



Correlating oriented grain number density of recrystallisation in particle-containing aluminium alloys



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Abstract: The recrystallized grain structure of Al–(Mn)–Fe–Si alloys after isothermal annealing was studied by electron backscatter diffraction (EBSD) technique. Statistical correlation suggests that the frequency of forming P-oriented ($\{011\}\langle 566 \rangle$) grains at a particle larger than the critical diameter (about 1.1 μm) is about 2% when the effect of fine dispersoids and concurrent precipitation is negligible. The overall grain number density is correlated linearly with the number densities of P and Cube ($\{001\}\langle 100 \rangle$) grains. The grain number densities of typical orientations (P, ND-rotated cube $\{001\}\langle 310 \rangle$ and Cube) and the overall recrystallized grains increase as rolling strain increases, following a similar exponential law.

Key words: recrystallisation texture; aluminium alloys; particle-stimulated nucleation; EBSD

1 Introduction

Aluminium is the metallic material of choice for light-weight applications. Industrial aluminium alloys usually contain second-phase particles which are formed during casting and heat treatments and induce inhomogeneity of deformation in the matrix. For instance, deformation zones are formed around large particles, which may act as nucleation sites of recrystallisation due to high stored energy during back annealing of deformed samples [1]. This mechanism is known as particle stimulated nucleation (PSN) [2]. By contrast, fine particles affect deformation [3], induce Zener drag effect on boundary migration and retard recrystallisation [4,5]. Thus, particle size and their distribution affect recrystallization structure and texture. Different recrystallisation texture components are formed by various mechanisms [6]. For instance, it is widely accepted that Cube component $\{001\}\langle 100 \rangle$ is formed at

cube (transition) bands by strain induced boundary migration (SIBM) [2,7]. P component is commonly observed in Al–Mn alloys with considerable precipitation [8–11]. Low heating rates promote P texture, when precipitation of dispersoids occurs prior to or concurrently with recrystallization [12]. Recently, P-oriented grains are found in commercially pure aluminium as well [13,14], and P component is usually very weak due to its low number fraction and grain size [14]. Simulations and experimental characterization suggest that P-oriented grains originate within deformation zones and are promoted by increasing rolling strain [12,15].

The activity of various recrystallisation mechanisms is influenced by microchemistry, deformation strains, and annealing treatments etc [2,4,6,16]. Modelling of recrystallisation texture is an important aspect of alloy and process optimizing in industry, and many efforts have been made to simulate recrystallisation texture [17–20]. However, we still lack a simple relationship to

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estimate the recrystallisation activity of different texture components, especially the contribution of PSN [17]. The present work aims to identify the correlation of some important recrystallisation texture components with coarse particle distribution and rolling strain in aluminium alloys, and to document the possibility of forming P-oriented grains at a particle, providing a practical relation to estimate the activity of PSN from the particle size distribution.

2 Experimental

Three aluminium model alloys were provided by Hydro aluminium, labelled as B2, C1 and C2. Their chemical compositions are given in Table 1. The raw materials were direct chill (DC) cast billets with a diameter of about 23 cm. Homogenization was performed in an air-circulation furnace with a heating rate of 50 °C/h. C1 was given two different treatments besides the as-cast condition. The homogenization treatments for each sample alloys are listed in Table 1, followed by water quenching. The long-time homogenization of B2 is designed to achieve an equilibrium level of solutes in solid solution. Following different homogenization treatments, all the samples were cold-rolled to 1.5 mm to achieve a thickness reduction of 95%, corresponding to a strain of $\varepsilon=3$. C1-0 slabs of varied thicknesses (30, 7.5 and 3 mm) were cut from the cast billet, and were rolled to final thickness of 1.5 mm, achieving the reductions of 95%, 80% and 50%, respectively. Flash annealing of the rolled sheets was performed in a pre-heated salt bath at 300–500 °C (heating rate in the order of 10^2 °C/s). The annealing time was selected to be long enough to finish recrystallisation and to avoid further grain growth, according to the softening curves measured by hardness tests (referred to Refs. [14,21]). Electrical conductivity, used as an indication of solid solute content and amount of precipitation, was measured by using a Foerster Sigmatest 2.069 at room temperature. The microstructure was characterized by using backscatter electron imaging in a Zeiss Ultra 55 field emission scanning electron

microscope with an EBSD detector. The orientation analysis of recrystallised samples was performed using EDAX's OIMTM software.

3 Results and discussion

3.1 Microstructure prior to back annealing

The constituent particles and dispersoids in the experimental materials have been characterised in Refs. [14,21] and a brief introduction is presented here. During homogenization, a relatively high density of fine dispersoids (54 nm in diameter, number density of about $1.3 \times 10^6 \text{ mm}^{-2}$) was formed in C1-2. The density of dispersoids was lower (about $5.5 \times 10^4 \text{ mm}^{-2}$, 127 nm in diameter) in C1-3, and the lowest (about $1.2 \times 10^4 \text{ mm}^{-2}$, 150 nm in diameter) in C2. The diameter and number density of constituent particles after homogenization were measured from SEM observations. The cumulative distribution of constituent particles with diameter larger than d , $N(d)$, can be described by the following equation [17]:

$$N(d)=A \cdot \exp(-k \cdot d) \quad (1)$$

where A and k are constants which are estimated by fitting the experimental measurements to Eq. (1). The fitting values are listed in Table 1. The morphology of constituent particles is complex, particularly the Si-containing particles, which could be rounded or branched, as demonstrated in Ref. [22]. Branched constituent particles are particularly prone to break during rolling. Figure 1 exemplifies by sample B2 that cold rolling did not evidently change the size distribution of constituent particles, although the number density of very large particles was reduced. The morphology and distribution of constituent particles after rolling for different conditions are demonstrated in Fig. 2. Clusters of particles are observed in C1-0, which are observed in C1-2 and C1-3 as well. The shape of the constituent particles in C2 is more rounded due to coarsening during homogenization at high temperature. A typical β -fibre rolling texture was formed after cold rolling to reduction of 95%.

Table 1 Nominal chemical composition, homogenization treatments, electrical conductivity, constants A and k in Eq. (1) of samples

Sample	Chemical composition (mass fraction)/%			Homogenization	Electrical conductivity/ ($\text{MS} \cdot \text{m}^{-1}$)	$A/$ 10^4mm^{-2}	$k/$ μm^{-1}
	Mn	Fe	Si				
B2	0	0.49	0.14	600 °C for 24 h, slowly cooled (in 50 h) to 450 °C for 34 h	34.6	1.69	1.53
C1-0	0.39	0.53	0.15	As-cast	24.1	6.99	2.13
C1-2	0.39	0.53	0.15	450 °C for 4 h	27.5	1.40	0.83
C1-3	0.39	0.53	0.15	600 °C for 4 h, cooled by 25 °C/h to 500 °C for 4 h	29.0	3.43	1.89
C2	0.97	0.50	0.15	600 °C for 24 h	22.4	3.24	1.21

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