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Thermal Impact on Laboratory-scale Heat Treatment Samples During Elevated Temperature Ageing for Short Duration

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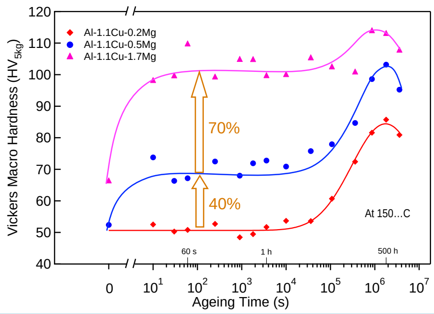
INTRODUCTION

From an alloy design viewpoint, it has become increasingly important to better understand the rapid hardening phenomenon (RHP) at the earliest stages of the decomposition of the supersaturated solid solution in Al-Cu-Mg alloys. The RHP occurs in Al-1.1Cu-xMg alloys that contain at least 0.5 Mg (at.%), and may provide > 50% of the total hardness increment within the first 60 seconds of ageing.

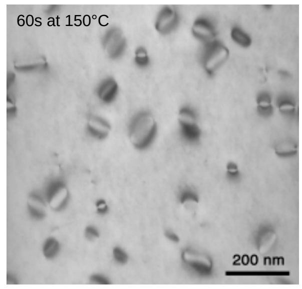
Research of this nature requires very short ageing heat treatments to study the expected clustering reactions. The actual thermal impact due to the application of short periods of elevated temperature ageing (150°C) to lab-scale specimens has been determined for various conditions by modelling the heat transfer using both the lumped capacitance method (LCM) and finite element modelling (FEM), and then comparing to experiments.

The resultant temperature versus time profiles are subsequently used to calculate the associated diffusion distance of the solute atoms by random walk. This information is useful for evaluation of the effect of short thermal ageing treatment and its influence on microstructure-property relationships.

