doi: 10.1017/S1431927609094070
Microsc Microanal 15(Suppl 2), 2009

Microstructure and Mechanical Behavior in Spinodal $Fe_{35}Ni_{15}Mn_{25}Al_{25}$ Alloy

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In order to understand the microstructure and mechanical behavior of a range of recently-discovered, very high strength FeNiMnAl spinodal alloys, ingots of $Fe_{35}Ni_{15}Mn_{25}Al_{25}$ were prepared by arc melt and drop cast separately. Then the drop-cast ingots were directionally solidified at a rate of 18 mm h^{-1} in a modified Bridgman furnace under Ar at 1873 K.

Previous studies using transmission electron microscope (TEM) found that these spinodal alloys' microstructure consisted of alternating coherent body center cubic (b.c.c.) and B2 (ordered b.c.c.) phases aligned along <100> directions.[1] The microstructures of three different states (as processed, 30min annealed, 2hrs annealed) of directionally solidified (DS) $Fe_{35}Ni_{15}Mn_{25}Al_{25}$ were characterized by using the high angle annular dark field (HAADF) scanning transmission electron microscope (STEM) viewed along <001>. The annealing temperature is 873 K. As showed in Figure 1, Mn-rich precipitates began to form and grow larger as annealing time went on. The SEM image in Figure 2 showed the spinodal structure clearly as well.

An Imago Inc. LEAP was used to determine the composition profile and overall phases' chemistry. In the LEAP, individual atoms were stripped and identified layer by layer by a high electric field from a sharp-needle like specimen sitting in a high vacuum. The composition distribution in Figure 3 showed that one phase (b.c.c.) was rich in Fe and Mn while the other (B2) was rich in Ni and Al. This result agreed with previous study of energy dispersive spectroscopy (EDS). A 3-D iso-concentration atom map was built in Figure 4 using the LEAP data.

Hardness measurements were performed on the specimens with different initial conditions as a function of annealing time at 823 K in Figure 5. The directionally solidified specimen showed a steady increase in hardness from 462 HV with annealing time. Hardness of the drop cast specimen experienced a drop from 530 HV for un-annealed to 472 HV for 30min annealed then increased steadily but after 120hrs annealing dropped back to 502 HV. The arc melt specimen was initially harder at 538 HV and behaved more complex. After 72hrs annealing, the appearance of the large Mn-rich precipitates caused the increase of the hardness.

Reference

[1] J.A. Hanna et al., J. Materials Research, 20 (2005) 791-795.

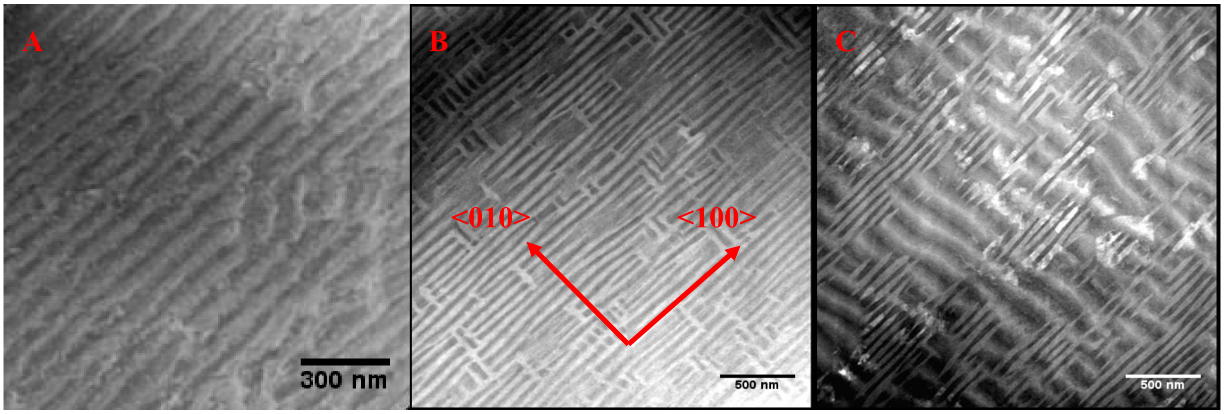

Fig.1. HAADF STEM images showed the spinodal structure of $Fe_{35}Ni_{15}Mn_{25}Al_{25}$ in three states. A. As directionally solidified. B. 30 min annealed at 873 K. C. 2hrs annealed at 873 K.

