Microstructures of W-Mo-Ni-Fe Heavy Alloys

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Abstract

Tungsten heavy alloys with different ratios of Mo and Ni-Fe matrix were liquid-phase-sintered to investigate their microstructural evolution. Results indicated that increased Mo in the alloy promoted the formation of a (W,Mo)(Ni,Fe) type intermetallic compound in the furnace-cooled condition. It was a monoeutectic reaction when the added Mo content was higher than 49at.%, or a eutectic reaction when this value was between 37at.% to 49at.%. When Mo was added between 25at.% to 37at.%, the precipitation of the intermetallic compound took place by either a eutectoid or peritectoid reaction.

Keywords: W-Mo-Ni-Fe, heavy alloy, microstructure, intermetallic

1. Introduction

The various superior properties of tungsten heavy alloys make them widely used in various fields [1]. Addition of Mo to W-Ni-Fe alloys was first reported by Bose and German [2].

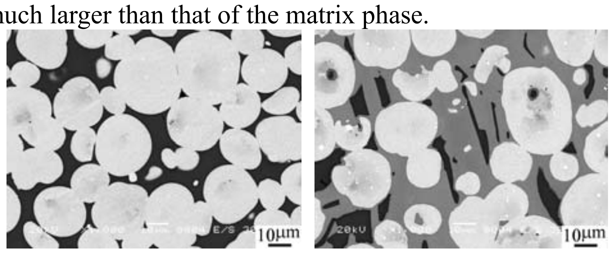
They believed addition of Mo reduced the concentration of W in the liquid matrix phase during sintering, and, conse quently, refined microstructure.

Subsequently, the effect of Mo addition on the mechanical properties [3], and the microstructural evolution of the alloys were reported [4]. These prior reports indicated the addition of high concentrations Mo led the brittleness of the alloys. The precipitated phase was found to be an intermetallic compound, (W,Mo)(Ni,Fe), having crystal structure the same as that of MoNi (orthorhombic) [5]. However, the precipitation mechanism of the intermetallic compound may vary with the variation in the added percentage of Mo in the alloys and the cooling rate.

2. Experimental and Results

W-Ni-Fe alloys with different percentages of Mo addit ion (15at.% to 59at.%) were investigated in this study. The specimens were then sintered in a tube furnace using a thermal profile that combined the functions of dewaxing, oxide reduction, decarburization, and densification. S canning electron microscope (SEM, JEOL JXA-8900R), x -ray diffraction (XRD, REGAKU, DMAX-VB), and d ifferential thermal analysis (DTA, LABSYS, TG-DTA/DSC, SETARAM) was carried out for five alloys. The transmission electron microscope (AEM, JEOL-2010), with an energy d ispersive x-ray spectrometer (EDS, OXFORD, ISIS-300) attachment, was operated at an accelerating voltage of 200kV.

Fig 1 show the BEI images of the furnace-cooled alloys. It can be observed that the relative abundance of the intermetallic compound increases with increase in the Mo concentration. With further increase of Mo concentration, the relative abundance of the intermetallic compound was much larger than that of the matrix phase.



(a) (b)

Fig. 1. BEI images of alloys sintered at 1500 °C for 240 min utes and fournace-cooled. (a) W-15Mo-18Ni-8Fe, (b) W-4 9Mo-18Ni-8Fe.

X-ray diffraction pattern of the Alloy 3 (W-37Mo-18Ni-8Fe) showthat some of the diffraction peaks of intermetallic phase, shifted slightly from the peak values of the MoNi phase (a = 0.9179 nm, b = 0.9142 nm, c = 0.8828 nm, orthorhombic, JCPDS 47-1129). A least square regression of the four equations yielded the lattice constants of a = 0.928 nm, b = 0.913 nm and c = 0.852 nm, which really showed an MoNi based intermetallic phase.

DTA tests revealthere was only one endothermic peak (1415°C) in the DTA heating pattern of Alloy 1, which was associated with the melting of the matrix phase. Two endothermic peaks were observed in Alloy 2. The endothermic peak of lower temperature (1350°C) was very close to the phase transformation temperature of MoNi (1362°C). The endothermic peak of higher temperature (1382°C) was similar to that for Alloy 1, being associated with the melting of the matrix phase.

