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Dissolution of hardening phases during deformation in an A6061 Aluminium alloy

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Abstract

The temperature limit for the technological usage of an A6061 aluminium alloy is investigated taking into account the initial precipitation state and the stability of hardening phases during the deformation process. In a critical temperature range, the dissolution of precipitates occurs parallel to deformation processes resulting in a characteristic strain rate-dependent shape of the stress strain curve. In the present contribution, we introduce a new tool for the comprehensive representation of precipitate dissolution in the form of dissolution maps. Starting from an initial precipitation state, the phase fraction evolution for hardening phases is modelled with the thermokinetic software package MatCalc for a series of deformation temperatures. The resulting diagram shows contour lines of constant phase fraction over temperature and time, depicting a critical region where precipitate dissolution represents a crucial microstructural mechanism for strength evolution. The modelling results are validated on a series of compression tests on a Gleeble 1500 thermo-mechanical simulator, where the samples are artificially aged and tested at different strain rates.

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1. Introduction

The A6061 alloy belongs to the Al-Mg-Si alloying system, which is the basis for numerous heat-treatable cast and wrought aluminium alloys. It is recognized for its superior mechanical properties, weldability and corrosion resistance.

The mechanical properties mainly result from precipitation of the equilibrium Mg_2Si β and its precursor phases [1]. The intermediate part of the precipitation sequence [2] is shown in Fig.1, modelled with the thermo-kinetic software package MatCalc for a simplified Al-Mg-Si ternary alloy (0.85 wt.% Mg, 0.69 wt. Si, Al bal.) within the composition range of A6061 aluminium alloy during artificial ageing at 170°C. It shows that the T6 state [3] corresponds very well with a high, almost maximum, phase fraction of $Mg_5Si_6-\beta''$. It is widely accepted that β'' is the major hardening phase in the T6 region (see Fig. 1) of the Al-Mg-Si system [4-7] and the strength of the material is closely related to its existence, shape and distribution. Beside β'' , β' and the Guinier-Preston-Matsuda phase [8], Cu rich alloys also contain the equilibrium Q phase ($Al_5Cu_2Mg_8Si_6$) and its precursor phases [9] that are not considered in this work for the sake of simplicity.

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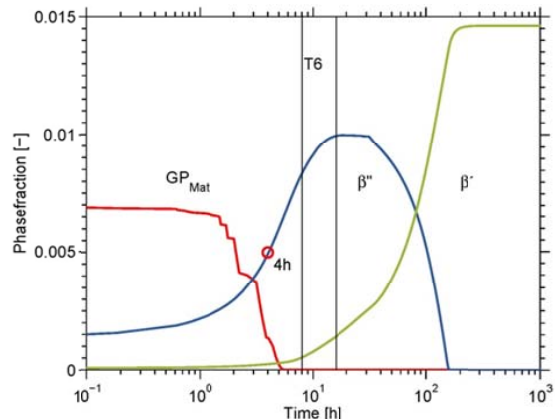


Fig. 1 Precipitation sequence of Mg-Si precipitates at 170°C for GP-Mat, β'' and β' , also shown the T6 region following DIN EN 2700 and the age hardened state for 4h.

The under-aged material state after 4h of artificial ageing at 170°C (red circle in Fig. 1) is taken as starting point for all further simulations and it is referred to as State 1. From this state, the dissolution kinetics of β'' is followed by simulation and plotted over a wide range of temperatures. The main focus lies on the short time dissolution process that is active during deformation with strain-rates of 0.01 [1/s]. The simulation results are compared to experimental results at temperatures around 300°C, where an unusual strain-rate dependent shape of the stress strain curve occurs, which cannot be attributed to conventional dynamic strain ageing effects. In addition, the long term phase stability is investigated from room temperatures up to the temperature range where artificial ageing treatments are commonly carried out.

2. Experiments and modelling

Experiments are carried out on a Gleeble 1500 thermo-mechanical simulator. Cylindrical specimens, made from A6061 aluminium alloy, are used with a length of 15mm and a diameter of 10 mm. The chemical composition is summarized in Table 1.

Table 1 Chemical Composition

Element	Al	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti
Concentration [%]	97.35	0.69	0.45	0.23	0.11	0.85	0.18	0.01	0.05	0.05

The specimens are solution heat treated for 1 h at 540 °C, water quenched and artificially aged at 170°C for 4h (State 1) and 8h. Compression tests are carried at several different temperatures and three different strain-rates of 0.1, 0.01 and 0.001 [1/s]. The presented results represent the mean value between three identical experiments. The stress is calculated under the assumption of constant volume and no barreling. The yield stress values are taken at a strain of 0.02.

In the present work, a CALPHAD based approach, implemented in the thermokinetic software package MatCalc (version 6.00 rel. 0.104) [10] is used for simulation. Predictive models for nucleation and growth of precipitates, along with thermodynamic, mobility and physical properties databases are embedded in the software package. The initial phase fraction of the β'' phase, as used for the simulation (State 1), has a numerical value of roughly 0.005. Dissolution maps are constructed from simulations of the phase fraction evolution for different temperatures with a step width of 10°C.

3. Results and discussion

Fig. 2(a) shows yield stress values for two different artificial ageing times over temperature. The experimental results fall into three regions: (i) a low temperature region, where hardening phases are stable (ii) an intermediate temperature region, where hardening phases are metastable and gradually dissolve and (iii) a high temperature region, where hardening phases dissolve rapidly and thus lead to identical stress levels for different ageing times. Fig. 2(b) shows stress strain curves for 4h of artificial ageing and five different temperatures.

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