



Effects of cobalt content on the microstructures of Fe–9Al–30Mn–1C–xCo alloys

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ABSTRACT

The microstructure of the as-cast Fe–Al–Mn–C–Co alloy was a mixture of the ($\alpha + \text{DO}_3 + \gamma + \kappa$) phases. However, the microstructure of the alloy with 9.0 wt.% Co content was nearly a single γ phase. As the alloys underwent heat treatment between 1000 °C and 1100 °C, their microstructure changed to the ($\gamma + \kappa$) phase. The κ phase carbides ((Fe,Mn)₃AlC_x) had an ordered L'1₂-type structure with lattice parameter $a = 0.385$ nm and were formed by a spinodal decomposition during quenching. The alloy with Co content ≥ 5.0 wt.% was aged at 650–950 °C, $a(\gamma + \kappa) \rightarrow (\gamma + \kappa + \text{Co}_{23}\text{C}_6) \rightarrow (\gamma + \text{Co}_{23}\text{C}_6)$ phase transition was observed in the matrix and on the grain boundaries. It is believed that the addition of Co not only stabilizes the austenitic structure at high temperatures but also inhibits and/or prolongs the precipitation of the κ phase during the aging process.

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1. Introduction

Fe–Al–Mn–C alloys are extensively investigated by many researchers because of their superior features, such as low density, high strength and high ductility, and well biocompatibility [1–4]. Hence, they are considered to be less expensive substitutes for some used in biomedical Fe–Cr–Ni stainless steels. The typical chemical compositions of Fe–Al–Mn–C alloys are in the range of Fe–(4.9–11.0)Al–(23.7–35.0)Mn–(0.5–1.5)C (wt.%) [5–9]. Moreover, it was found that the Fe–Al–Mn–C alloys exhibit a well oxidation resistance at high temperatures due to Al contain between 8.5 wt.% and 10.5 wt.%, results in the formation of a protective Al₂O₃ layer on the Fe–Al–Mn–C alloys surface continuously [10,1]. But, the corrosion resistance of the Fe–Al–Mn–C alloys was

inferior to that of the conventional stainless steels. Su et al. [11] indicated that both the corrosion and oxidation resistances of the Fe–Al–Mn–C alloy treated by hot-dip aluminization can be significantly increased.

Furthermore, the addition of alloying elements to Fe–Al–Mn–C alloys not only increases the anti-high-temperature corrosion behavior and oxidation resistance but also enhances the mechanical properties. For example, the addition of Si into the Fe–Al–Mn–C alloy would enhance their oxidation resistance by forming a protective passive film of SiO₂ [4,12]. Si would also increase the mechanical properties of the alloy at high temperatures [13]. The Ni addition to Fe–Al–Mn or Fe–Al–Mn–C alloy can promote mechanical strength at room temperatures [14]. Baker et al. [15] also demonstrated that the strengths of the spinodally formed Fe–Ni–Mn–Al alloys are comparable to the strongest maraged aircraft steels and hardest bearing steels, but they possess a better strength-to-weight ratio. The addition of Cr was found to be the most effective in improving the resistance to high-temperature oxidation and environmental embrittlement. Additionally, we found that the addition of Cr has a great influence on the phase transformation and liquidus temperatures of the Fe–Al–Mn–C alloy [16,17]. Other researchers have not previously observed these features in the Fe–Al–Mn–C–Cr alloy system. However, there is a lack of

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Table 1
Chemical compositions of the investigated alloys.

Alloy	Chemical composition (wt.%)				
	Fe	Al	Mn	C	Co
A	Bal.	8.48	29.91	1.01	1.09
B	Bal.	8.74	29.69	0.96	3.15
C	Bal.	8.43	30.20	0.98	5.13
D	Bal.	8.49	30.14	0.91	7.05
E	Bal.	8.65	30.12	0.96	9.12

information about the influence of Co on the microstructure and mechanical properties of the Fe–Al–Mn–C alloy. Co is an important alloying element used in many alloys such as corrosion resistant alloys, Fe–Mn alloys, and high Cr ferritic steels to improve their physical, chemical, and mechanical properties [18,19]. Therefore, the purpose of the present study is to investigate the effects of the Co content on the microstructures of Fe–9Al–30Mn–1C–xCo (wt.%) alloys, and consequently, obtain valuable information for industrial and biomedical applications.

2. Experimental procedures

Fe–9Al–30Mn–1C samples containing 1.0 wt.%, 3.0 wt.%, 5.0 wt.%, 7.0 wt.%, and 9.0 wt.% Co were prepared in an air induction furnace with a protective N₂ atmosphere using AISI 1008 low carbon steel, 99.7% pure electrolytic Al, 99.9% pure electrolytic Mn, pure C powder, and pure Co. The alloy was poured into an investment casting mould (ϕ 40 mm \times 100 mm) preheated at 1150 °C. The chemical compositions of the investigated alloys were determined by inductively coupled plasma-atomic emission spectrometry, and the results are presented in Table 1. After homogenization at 1200 °C for 4 h in a protective argon atmosphere, the ingots were hot-forged to a final thickness of 3.0 mm. The as-forged specimens were subsequently heat-treated at temperatures ranging from 450 °C to 1100 °C for various

