

## Quantitative Dark-Field Transmission Electron Microscopy of the Microstructure Evolution in a 2618A Aluminum Alloy During Ageing

C. Rockenhäuser<sup>1</sup>, B. Skrotzki<sup>1</sup>

<sup>1</sup> Bundesanstalt für Materialforschung und -prüfung, Experimentelle und modellbasierte Werkstoffmechanik, Berlin, Germany.

The Al-Cu-Mg alloy 2618A is part of the 2XXX series of age-hardenable aluminum alloys, which are used in transportation and aerospace industries for long-term operation. The distribution of nanoscale Al<sub>2</sub>CuMg precipitates within the matrix determines the desired properties (for example hardness, damage tolerance, and creep behavior) [1]. However, the strength and hardness of the 2618A alloy declines due to overageing [2]. Investigations of high purity model alloys and technical alloys attribute this material degradation to the coarsening of two competing precipitate phases (S1 and S2) and an ongoing transformation of S2 into S1 [3-5]. A quantitative model for the overageing process of the alloy 2618A would be desirable for precise predictions of the strength of alloy 2618A. Such a model requires measurements of the precipitate size distribution at the initial stage (peak hardened alloy in the T61 condition) and at different aging stages. To investigate the aging process of the alloy samples were fabricated from circular blanks aged at 190 °C for durations up to 8760 h.

The precipitate radii were determined using dark-field transmission electron microscopy, which allows selective imaging of the Al<sub>2</sub>CuMg S-Phase precipitates due to their orientation relation to the  $\alpha$ -Al matrix. The precipitates form as rods along the  $\langle 001 \rangle_{\alpha}$  direction of the  $\alpha$ -Al matrix and hence the investigated samples were oriented in the  $[001]_{\alpha}$  direction for the TEM investigations. The inset of Fig. 1 b) shows a selected area diffraction pattern of the investigated sample area with clearly visible reflections of the oriented Al-matrix. The rod shaped precipitates cause the streaks in between the matrix reflections. An aperture was used to select the streaks for imaging as indicated by the circle. Dark-field images of the Al<sub>2</sub>CuMg precipitates are shown in Fig. 1 a-b). The spots with bright contrast correspond to S-phase precipitates oriented along the  $\langle 001 \rangle_{\alpha}$  direction and penetrate the image plane. Coarsening of the initially small particle radii of the initial T61 condition (Fig. 1 a)) is clearly visible after heat treatments at 190 °C for 2500 h (Fig. 1 b)). The elongated line shaped contrasts are caused by rods oriented orthogonal to the incident electron beam. The dark-field images are analyzed using a standard procedure involving several steps: edge-conserving median filtering, thresholding, binarization and particle detection. The determined mean radii for all investigated samples are 2.1 nm for the T61 state (717 particles), 2.9 nm for 250 h (234 particles), 3.4 nm for 1000 h (104 particles), 4.1 nm for 2500 h (212 particles), and 5.7 nm for 8760 h (208 particles).

A possible coarsening model is Ostwald ripening of cylindrical particles described by the equation

