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Stability and Transformation of Quasicrystalline Phase in Transition Metal Modified Al-(Mn-Fe)-based Alloys.

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Due to environmental and economic concerns significant interest has arisen in the development of higher strength low-density Al-based alloys for aerospace and automobile applications. One notable Al-alloy strengthening approach uses fine dispersions of quasicrystalline (icosahedral) particles. These metastable phases can be formed through rapid solidification methods (e.g. melt spinning, suction casting, gas atomization), and lead to enhanced hardness (> 450 HV) and tensile strength (>1000 MPa) [1] of the obtained material. However, the high cooling rates necessary for icosahedral phase (I-phase) formation limits the final dimensions of castings to a few millimeters. Fabrication of bulk forms of quasicrystal dispersion strengthened Al alloys typically necessitates hot-compaction of melt-spun ribbon, for instance. Thus, the thermal stability of the quasicrystalline phase in these microstructures is important to retain the enhanced alloy properties after warm-extrusion or -compaction.

Ternary $Al_{91}Mn_7Fe_2$ alloys exhibit one of the highest tensile strengths values (1250 MPa) among the group of quasicrystal strengthened Al-Transition Metal (TM) systems [2]. Unfortunately, their thermal stability is amongst the lowest. Since the thermal stability of the icosahedral phase has been shown to relate directly to its chemical composition [3], alloying with transition metal elements characterized by high melting temperature and low diffusivity in Al, such as Mo, W, and V may offer potential for enhanced thermal stability. The main objective of this work is the determination of the influence of the alloying TM additions on the I-phase decomposition under thermal stimuli.

$Al_{91}Mn_7Fe_2$ and $Al_{91}Mn_6Fe_2X_1$ (X_1 stands for 1 at% Mo, W or V) ribbons were prepared by melt-spinning under argon atmosphere. A combination of electron microscopy, x-ray diffraction, and thermal analysis techniques were used to investigate the thermal stability of the I-phase in melt-spun ribbon and hot-compacted conditions. The microstructure in the ribbons consisted of I-phase dispersoids and FCC Al solid solution (Fig. 1a). The Mo, W and V additions are incorporated preferentially into I-phase (Fig. 1b). Differential scanning calorimetry (DSC) measurements revealed a shift of peak temperature for the exothermic peak of the I-phase decomposition towards higher temperatures (60-80 K) for the TM modified samples. The activation energies for decomposition determined using the Kissinger method exhibited an increase from 192 kJ/mol ($Al_{91}Mn_7Fe_2$) to 227 kJ/mol ($Al_{91}Mn_6Fe_2V_1$). After short term annealing near the exothermic peaks observed by DSC (Fig.2a), the I-phase decomposed into the following product phases: i) $Al_{91}Mn_7Fe_2$, orthorhombic Al_6(Mn,Fe); ii) $Al_{91}Mn_6Fe_2Mo_1$, orthorhombic Al_6(Mn, Fe) and cubic Al_{12}(Mn, Mo); iii) $Al_{91}Mn_6Fe_2V_1$, monoclinic Al_{45}(Mn,Fe,V)$_7$ and orthorhombic Al_6(Mn,Fe) (Fig. 2b). In all cases, the decomposition products formed at the interface between Al-matrix and I-phase, appearing to grow into the latter. The distributions of the alloy additions after annealing suggest that Mn and Fe diffuse to the I-phase/Al matrix interface to facilitate the decomposition (Fig. 3). Although the hot-compaction process results in a complete loss of I-phase for the $Al_{91}Mn_7Fe_2$ alloy, the Mo and V modified alloys still retained a significant fraction of the I-phase after consolidation. A discussion of the difference in the diffusivity of constituent elements in the quasiperiodic lattice and its effect on the thermal stability will be presented.

