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The Effect of Group 5 (V, Nb, Ta) Additions on Precipitation in Al-Sc Alloys

Keith E. Knipling[1]

[1.] U. S. Naval Research Laboratory, Multifunctional Materials Branch, Washington, DC 20375

Al-Sc alloys, strengthened by nanoscale Al_3Sc ($L1_2$ structure) precipitates, have excellent coarsening and creep resistance to 300 °C [1,2], and can be improved up to 400 °C with ternary additions of the neighboring Group 4 elements, Ti [3] Zr [4,5] or Hf [6]. These ternary solutes have a much smaller diffusivity than Sc [1], resulting in $Al_3Sc_{1-x}M_x$ (M = Ti, Zr, or Hf) precipitates with a Sc-rich core enveloped in a Zr, Ti, or Hf-enriched shell. These slower-diffusing atoms limit coarsening and, since they substitute for Sc in the precipitates, can also reduce the relatively high cost of Sc additions.

The Group 5 elements in the periodic table (M = V, Nb, or Ta) may also be beneficial alloying additions to Al-Sc alloys. They each form an Al_3M trialuminide and also exhibit some solubility in Al_3Sc [7], and are anticipated to be much slower diffusers than Ti, Zr, or Hf [1], potentially providing better thermal stability than Al-Sc-Ti, Al-Sc-Zr, or Al-Sc-Hf alloys. This study investigates the nanostructures and compositions of $Al_3Sc_{1-x}M_x$ precipitates formed during isochronal aging in (i) highly supersaturated Al-Sc-V-(V/Nb/Ta) alloys produced by melt-spinning and (ii) dilute Al-Er-Sc-(V/Nb/Ta) made by arc melting. The alloys are evaluated by Vickers microhardness, electrical conductivity, bright-field and dark-field transmission electron microscopy (TEM, FEI Tecnai G^2 30 operating at 200 kV), and atom-probe tomography (APT, Cameca LEAP 4000x Si).

Figure 1 displays $Al_3Sc_{1-x}M_x$ precipitates, and their compositions (as measured by proxigrams [8]), formed after isochronal aging to 400 and 500 °C. As observed in prior APT studies on Al-Sc-Ti, Al-Sc-Zr, and Al-Sc-Hf alloys [3–6], the V, Nb, or Ta atoms constitute a small fraction of the Al_3Sc precipitates. The degree of partitioning of the Group 5 solutes is, however, much less than that observed with Group 4 additions, indicating the Group 5 solutes have smaller diffusivities, as expected. In Figure 1, only V segregates appreciably to the precipitates, suggesting that it is a faster diffuser than Nb or Ta, and forms a ~1 nm thick shell with a peak concentration of ~2.75 at.% V.

Similar trends are observed in the dilute Al-Er-Sc-Zr-(V/Nb/Ta) alloys, where the Group 5 additions have a minor effect on the observed microhardness and precipitation behavior (Figure 2). These properties will be correlated to the precipitate size and compositions, as measured by TEM and APT.

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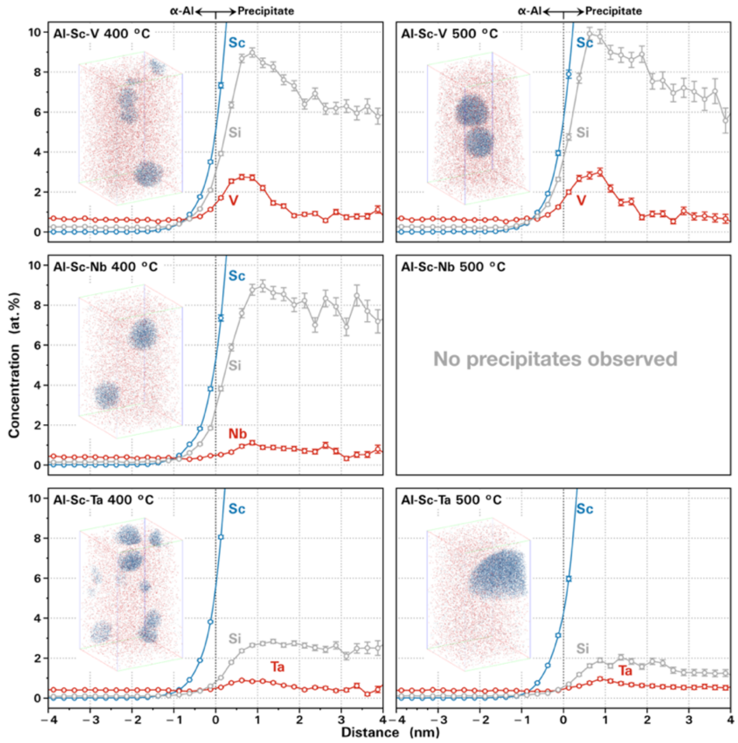

Figure 1. Proxigrams of the Al-Sc-V, A-Sc-Nb, and Al-Sc-Ta alloys isochronally aged to 400 and 500 °C. Inset are 15×15×50 nm^3 APT reconstructions, with each Sc atom represented as a blue pixel, V/Nb/Ta atoms with red pixels, and Si atoms with gray pixels (Al atoms are not shown for clarity).

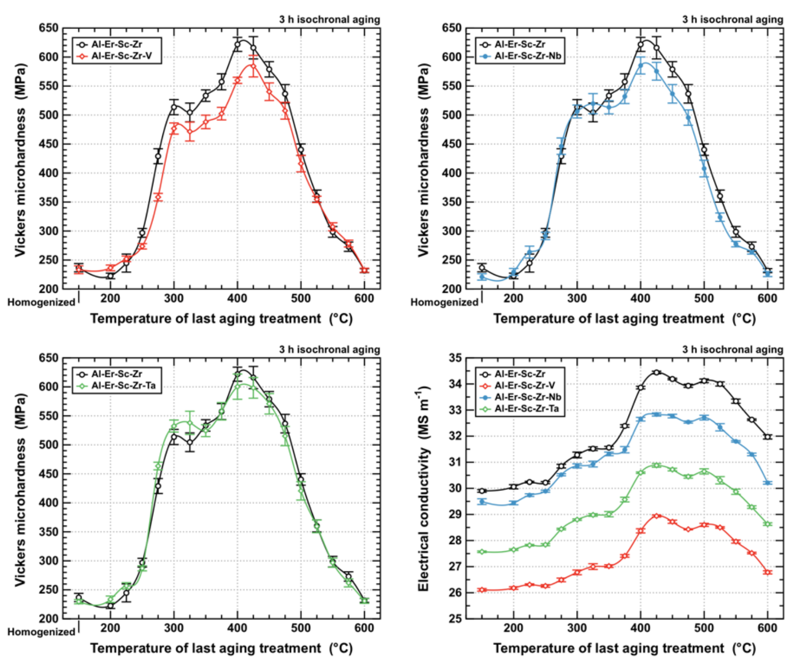

Figure 2. Vickers microhardness and electrical conductivity evolution during isochronal aging (3 h at each temperature) of the Al-Er-Sc-Zr and Al-Er-Sc-Zr-(V,Nb,Ta) alloys.