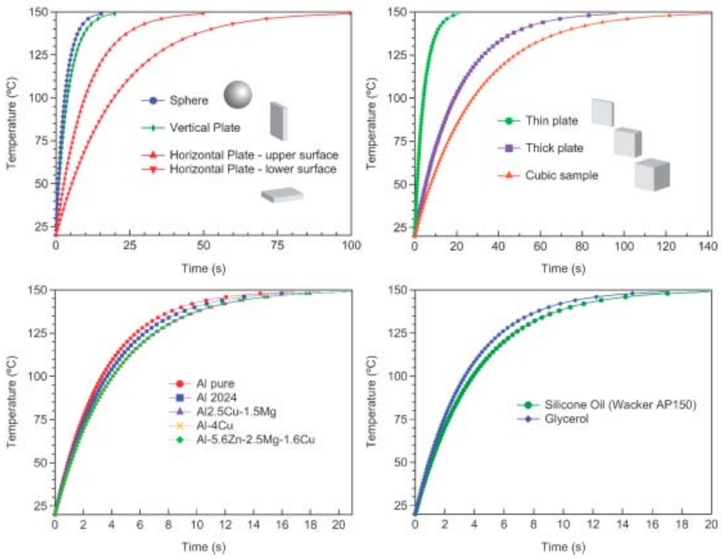
AGE HARDENING



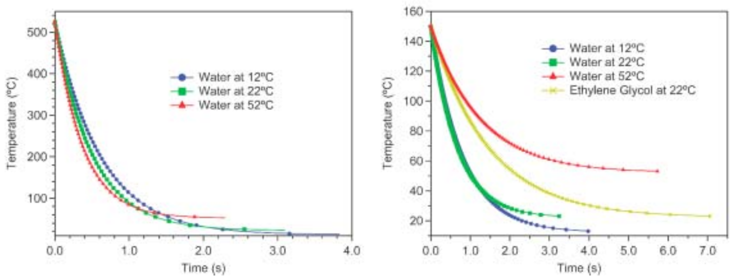
TEM - Al-1.1Cu-0.5Mg



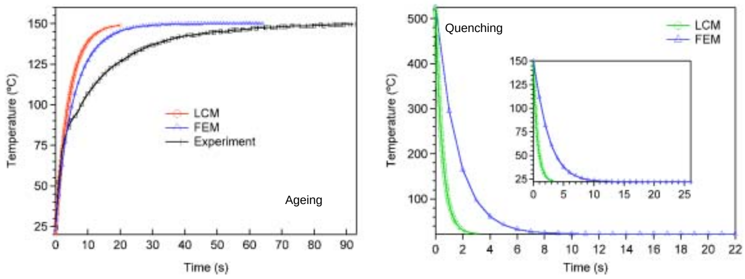
LCM RESULTS - AGEING



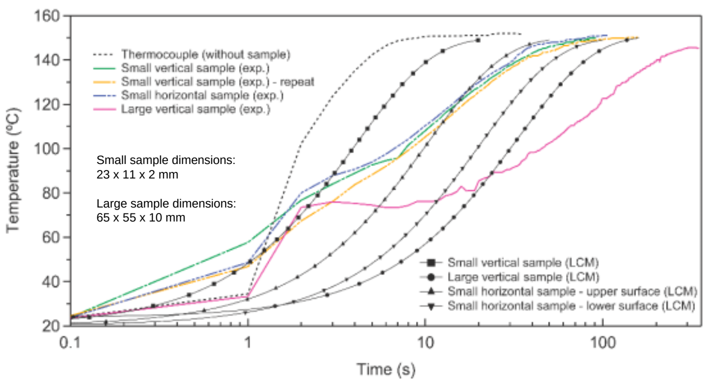
LCM RESULTS - QUENCHING



LCM VS FEM



LCM VS EXPERIMENT



SOLUTE DIFFUSION BY RANDOM WALK

- For a random walk in 3D, after time (*t*) the average atom will have advanced a radial distance (*x*) from the origin:

$$x = \sqrt{6Dt}$$

- Diffusivity is expressed as:

$$D = D_0 \exp\frac{Q}{RT}$$

Where the pre-exponential factor D_0 is a material constant, *Q* is the activation energy of substitutional diffusion, *R* is the gas constant and *T* is absolute temperature.

- An upper bound limit for diffusivity is found by using the literature diffusion parameters (D_0 and *Q*), which approximate instantaneous thermal equilibrium at each increasing temperature, allowing for maximum vacancy retention and the highest potential for vacancy-assisted diffusion.

Diffuser	D_0 (m^2/s)	Q (kJ/mole)
Cu	4.44 x 10^{-5}	133.9
Mg	1.49 x 10^{-5}	120.5

Ref: Y. Du et al. Materials Science & Engineering A: 363, 140-151 (1970).

Diffuser	*x* (nm) - maximum diffusion distance in Al by random walk		
	Ageing up to 150°C (LCM)	Ageing up to 150°C (Experimental)	Quenching from 150°C (LCM)
Cu	0.38	0.85	0.014
Mg	1.47	3.31	0.056

CONCLUSIONS

- For lab-scale ageing experiments, the fastest heat transfer conditions are achieved by using small, thin samples with a vertical orientation in the oil bath. Glycerol or silicone oil are good ageing media.
- Water at room temperature or below will provide sufficiently fast quenching conditions for Al-alloys, but the heat treated state will be better preserved if immediately after quenching the sample is stored at liquid nitrogen temperature.
- During a 60 s ageing heat treatment the Al-alloy sample may not reach a set-point of 150°C. This issue needs to be considered when designing short heat treatments at the lab-scale for end use at the industrial scale.
- Solute diffusion distance by random walk during 60 s ageing at 150°C in Al-Cu-Mg is of the nanometre scale (< 4 nm), which is significantly smaller than the average dislocation loop interspacing (~100 nm).
- It is not expected that a large percentage of solute will segregate to the loops, hence it is unlikely that the RHP is caused by a dislocation-locking mechanism.

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