Modeling Mg_2Si Dissolution in 6063 Aluminum Alloy During Preheating to the Extrusion Temperature

N. C. W. Kuijpers[1], W. van Til[2], J. van den Langkruis[2], C. Vuik[3], S. van der Zwaag[1,2].

[1]*Netherlands Institute for Metals Research, Delft, The Netherlands,*
[2]*Laboratory for Materials Science, Delft University of Technology, Delft, The Netherlands,*
[3]*Department of Applied Mathematical Analysis, Delft University of Technology, Delft, The Netherlands.*

INTRODUCTION

Vermolen *et al*. [1] developed a finite element model for dissolution of precipitates, which consists of multiple chemical elements. This model has been employed in the present work [2] to describe the solid state dissolution of the Mg_2Si precipitates in a 6063 type aluminum alloy during preheating to extrusion temperatures as a function of *dT/dt* and initial particle size.

This model has been used to:

- Compare with differential scanning calorimetry (DSC) measurements.
- Calculate the mean concentration of the Mg dissolved in the Al-matrix (Mg solute content) after preheating.

THE MODEL

The model considers a dissolution process of a spherical Mg_2Si precipitates surrounded by an aluminum matrix with cut-off radius $r=R_{Al}$, shown in Figure 1. The cell with central particle can be regarded as representative volume element for the initial microstructure.

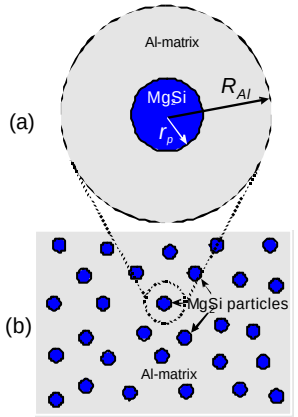

Figure 1 *(a) Modeled configuration, indicating r_p and R_{Al}. (b) Schematic display of an aluminum alloy with Mg_2Si precipitates.*

The diffusion of the alloying elements inside the Al-Matrix is represented by Fick's second law for spherical coordinates:

$$\frac{\partial c_i}{\partial t} = \frac{D_i}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial c_i}{\partial r}\right), \quad i=\text{Mg,Si}.$$

The diffusion coefficient D_i in the aluminum matrix is given by the Arhenius relationship:

$$D_i = D_i^0 \exp\left(-\frac{Q_i^d}{RT}\right)$$

The concentrations of the elements on the moving boundary are dependent on time. The solubility product of these concentrations are connected by the following hyperbolic relation [1]:

$$\left(c_{Si}^{sol}\right)^{\frac{1}{3}}\left(c_{Mg}^{sol}\right)^{\frac{2}{3}} = K_0 \exp\left(-\frac{Q_{sol}}{RT}\right)$$

Thus, on the moving boundary the following Dirichlet condition is imposed:

$$\left(c_i\right)_{r=r_p} = c_i^{sol}.$$

A Stefan condition is imposed which describes the velocity of the boundary:

$$\frac{dr_p}{dt} = \frac{D_i}{c_i^p - c_i^{sol}}\left(\frac{\partial c_i}{\partial r}\right)_{r=r_p},$$

which counts both for *i*=Mg and *i*=Si.

There is no flux through the boundary $r=R_{Al}$, so the second boundary condition becomes:

$$\left(\frac{\partial c_i}{\partial r}\right)_{r=R_{Al}} = 0.$$

The initial conditions are the radius of the particle and the initial element concentrations:

$$r_p = r_0,$$
$$c_i(r,0) = c_i^{init}.$$

EXPERIMENTAL

Table 1 and Table 2 shows the alloy content of the sample and the parameters of the Mg_2Si particles, respectively.

