MS-4-O-3093 Micro-structural evolution in age-hardening alloys revealed by atomic-scale in-situ heating electron microscopy

Liu C. H.1,2, Xu Q.1,3, Chen J. H.2, Malladi S. K.1, Erdamar A.1, Tichelaar F.1, Zandbergen H.1

1Quantum Nanoscience, Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands., 2Center for High Resolution Electron Microscopy, College of Materials Science and Engineering, Hunan University, Changsha, China., 3DENSsolutions, Delft, The Netherlands

Email of the presenting author: c.liu-1@tudelft.nl

Thermal treatment is of vital importance in producing metal alloys with the desired performance. Many industrial tempers are designated by the temperature and duration adopted to treat the materials. Though tremendous microstructure characterizations have been done to understand the transformation process induced by heating, ambiguities pertaining to the underlying mechanisms still persist even for the well-known phenomenon such as precipitation hardening. The reason is related mainly with the fact that the microstructure observation and heat treatment weren’t done simultaneously in most previous literatures. In the present study, by using MEMS based in situ heating holder (DENSsolutions) we successfully carried atomic-scale real-time scanning transmission electron microscopy (STEM) investigations on the micro-structural evolution in metal alloys (AlCu alloy, AlCuMg alloy, AMgSiCu alloy and NiAl superalloy). The same thermal history as that used for treating metal alloys in factory has been applied on the specimens inside TEM. Solution treatment, quenching and annealing can be precisely controlled regarding the temperature, time as well as heating/cooling rate. This detailed study provides valuable data for quantifying the thermodynamics and kinetics governing the micro-structural evolution including nucleation, growth and coarsening of individual strengthening precipitate (θ' (AlCu2) and γ' (Ni3Al)) (Fig. 1). The direct atomic-scale imaging of the thickening and lengthening of the plate-like θ' (AlCu2) phrase generates new mechanistic insights into the growth process (Fig. 2 and 3). It is noteworthy to mention that the tip of the θ' precipitate is slightly broader than the inner part (Fig. 2). Contrary to this, the tip of this precipitate in Fig. 3 is narrower than the inner part possibly because of the proximity to another precipitate. Such kinds of local changes provide new insights into the interaction of different growing precipitates due to the overlap of diffusion field. The alloying elements diffusion behaviours monitored during heating are critical for unravelling the factors affecting the formation of the effective strengthening particles especially those in the confusing multi-step ageing frequently used in processing high performance aluminium alloys. Our study also demonstrates that in-situ heating electron microscopy is a powerful tool to assess the effect of alloying elements and tempers on the microstructure and is fruitful for developing metal alloys with enhanced properties.

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Fig. 1: Snapshots from a video showing the evolution of plate-like precipitates viewed along [001]$_{Al}$ direction in AlCu alloy aged at 180°C from as-quenched to 10 h.

Fig. 2: Snapshots from a video showing the thickening of θ’ precipitate viewed along [001]$_{Al}$ direction in AlCu alloy aged at 180°C. The arrow points to the changing position of the growth ledge.

Fig. 3: Snapshots from a video showing the lengthening of θ’ precipitate viewed along [001]$_{Al}$ direction in AlCu alloy aged at 180°C. The arrow points to the changing position of the interface. The red box represents the unit cell of θ’ phase.