Figure 2 shows that the melting temperature of the matrix phase is lower than the phase transformation temperature of the intermetallic compound ($T_m < T_{int}$) when the Mo content was higher than 49at.%. This fact means that, during cooling, the phase transformation of the intermetallic compound takes place by a monotectic reaction. When the Mo content was between 37at.% to 49at.%, the melting temperature of the matrix phase and the phase transformation temperature of the intermetallic compound are almost the same ($T_m = T_{int}$). Accordingly, the formation of the intermetallic compound takes place by a eutectic reaction. When the Mo content was between 25at.% to 37at.%, the melting temperature of the matrix phase is higher than the phase transformation of the intermetallic compound ($T_m > T_{int}$), the intermetallic compound forms subsequent to the solidification of the matrix phase during cooling. The formation of the intermetallic compound can take place by a eutectoid reaction or a peritectoid reaction. Finally, No intermetallic compound was found for the Mo adding level being lower than 15at.%.

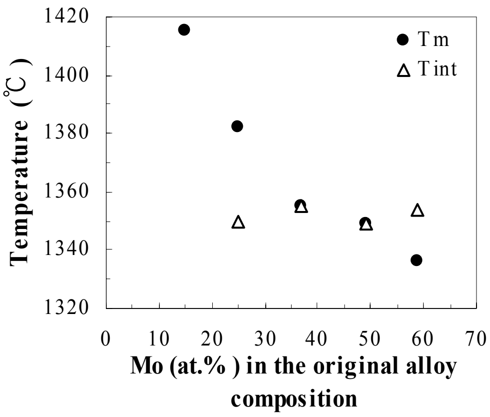
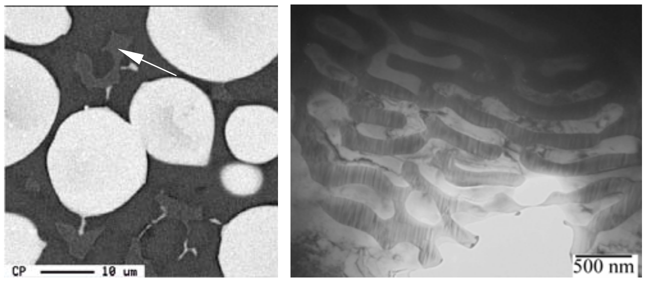


Fig. 2. Variation of the phase transformation temperatures of the matrix phase (T_m); and the intermetallic compound (T_{int}) with Mo addition in the original alloy composition.

Fig. 3(a) shows the BEI photograph of the water-quenched specimen of W-27Mo-35Ni-18Fe alloy. Obviousl y, quenching retarded the precipitation of the intermetallic phase around W-Mo grains. However, the gray domain indicated by the arrow shows the different composition from the matrix and intermetallic phase. When examined under TEM (Figure 3(b)), the gray domain was shown to be constituted by a Ni-based matrix phase and the intermetallic phase. These two phases feature a lamellar structure, with an interlayer spacing of about 350nm. The lamellar structure was very tiny and uniformly dispersed in the matrix, which could be a reinforcing phase for the matrix phase.



(a) (b)

Fig. 3. BEI images of the W-27Mo-35Ni-18Fe alloy; (a) water-quenched specimen, (b) TEM bright field image of the domain indicated by arrow in (a).

3. Summary

It can be observed in the W-Mo-Ni-Fe alloy that the relative abundance of the intermetallic phase increases with increase in the Mo concentration. The diffraction peaks of the intermetallic phase (W,Mo)(Ni,Fe) shows an MoNi based structure. According to the amount of Mo addition, the precipitate mechanism of the furnace-cooled W-Mo-Ni-Fe alloy could be monoeutectic reaction, eutectic reaction, eutectoid, peritectoid or eutectic. No intermetallic compound was found for a Mo addition level lower than 15at.%. Quenching retarded the precipitation of the intermetallic phase around W-Mo grains, yet promoted the formation of lamellar intermetallic phase dispersed in the matrix, which can possibly improve the mechanical properties of tungsten heavy alloys.

4. References

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