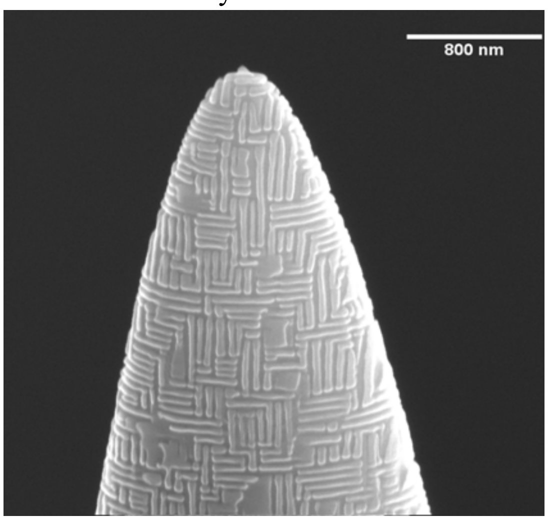

Fig.2. SEM image of drop cast $Fe_{35}Ni_{15}Mn_{25}Al_{25}$ LEAP tip.

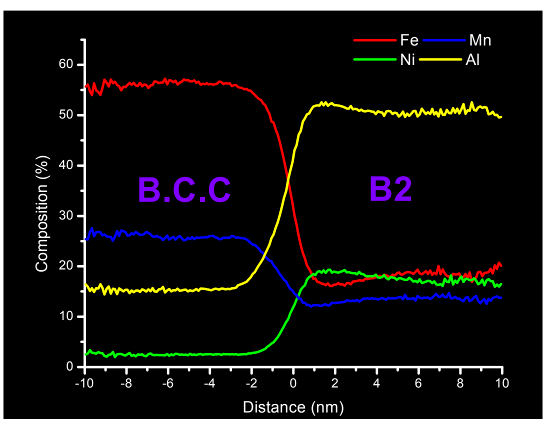

Fig.3. LEAP composition profile of drop cast $Fe_{35}Ni_{15}Mn_{25}Al_{25}$.

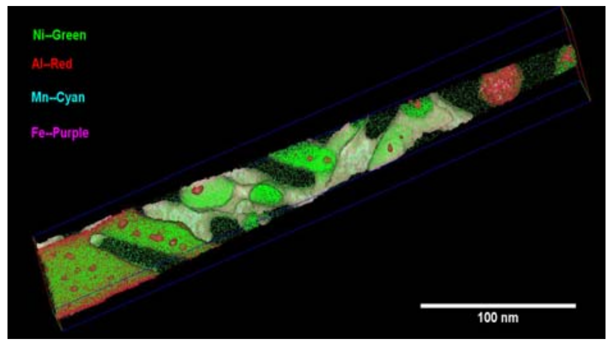

Fig.4. 3-D iso-concentration atom map for drop cast $Fe_{35}Ni_{15}Mn_{25}Al_{25}$.

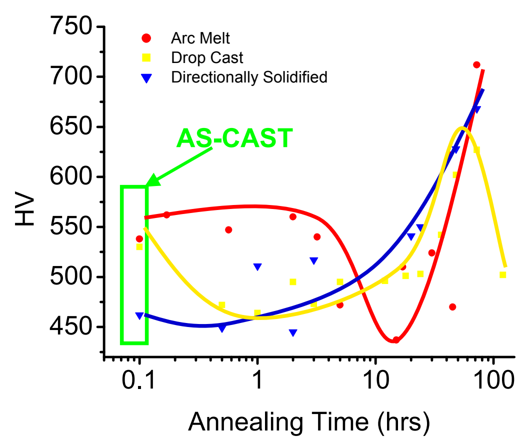

Fig.5. Hardness behavior of $Fe_{35}Ni_{15}Mn_{25}Al_{25}$ as a function of annealing times.

https://doi.org/10.1017/S1431927609094070 Published online by Cambridge University Press