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Nanoscale Phase Separation in $Al_{0.5}CoCrFeNi(Cu)$ High Entropy Alloys as Studied by Atom Probe Tomography

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High entropy alloys (HEAs) typically contain five or more principal elements in nearly equiatomic proportions [1–3]. The most studied HEA systems are the AlCoCrFeNi and AlCoCrFeNiCu alloys, which solidify into dendritic and interdentritic regions with an attendant microsegration of solute species. Within these microscale heterogeneities the material microstructures further segregate into (i) nanoscale modulated structures composed of alternating Al/Ni-rich and Fe/Cr-rich phases formed by spinodal decompostion, and (ii) nanoscale Cu precipitate formation. The microstructures formed during casting and after annealing of an $Al_{0.5}CoCrFeNi$ (atomic fraction) HEA, with and without Cu additions, are studied by atom probe tomography (APT). These microstructures are correlated to the observed strength, as measured by Vickers microhardness and uniaxial tensile tests.

Figure 1 shows the as-cast microstructure of the $Al_{0.5}CoCrFeNi$ alloy, as observed by scanning electron microscopy (SEM). Dendritic microsegregation results in Co-, Cr-, and Fe-rich dendrites which have a face-centered cubic (FCC) crystal structure. The composition of the dendrites, as measured by APT (results not shown), is $Cr_{23.06}Fe_{22.79}Co_{22.55}Ni_{20.66}Al_{10.94}$ (at.%) with all elements uniformly distributed with no evidence of clustering.

The dendrites are surrounded by an interdentric region that is enriched in Ni and Al with composition $Cr_{23.26}Ni_{22.01}Co_{19.64}Fe_{19.19}Al_{15.89}$ (at.%) and is comprised of a disordered body-centered cubic (BCC, A2) phase and an ordered BCC phase (B2) that is formed by spinodal decomposition. Figure 2 displays APT reconstructions of the spinodally decomposed interdentric region. The BCC phase has a composition of $Cr_{42.03}Fe_{23.70}Co_{22.47}Ni_{8.31}Al_{3.47}$ while the B2 phase is $Ni_{37.51}Al_{29.67}Co_{16.57}Fe_{11.59}Cr_{4.62}$ [4].

References:

[1] JW Yeh, JOM **65** (2013), p. 1759.
[2] JW Yeh, JOM **67** (2015), p. 2254
[3] MH Tsai and JW Yeh, Materials Research Letters **2** (2014), p. 107
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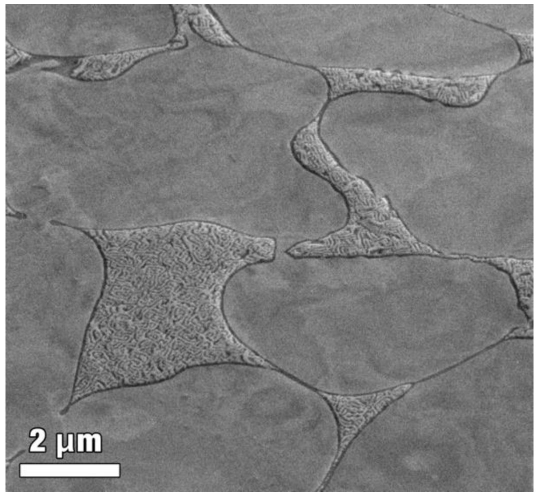

Figure 1. Scanning electron micrograph of the as-cast $Al_{0.5}CoCrFeNi$ (atomic fraction) alloy investigated, showing dendritic and interdendritic regions. The interdendritic region has undergone spinodal decomposition.

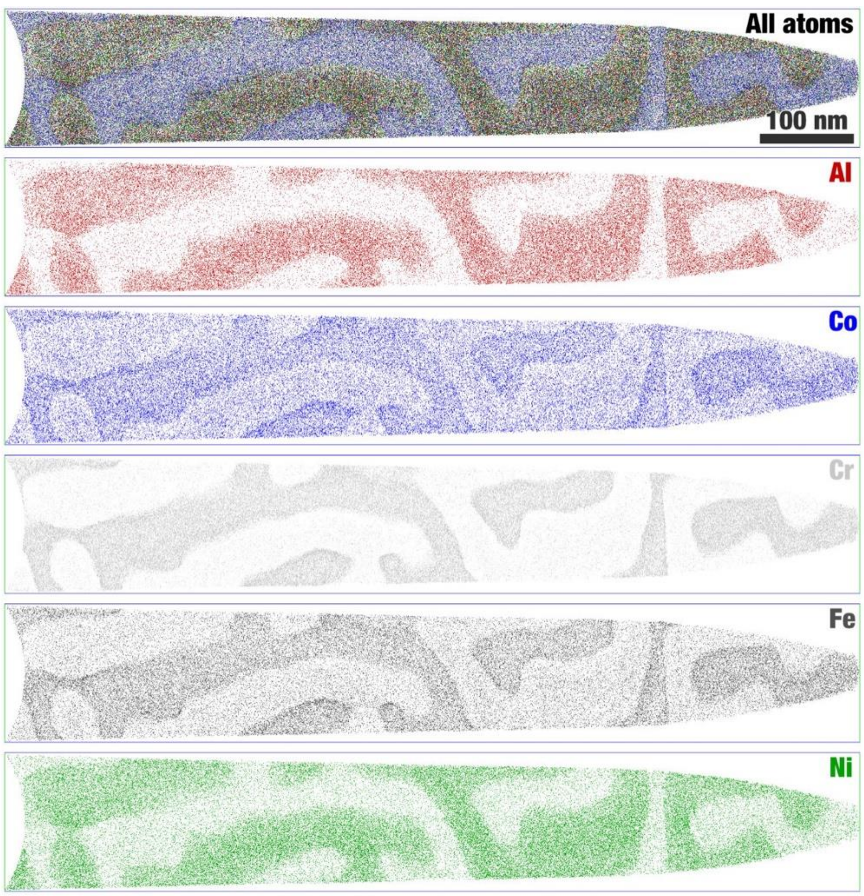

Figure 2. Atom probe tomography (APT) reconstructions displaying the chemical segregation between the spinodally decomposed BCC and B2 phases within the interdendritic region.

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