References:
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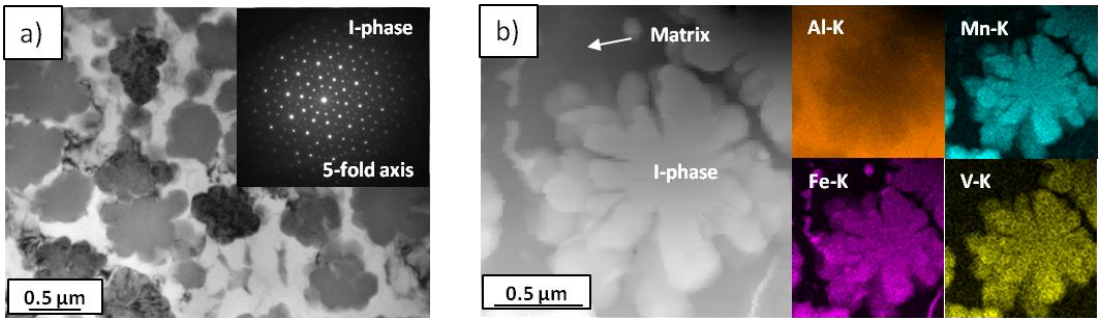

Figure 1. a) TEM bright field image of as spun $Al_{91}Mn_6Fe_2V_1$ ribbon with inserted an electron diffraction pattern form one of particles, b) STEM image with distribution of elements in the I-phase.

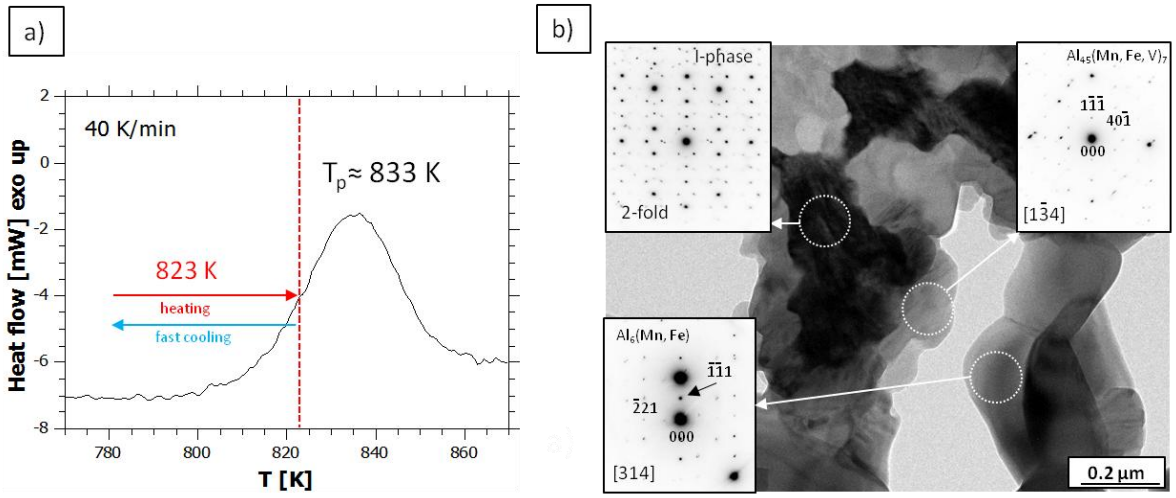

Figure 2. a) DSC curve for V modified alloy ribbon; b) TEM bright field image of sample annealed to 823K (e.g. see arrows in a)) with I-phase partially decomposed into two types of intermetallics.

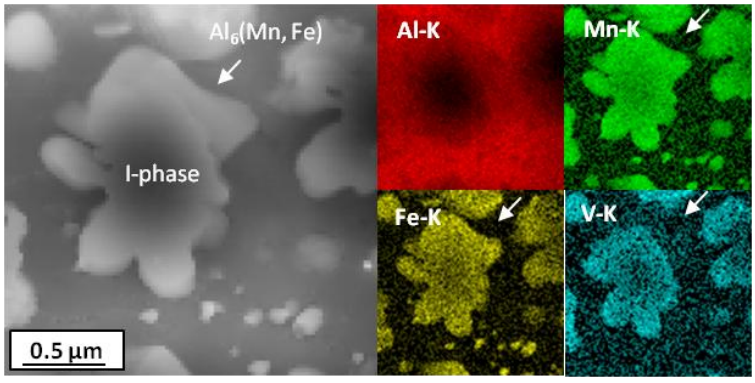

Figure 3. STEM image of $Al_{91}Mn_6Fe_2V_1$ ribbon after annealing at 773K for 30 minutes showing distribution of elements in both I-phase and orthorhombic $Al_6(Mn, Fe)$.