Numerical methods of microstructural changes and predictions of mechanical properties in friction stir welding of AA6005-T6

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Abstract

Based on the microstructural evolution rules on Al-Mg-Si alloy in isothermal and non-isothermal conditions, the precipitation evolution model is established. The nucleation, solid solution and the coarsening are comprehensively included in the established model. With combination of the adaptive re-meshing thermal-mechanical coupling [1] FEM in numerical simulation of friction stir welding of 6005-T6, the microstructural evolution and the strengthening model of AA6005-T6 in friction stir welding is further established.
With consideration of the solid solution strengthening and the precipitation strengthening, the evolutions of the second phase and the variations of the mechanical properties in friction stir welding of AA6005-T6 can be predicted.
By calculating the artificial ageing after welding process, a result can be clearly concluded. The soft region can be found in stirring zone area in as-welded condition, whereas the soft one lies in the heat affected zone after artificial ageing because of the reason that the re-precipitation occurs in the stirring zone.
To predict the microstructural evolutions in processes of all thermal stages, the temperature history should be precisely shown. As shown in Fig.1, the obtained temperature distribution (during welding process) and histories are displayed. And the nucleation of precipitation during thermal process can be expressed by [2],

$$j = j_0 \exp\left(-\frac{\Delta G^*_{\mathrm{het}}}{RT}\right)\exp\left(-\frac{Q_d}{RT}\right) \tag{1}$$

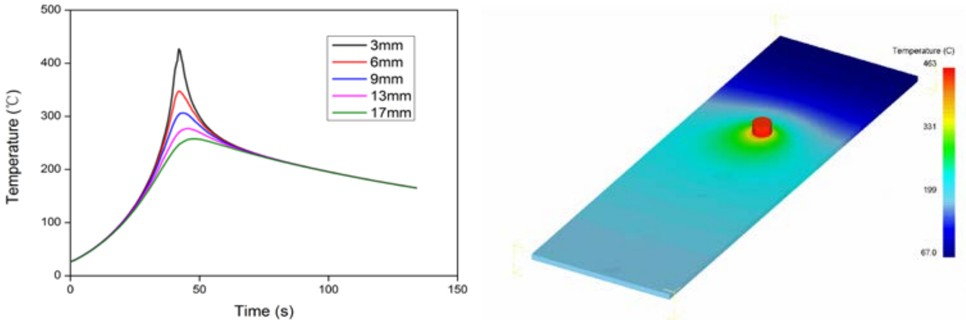

Figure 1. Temperature histories and distribution in FSW

where j_0, Q_d, R, ΔG^*_{het} are the pre-exponential term to the nucleation rate; the diffusion activation energy of element Mg and the gas constant. ΔG^*_{het} is used for the critical energy barrieragainst heterogeneous nucleation,

$$\Delta G_{het}^{*} = \frac{(A_0)^3}{(RT)^2[\ln(\overline{C}/C_e)]^2} \tag{2}$$

where A_0 is a parameter related to the energy barrier for nucleation. $\overline{C}$, C_e are the mean concentration of Mg in matrix and the equilibrium solute concentration at the precipitate/matrix interface [2].

The model for precipitation discretizes the size distribution in radius direction, as can be shown in Fig.2.

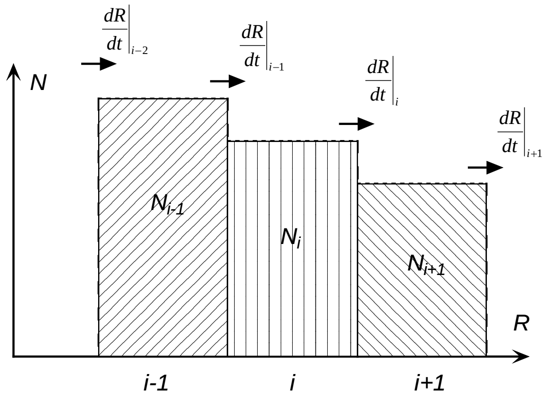

Figure 2. Discretization in radius direction

The precipitate hardening strengthening is given by,

$$\sigma_p = \frac{M}{b\overline{r}}\left(2\beta G b^2\right)^{-\frac{1}{2}}\left(\frac{3f}{2\pi}\right)^{\frac{1}{2}}\overline{F}^{\frac{3}{2}} \tag{3}$$

where M is the Taylor factor, b is the Burgers vector, β is the dislocation tension factor, G is the shear modulus of matrix, $\overline{F}$ is the mean obstacle strength, $\overline{r}$ is the mean particle radius, f is the volume fraction of precipitates [3].

Fig.3 and Fig.4 show the comparison of precipitation and mechanical properties between as-weld state and 5 hours of artificial ageing at 180^{o} C after FSW.

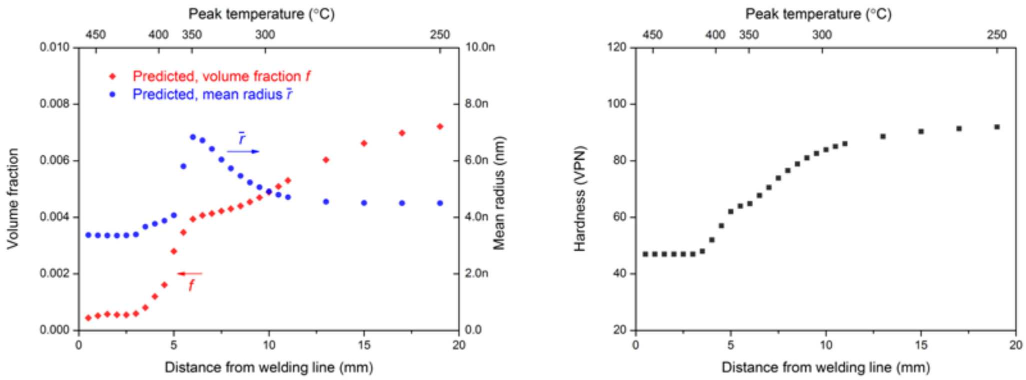

Figure 3. Precipitations and mechanical properties in as-weld state

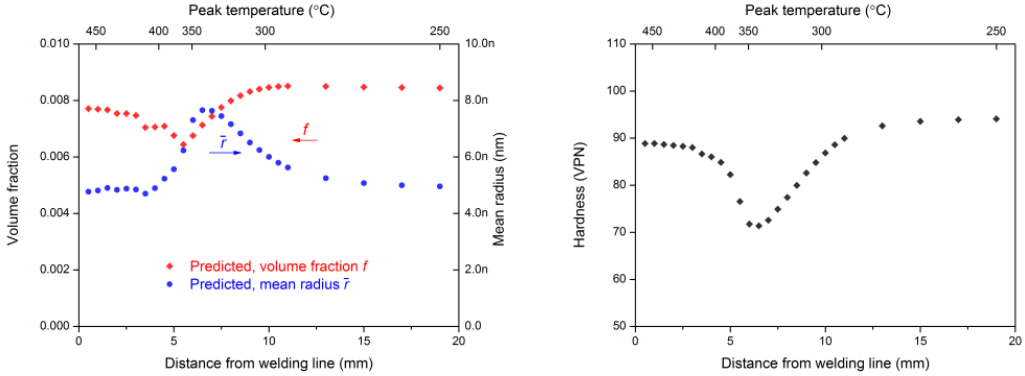

Figure 4. Precipitations and mechanical properties after post-weld artificial aging at 180^{o} C for 5 hrs

Keywords: friction stir welding, precipitate evolution model, mechanical property prediction, post weld heat treatment

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