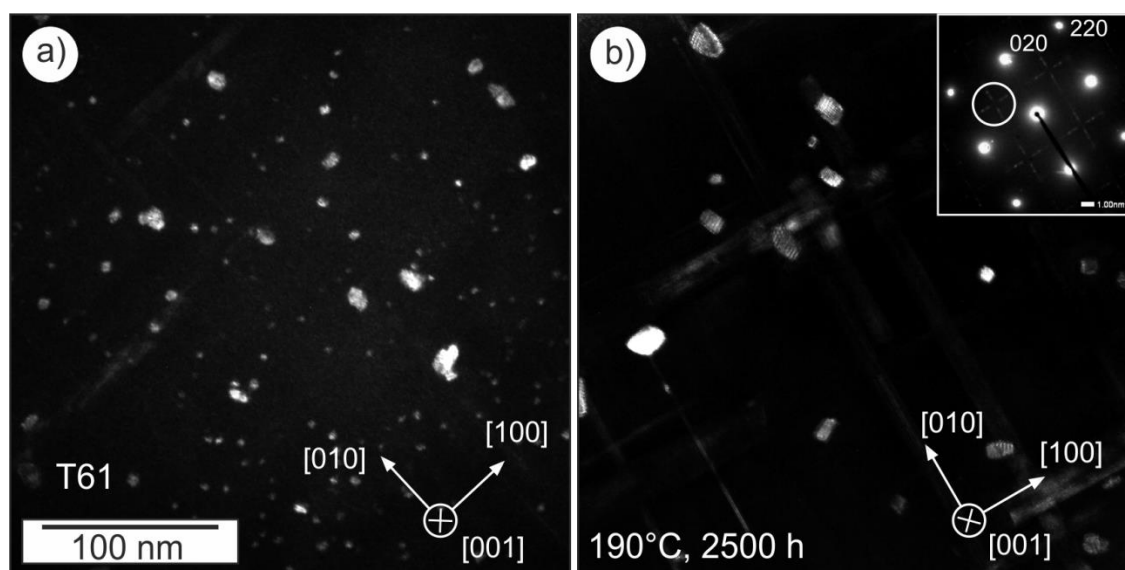
$$r(t)^3 - r(0)^3 = \frac{K}{(l/2r)\ln(l/r)}t$$

with the mean radius  $r$ , duration of coarsening  $t$ , cylinder length  $l$ , and a constant  $K$  [6]. Fig. 2 shows a plot of  $r^3(t) - r^3(0)$  against  $t$ . Assuming a constant length to radius ratio  $l/r$  should result in a straight line through all measured values. However, the red line fitted for all measurements deviates clearly from a linear relationship. This suggests that during the initial stages of ageing the length to radius ratio is not constant. A linear relationship is found evaluating the equation only for measurements for durations  $\geq 1000$  h. This change in behaviour is attributed to the conversion of the S1 phase the S2 phase found by Styles [5]. The authors assert that Ostwald ripening of the S2 phase occurs after the complete

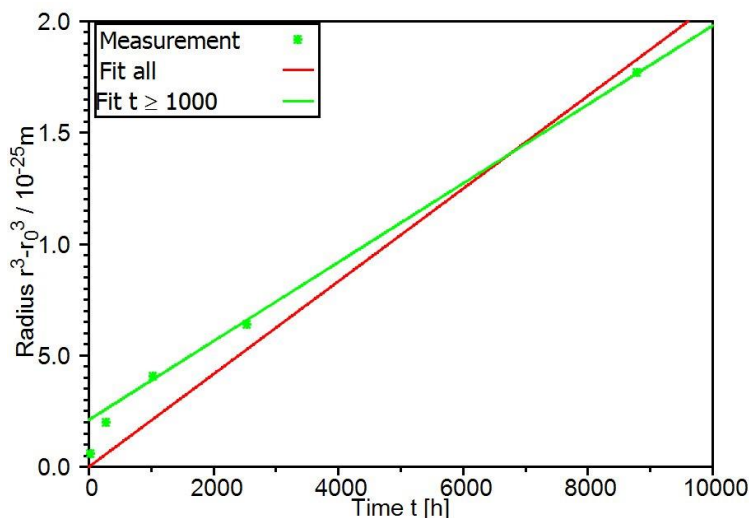
conversion of the S1 phase. The measurement of the volume fraction of the phases and the rod length allows further validation of this hypothesis and is in progress.

#### References:

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**Figure 1.** Dark-field images of the  $\text{Al}_2\text{CuMg}$  precipitates oriented along the  $[001]$  zone axis of the Al-matrix for a) the initial state T61 and b) the heat treatment at  $190^\circ\text{C}$  for 2500 h.



**Figure 2.** Plot of  $r^3(t) - r^3(0)$  against  $t$  with fitted straight lines for all measured values and for measured values at durations  $\geq 1000$  h.