Microscopic Characterization of Cu-Ni-rich Bridges in Alnico Alloys

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Despite decades of research and development of Alnico alloys, there are still significant uncertainties in the underlying structure-property relationships. This research focuses on the Cu-rich bridges between the α_1 and α_2 phases, which are studied via energy-dispersive X-ray spectroscopy (EDS) performed in an aberration-corrected FEI Titan G2 microscope in scanning transmission electron microscopy (STEM) mode. Interesting features that were observed include: an inhomogeneous distribution of Ni in the α_2 phases, including loops with high Ni concentration around the α_1 phase and also high concentrations in the bridges; a high Cu concentration in the Ni loops (so called Cu-Ni loop); the Cu-rich bridges directly contact the Cu-Ni loops but do not directly contact the α_1 phases; the bridges are not perfectly round but oval, with the long axis along the connection of two adjacent α_1 phases. In addition to the Cu-rich bridges (i.e. Cu>Ni bridges), a new type of bridge was identified, containing more Ni than Cu (i.e. Cu<Ni bridges); these are referred to as Cu-Ni-rich bridges.

The distribution of the elements in the bridges varies with bridge type as seen in Figure 1. Cu has the same distribution in both types, with the maximum concentration at the center and decreasing radially from the center. Co, Fe and Ti have opposite distributions relative to Cu in both types. In the Cu>Ni bridge, the Ni also distributes oppositely as compared to Cu, while in Cu<Ni bridge, Ni forms a stripe with the highest concentration along the connection. The Ni concentration decreases with increasing distance from the connected area. The Al distribution is probably affected by Ni and is opposite to Cu in Cu>Ni bridge and almost uniform in Cu<Ni.

High-resolution HAADF images of the bridges along the [100] direction are obtained as well as α_1 and α_2 phases along the [100], [110] and [111] directions. The crystal structure is the same as that of alnico8 in that α_1 is bcc and α_2 is $L2_1$, so the high-resolution HAADF image of the bridges along [100] is representative. One schematic 3D model with the corresponding transverse view (along magnetic field // [100]) was built to visually represent the bridge formation mechanism as well as element distributions and the manner in which the bridges affect the morphology of spinodal decomposition and magnetic properties.

Key Words: Cu-Ni-rich bridges, oval shape, Alnico, EDS mapping, HAADF

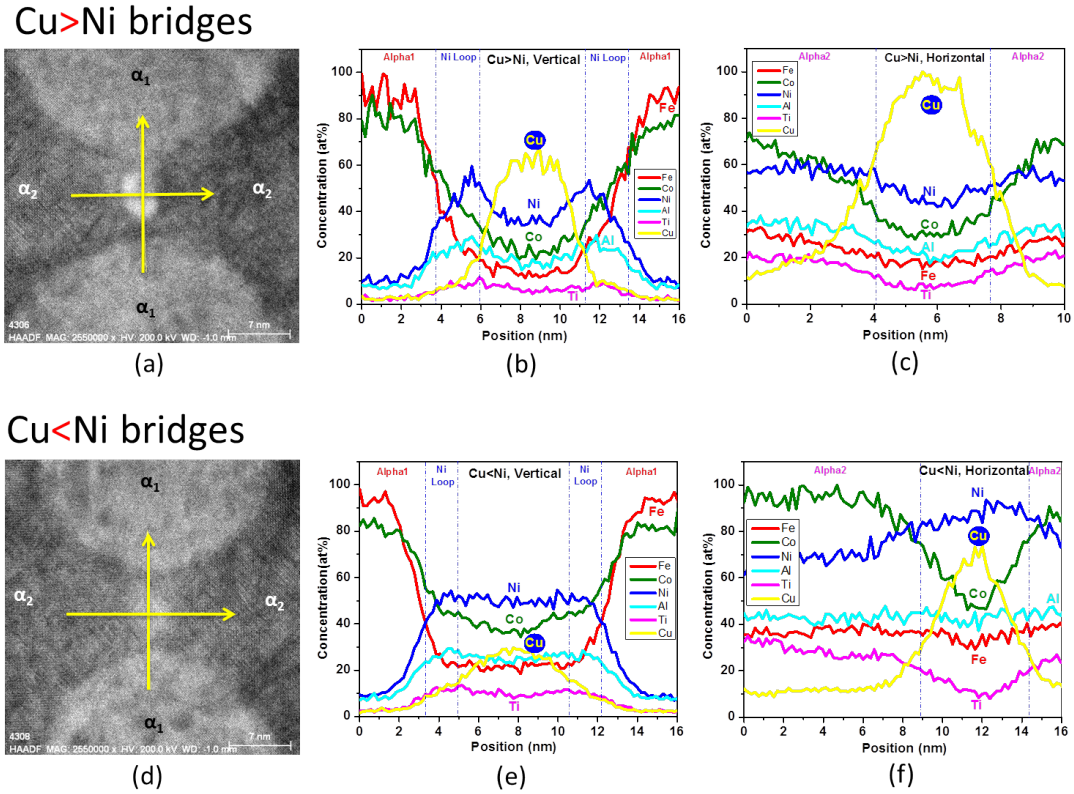

Fig. 1. (a) HADDF of the Cu>Ni bridges; (b) line scans along vertical direction (α1➔ α2➔bridges➔α2➔α1); (c) line scans along horizontal direction (α2➔bridges➔α2); (d): HADDF of the Cu<Ni bridges; (e) line scans along vertical direction (α1➔ α2➔bridges➔α2➔α1); (f) line scans along horizontal direction (α2➔bridges➔α2).

The contribution of the applicant:

The composition of the sample was determined by Florida International University based on their simulation work. The contribution of the applicant includes sample preparation (weighing, casting and thermomagnetic treatment), magnetic property measurement, TEM sample preparation via Focused Ion Beam (FIB) lift-out technique, FIB sample pre-checking with a JEOL 2010, the EDS mapping in Aberration corrected STEM FEI Titan, data processing, analysis and interpretation. Dr. Yang Liu assisted partly in the EDS mapping to get higher quality images. All the work was done under the guidance of Dr. Carl Koch and Dr. Justin Schwartz.

The significance of the work in the field:

This work is the first time that the morphology and elemental distributions of Cu-Ni-bridges has been observed, which supplies critical information to understand the underlying structure-property relationships of alnico alloys containing Ti.