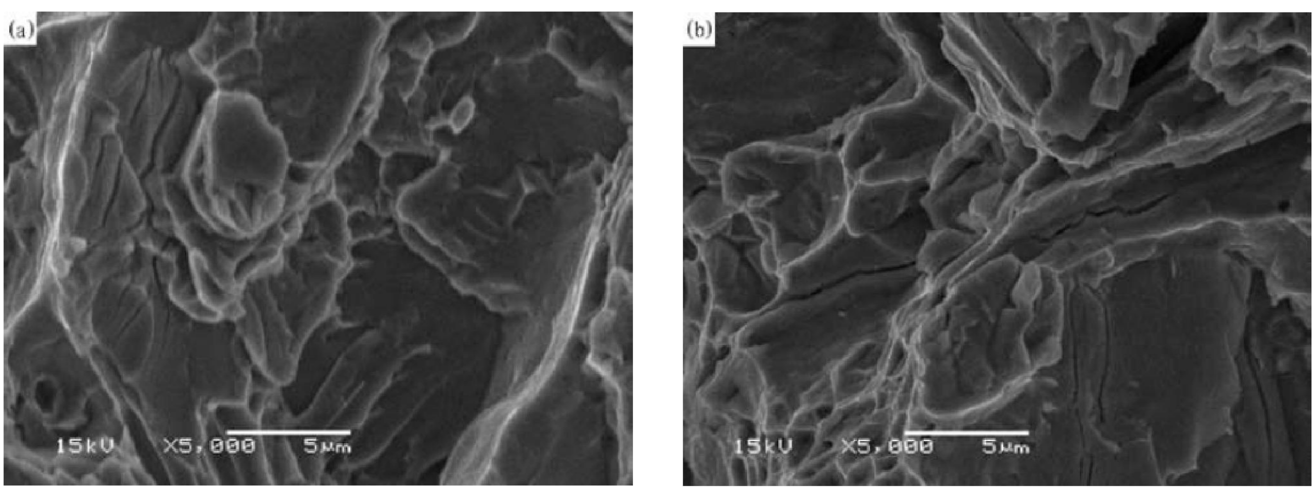

Figure 4 : SEM of tensile fracture surface of the as-cast and aged $Al_{0.5}CoCrFeNiB_{0.2}$ alloys: (a) as-cast, (b) aged at 1000°C

In order to verify the compositions of all the phases in the as-cast and aged alloy, EDS was used and the results are shown in TABLE 1. According to TABLE 1, Granular-liked phase is rich in Al and Ni, while stringer-shaped phase is rich in Cr and B. This is reasonable, because the mixing enthalpy of Al-Ni and Cr-B are much negative[7,10]. From the thermodynamic equilibrium equation, $\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix}$, a phase with large negative mixing enthalpy has a low Gibbs free energy. From the above discussion and in previous report[11], one can draw a conclusion that the dendrite is fcc solution phase.

Figure 3 shows the room-temperature tensile curves of the as-cast and aged $Al_{0.5}CoCrFeNiB_{0.2}$ alloys. For the alloy aged at 1000! for 10 hours, the room-temperature tensile strength increases from 847.04Mpa of the as-cast to 996.45MPa. Meanwhile, the elongation at break increases from 8.13% of the as-cast to 11.2%. The needle-liked precipitate must play a positive role in affecting the strength after aging treatment. And plastic strain improvement may be attributed to the increased volume fraction of ductile dendrite. The fracture surfaces are shown in Figure 4. It shows the fracture mainly consists of cleavage facets for the as-cast and aged $Al_{0.5}B_{0.2}CoCrFeNi$ alloy.

CONCLUSIONS

The as-cast $Al_{0.5}CoCrFeNi\ B_{0.2}$ alloy was found to exhibit simple fcc and bcc solid solution phases, as well as the alloy aged at 1000!. And as-cast alloy consists of dendrite and interdendrite, where granular-liked and stringer-shaped phases appear. However, after the aging treatment, needle-liked phase precipitates in dendrite, which grows with stringer-shaped dissolution. Furthermore, the room-temperature tensile strength of the alloy aged at 1000! for 10 hours increases from 847.04Mpa of the as-cast to 996.45MPa. Meanwhile, the elongation at break increases from 8.13% of the as-cast to 11.2%.

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