Development and validation of the crystal plasticity model for AA6082 aluminum alloy during hot deformation

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1. Introduction

The wide use of aluminum alloy is due to the high resistance to fatigue of structural elements made of these alloys as well as good specific strength [1]. The 6XXX series contains age-hardenable aluminum alloys that provide a good combination of ductility and strength, and the main alloying elements include Si and Mg. [2]. The low resistance to plastic forming of such alloys allows forming them both at elevated temperatures and at room temperature. Obtaining finished products is possible through the use of forging or stamping under isothermal and non-isothermal conditions [1], as well as extrusion techniques can be carried out at high temperatures [3] to ensure stable material flow.

Homogenization processes are successfully used in order to increase the quality and mechanical properties after aging and to homogenize the cast microstructure before deformation [4]. Another important aspect is the controlled homogenizing cooling, which will affect the precipitation due to the content of Mg and Si [5].

In addition, increasing the formability of these alloys can be achieved by heating the dies to elevated temperatures. Through the appropriate selection of plastic deformation parameters (temperature, strain, and strain rate), it is possible not only to close defects or porosities resulting from the casting process but also to obtain a fine-grained structure as a result of recrystallization. In this way, strength properties, fatigue strength, and impact strength are improved as well as a uniform structure is obtained [6].

Understanding the behavior of individual precipitates depending on temperature allows the optimization of thermo-mechanical parameters. The typical Al-Mg-Si alloy precipitation sequence includes [7]: supersaturated solid solution SSSS → clustering (Mg/Si clusters and co-clusters) → Guinier–Preston (GP)-I zones → β'' → β' → β (Mg_2Si). AA6082 aluminum alloy also contains the so-called intermetallic α-Al(FeMn)Si precipitates formed during casting and homogenization [8]. Mn in this alloy increases corrosion resistance and deformation uniformity [9] while Fe is an

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impurity element [10]. Generally, Mg and Si are the main elements that create hardening precipitates and thus increase the strength of Al Mg-Si alloys [11].

2. Material, methods and results

Table 1 presents the chemical composition of AA6082 aluminum alloy. An important aspect is the distribution of individual precipitates in the microstructure, especially within grains, which will affect both the mechanical properties of the alloy and its formability. Figure 1 presents precipitates distribution in the grain area after isothermal holding at 400ºC for 4 min AA6082 aluminum alloy investigated by electron backscatter diffraction (EBSD) method with energy dispersive X-ray spectrometry (EDS) as well as scanning electron microscope (SEM). EDS (Mn) and EDS (Si) elements peaks correspond to the distribution of α Al(FeMn)Si precipitates. This type of intermetallic fine precipitate does not affect the hardening of the alloy [12]. Cooling from the supersaturated state and subsequent aging causes, above all, high susceptibility of grain boundaries (GB) to the formation of large β-Mg_2Si precipitate [13] (EDS(Si) with EDS(Mg) peaks).

Table 1. Chemical composition of the investigated AA6082 alloy.

Si	Fe	Mn	Mg	Al
1.05	0.37	0.662	0.80	Bal.

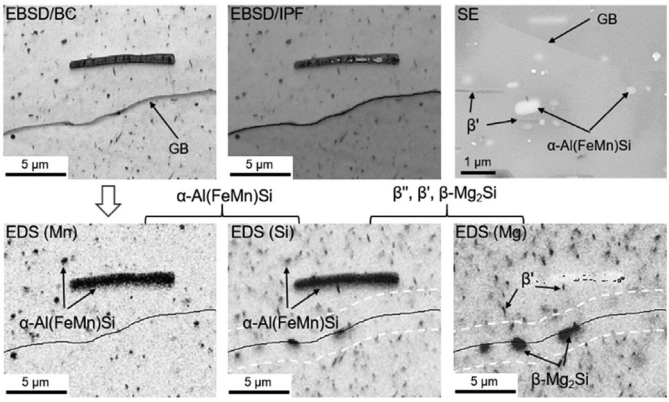

Figure 1. EBSD maps with corresponding EDX maps of the distribution of Mn-, Si- Mg- elements (indicating α Al(FeMn)Si, β', β-Mg2Si precipitates respectively) and SE image of AA6082 aluminum alloy after solution annealing and isothermal holding at 400ºC for 4 min. The maps as well as the image present grain boundaries (GB).

Optimization of the deformation parameters in this situation and control of strain during plastic deformation is possible basing on the understanding of crystal plasticity behavior with particular consideration of factors such as crystallographic orientation, type, and distribution of individual precipitates as well as the density of dislocations.

2.1. Dislocation-based model

Basing on the constitutive laws of dislocation-based model the deformation gradient for kinematics can be calculated as follows:

$$F = F_e F_p \tag{1}$$

where: F_e – the rigid body rotations and elastic deformation of the lattice, F_p – the plastic deformation gradient and for the evolution of plastic deformation where the plastic velocity gradient depends on dislocation slip.

More information about the model and methodology of such simulations can be found in work [14]. Figure 2 presents crystal plasticity simulation results. It can be observed that stress concentration is along the edges of the particles and high-strain interlocked regions.

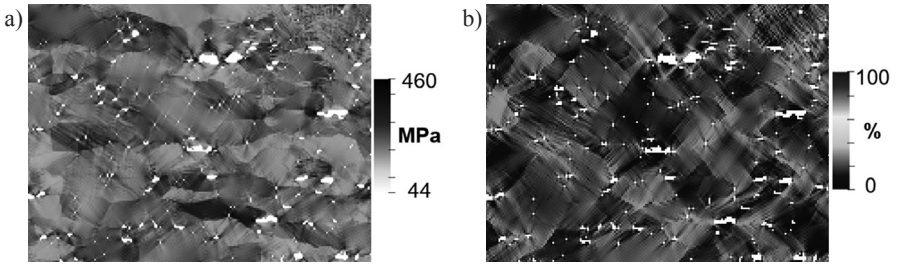

Figure 2. Simulation results after 20% global true tensile strain along the horizontal axis at 200°C. Local (a) True Mises stress (b) True Mises strain, distributions. White areas indicate precipitates.

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