Table 1 *Alloy composition of samples in wt%.*

Mg	Si	Fe	Other	Ti
0.45	0.40	0.19	<0.01	0.01

Table 2 *Parameters values for Mg_2Si particles and the concentrations in the matrix.*

parameter	*value*
r_0 of Mg_2Si particle	0.40 ± 0.2 µm
Mg_2Si vol%	0.65 vol%
R	2.14± 0.5 µm

RESULTS

1. Model Validation

The latent heat of dissolution measured by DSC is linearly related to the dissolved volume of the Mg_2Si precipitates. Therefore DSC measurements were used to compare to the modeled dissolved volume, these results are shown in Figure 2. It can be seen that the peak positions of the experimental curves correspond to the numerical calculations. The misfit in the tail is the result of particle size distribution not being taken into account.

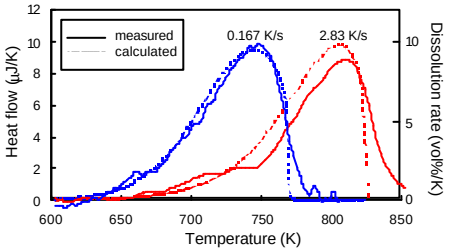

Figure 2 *Experimental DSC curves (solid line) and calculated dissolution rate (dashed line). (a) dT/dt = 0.167 K/s, (b) dT/dt = 2.83 K/s.*

2. Dissolution Contours

The model uses the preheat temperature path as depicted in Figure 3, with a holding temperature of 553 K.

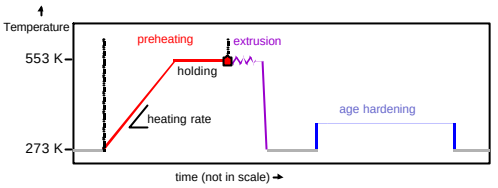

Figure 3 *Temperature path of preheating, extrusion and age hardening.*

The model yields the instantaneous particle size and the average solute content, both Mg and Si, in solid solution. To ensure maximum hardness after age hardening (Figure 3) it is essential that all alloying elements are in solid solution at the end of the reheating process.

In Figure 4 iso-solute Mg contours are shown for holding times of 4 s and 300 s at 553 K after linear heating to this temperature. The shaded region of each graph indicates conditions for complete dissolution. The diagrams show that:

- Solute content after preheating increases as particles size decreases, or with lowering heating rate.
- Mg dissolution contours are strongly influenced by holding time.

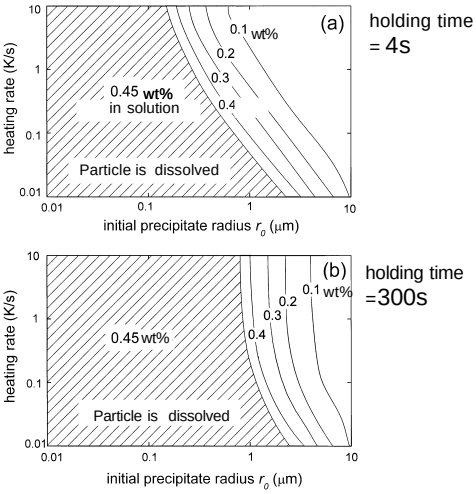

Figure 4 *Mg solute content after preheating, as a function of heating rate and initial particle radius (a) holding time 4 s, (b) holding time of 300 s.*

CONCLUSIONS

- The model predicts successfully the results of DSC experiments.
- The model enables qualitative prediction of combination of *dT/dt* and the initial particle size to ensure full dissolution upon reheating to the extrusion temperature.

REFERENCES

1. F. J. Vermolen, K. Vuik, S. van der Zwaag, *Mat. Sci. Eng. A*254 (1998) 13.
2. J. van de Langkruis, N.C.W. Kuijpers, W.H. Kool, F.J. Vermolen, S. van der Zwaag, *ET2000 Conference Proceedings*, may 2000, accepted.

Contact: N.C.W.Kuijpers@tnw.tudelft.nl, W.vanTil@tnw.tudelft.nl