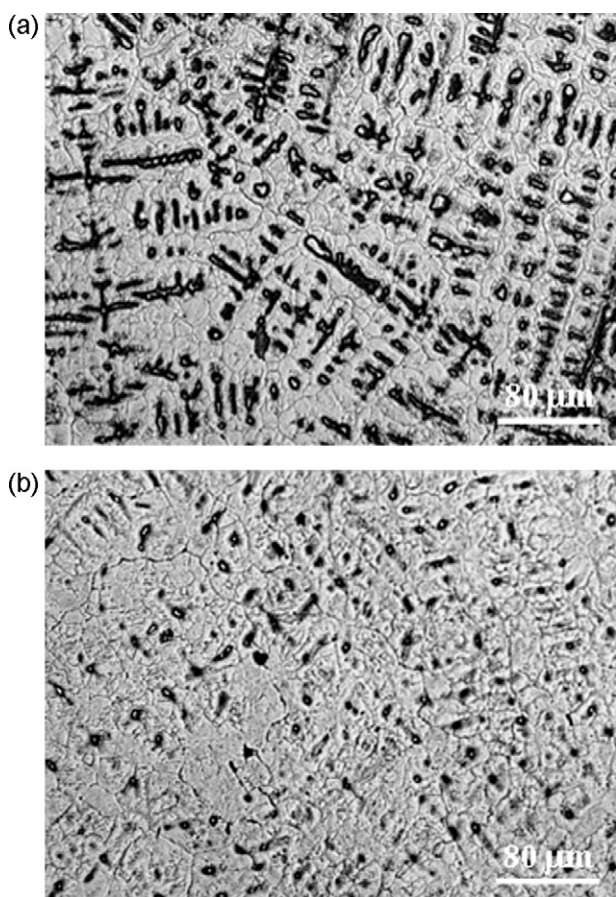


Fig. 1. (a) and (b) are optical micrographs of the as-cast alloy A and alloy C, respectively.

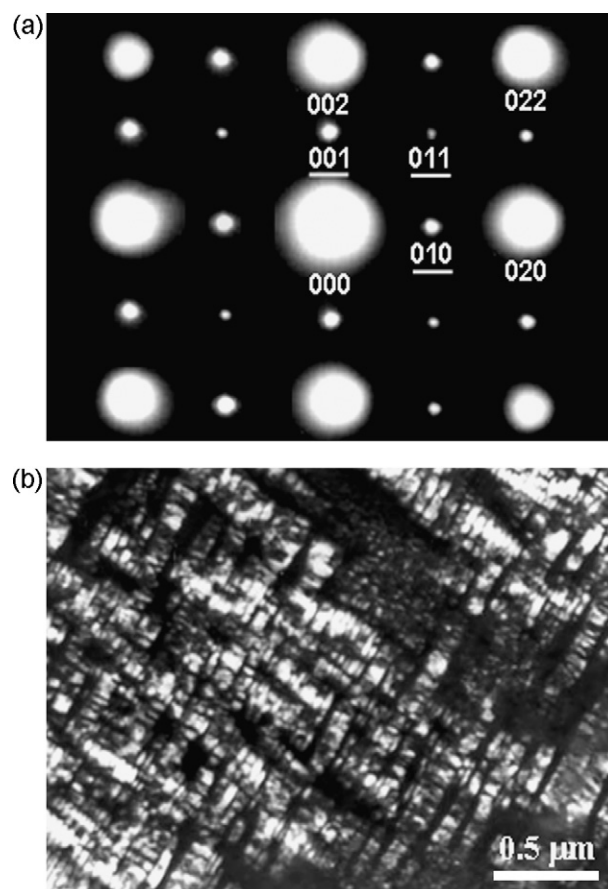


Fig. 2. TEM images taken from the matrix of the as-cast alloy A, shown in Fig. 1(a): (a) [100] SADP taken from the matrix ($hkl = \gamma$ phase, $hkl = \kappa$ carbide), (b) $\bar{g} = 110$ κ phase DF image.

periods in a vacuum furnace. The specimens were then rapidly quenched at room temperature. The specimens for optical microscopy (OM, Olympus BX-51) were abraded with SiC paper, polished with 1- μ m Al₂O₃ powder, washed with distilled water, ultrasonically degreased with acetone, and etched with 5–10% nital solution. The percentage volume of each phase was measured using an image analyzer (Buehler OmniMet); the average of ten tests was considered. The phase transformation of the specimens after the above-mentioned treatments was investigated by means of a transmission electron microscopy (TEM, JEOL-2100) at 200 kV. Elemental distributions were examined using an energy-dispersive X-ray spectrometer (EDS). The average atomic percentages of alloying elements examined by analyzing at least ten different EDS spectra of each phase. Samples for TEM were prepared by mechanical grinding the treated specimens to a thickness of 30 μ m and electropolishing them with an electrolyte containing 60% ethanol, 30% acetic acid, and 10% perchloric acid, at a current density of 1.5–2.5 $\times 10^4$ A/m² at less than –10 °C.

3. Results and discussion

Fig. 1(a) presents an optical micrograph of the as-cast alloy A. Macroscopically, the microstructure of the as-cast alloy A was dendritic. However, it was apparent that the as-cast alloy A contained a small percentage of the island-like phase (black region) in the matrix. This microstructural characteristic was similar to that of the as-cast Fe–Al–Mn–C alloy [2]. Fig. 1(b) is an optical micrograph of the as-cast alloy C, which reveals that the island-like phase could also be found in the matrix. However, we observed that the average volume percentage (AVP) of the island-like phase decreased with an increase in the Co content. The AVP of the island-like phase in the alloys A, B, C, D, and E was 7.25%, 6.62%, 3.24%, 1.21%, and 0.74%, respectively. The microstructure of the alloy with 9.0 wt.% Co content was nearly a single austenite (γ) phase. Fig. 2(a) is a zone axis [100] selected area diffraction pattern (SADP) taken from the matrix of the as-cast alloy A, shown in Fig. 1(a); this indicates

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