

Dissolving alloying additions inside precipitates of lightweight alloys to promote phase transformations

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Background incl. aims

Microalloying elements are commonly added to high-strength aluminium alloys, mainly to promote the formation of key strengthening precipitate phases. Classic examples include Sn, Cd and In at the 100 ppm level [1], which significantly accelerate the nucleation of the strengthening phase θ' in Al-Cu alloys, thereby improving the precipitation hardening response. More dramatic is the effect of Ag additions to Al-Cu-Mg and Al-Cu-Li alloys, where new phases (Ω and T1) form in high number densities, leading to ultra-high-strength alloys typically used in the aerospace industry. In all these cases, the microalloying additions either segregate at the precipitate-matrix interfaces or precipitate first as a well-defined crystalline phase before acting as heterogeneous nucleation sites [1].

An unusual case is that of Au additions to Al-Cu, where the precipitation hardening response is enhanced and accelerated through Au dissolving inside the strengthening precipitate phase θ' [2]. This observation leads to two questions which this work aimed to address:

- (1) What is the mechanism by which Au enters the precipitates and promotes their formation?
- (2) Can other elements behave in this way?

Answering these questions would be useful not only for improving one's fundamental understanding of phase transformations, but also to provide a potential way of immobilizing contaminants.

Methods

This work employed a combination of aberration-corrected scanning transmission electron microscopy, density functional theory (DFT) simulations and classical nucleation theory (CNT) calculations. The microscopy was performed on a FEI Titan3 FEGTEM and a Thermo Fisher Scientific Spectra- ϕ FEGTEM, both double-aberration corrected and operated at an accelerating voltage of 300 kV in scanning transmission electron microscopy (STEM) mode. Al-1.7at%Cu-0.02at.%Au alloys having undergone different ageing treatments were examined. More details about the experimental and computational procedures can be found in Refs. [3-4].

Results

In order to understand how Au atoms are incorporated into θ' precipitates, the alloy was characterised at the very early stages of ageing. It was found that the overwhelming majority of θ' precipitates at the earliest stages of precipitation were 80-100 nm long and only 1 to 1.5-unit cell high, with \sim 2nm long θ'' precipitate regions at the semi-coherent interfaces (see Fig. 1). The 1c-high configuration has never been observed in pure Al-Cu alloys. Chemical analysis indicated the presence of Au atoms within the structure. An atomic-scale mechanism is proposed that involves the transformation of the plentiful coherent θ'' precipitates into 1c-high θ' through the incorporation of Au solute and vacancies. This mechanism is supported by DFT and CNT calculations [3,5].

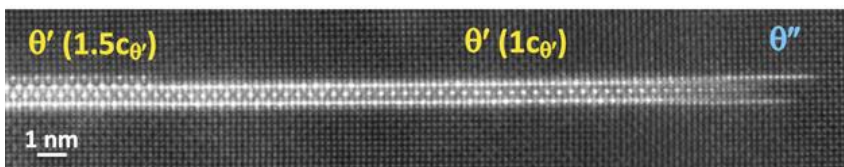
The intriguing possibility that other solute elements may dissolve into the θ' phase was also examined through DFT simulations.

Conclusion

An unusual mechanism through which a microalloying element (here Au) promotes the formation of a strengthening precipitate phase (here θ') by dissolving inside it, was investigated at the atomic scale. This was found to lead to sub-nanoscale thick precipitates of aspect ratio >100 . This direct transformation mechanism may also be at play in other important aluminium alloy systems, such as Al-Cu-Li with Ag additions.

The authors acknowledge the Monash Centre for Electron Microscopy, a Node of Microscopy Australia, and the Australian Research Council.

Graphic:



Keywords:

STEM; aluminium; precipitates; phase transformations

Reference:

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