Proceedings of the 9th International Conference on Aluminium Alloys (2004)
Edited by J.F. Nie, A.J. Morton and B.C. Muddle

Texture-Dependent Recrystallization in Aluminum 1050

A.D. Rollett, M. Alvi, A. Brahme, J. Fridy[1], H. Weiland[1], J. Suni[1], S. Cheong[1]

Materials Science & Engineering Department, Carnegie Mellon University, Pittsburgh, PA 15213
[1]Alcoa Technical Center, PA 15609

Keywords: Recrystallization kinetics, grain orientation spread, texture, aluminum, JMAK.

Abstract

Recrystallization kinetics has been studied in hot rolled 1050 with the objective of understanding the local variation in the rate of recrystallization as a function of texture component. Automated electron back-scatter diffraction (EBSD, or OIM) has been used to quantify microstructures at various stages of recrystallization. Analysis of the grain orientation spread (GOS) was found to be the most effective method for partitioning EBSD maps into recrystallized and unrecrystallized regions. The cube component is weak in the as-deformed state but increases to between 25% and 40%, depending on annealing temperature. In order to verify that we understand the recrystallization process at the microstructural level, 3D Monte Carlo simulation of recrystallization has been undertaken using statistically reconstructed input microstructures to represent the deformed material.

1. Introduction

The microstructural and texture evolution during annealing of hot rolled samples of commercial purity aluminum alloy is an important way to influence the final properties of cold rolled sheets and finished products. The microstructural features of deformed and recrystallized regions differ considerably. Whereas the dislocation content of a deformed grain is high thereby giving a large intragranular orientation spread, recrystallized grains are characterized by low dislocation content having a small intragranular orientation spread. The present analysis uses this property of microstructure in identifying deformed and recrystallized regions in partially recrystallized samples.

The main aspect analysed in the present study is the intragranular orientation spread of deformed and recrystallized grains and the variation in different texture components in these regions. The orientation spread is defined as the misorientation angle between all the points in a grain and Grain Orientation Spread (GOS) is the average value of orientation spread in a grain. The difference in GOS value between deformed and recrystallized grains provides a useful way of partitioning the deformed and recrystallized regions in partially recrystallized and deformed samples scanned with automated Electron Back Scattered Diffraction (EBSD). Different methods have been analysed previously for obtaining recrystallized fraction from EBSD data, namely Image Quality (IQ) and Confidence Index (CI) [1, 2]. An advantage offered by the method based on individual orientations is that a fixed value can be used for deformed and recrystallized regions and this value can be used for all scans of the material. The regions partitioned in this way can be further analysed for texture evolution of deformed and recrystallized grains during annealing of deformed samples.

2. Experimental Procedure

The chemical composition of hot rolled Aluminum Alloy 1050 (AA1050) used in the present analysis is given in Table 1. The as received sheet was hot rolled at 325^{o}C and allowed to cool in air. As a consequence of slow cooling at room temperatures, the material showed a significant amount of recovery in the as-deformed structure. Samples of size 20mm×10mm×6mm were obtained from the hot rolled sheet and were annealed at 375^{o}C and 400^{o}C for time intervals ranging from 30s to 1800s for complete recrystallization of deformed samples. These samples were polished with SiC papers up to 1200 grade and 1µm alumina. The annealed samples were ground and electropolished with perchloric acid solution for characterization in a Philips FEI XL40 Field Emission Gun scanning electron microscope using TSL™ EBSD software. A typical scan area of 800µm×800µm was selected for a scan and on an average three scans were obtained from each sample surface. A step size of 1µm is used for deformed samples and 2µm for partially recrystallized and fully recrystallized samples.

Table 1: Chemical composition for AA1050 (mass % element)

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
Mass (%)	0.08	0.31	0.003	0.036	0.004	0.009	0.008	99.54

3. Recrystallization Kinetics Obtained from GOS

Measurements of intra-granular misorientation in metals and alloys have revealed the presence of orientation spread in deformed as well as recrystallized samples. [3] The orientation spread in a metallic sample corresponds directly to the level of deformation and to the dislocation content in that sample. A high value of orientation spread indicates a high geometrically necessary dislocation (GND) content and more deformation in the sample whereas the recrystallized samples are characterized by low dislocation content and a corresponding lower value of orientation spread as measured by GOS. A Grain Orientation Spread (GOS) parameter, defined as the average misorientation between all pixels within a grain is used for differentiating between the two types of regions.

An appropriate threshold GOS value must be determined in order to partition EBSD maps into deformed versus recrystallized regions. This value can be obtained by analysing fully recrystallized samples and analysing the distribution of GOS values. A cumulative frequency plot of GOS values for eight different fully recrystallized samples is shown in Fig 1. A threshold GOS value for distinguishing a recrystallized grain from an unrecrystallized one was chosen such that only 5% of the points in these fully recrystallized samples are counted as unrecrystallized. Based on this criterion, a threshold value of 3° was chosen for the present analysis. Grains with GOS>3° are considered unrecrystallized whereas grains with GOS <3° are deemed recrystallized. Another important parameter in the study of deformed and recrystallized samples with GOS criteria is the step size used in the scan. Although a larger step size can be used for fully recrystallized samples, a lower value had to be used for deformed samples to include more points in the recrystallized nuclei in deformed and partially recrystallized samples [3]. A step size of 2µm was used for partially recrystallized and fully recrystallized samples while a value of 1µm was used for deformed samples. The important parameters affecting the partitioning of deformed and recrystallized regions and eventually for selection of a nucleus among all the subgrains present are the minimum grain size used for defining a recrystallized grain and the presence of a high angle boundary surrounding a nucleus. The presence of a 15^{o} boundary misorientation and a grain size minimum of 5µm are used as secondary parameters for determining a potential nucleus.

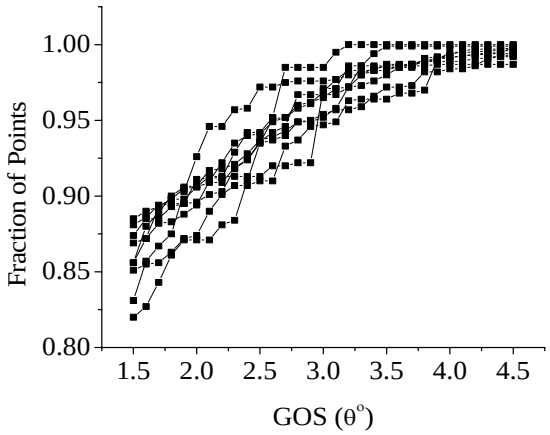
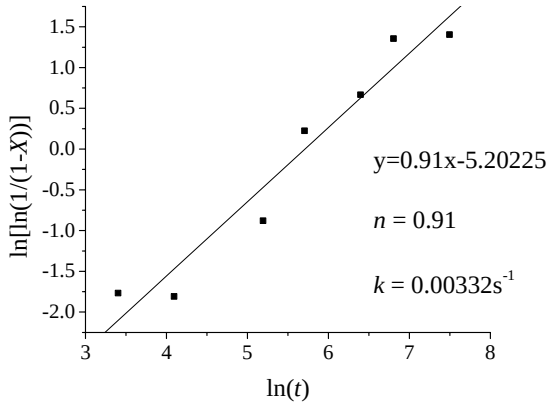


Figure 1: Variation of fraction of points with GOS for completely recrystallized samples.

Samples annealed for different time intervals at 375°C and 400°C were scanned and analysed. The scanned surfaces were partitioned into deformed and recrystallized regions using the GOS criterion of 3°. The JMAK parameters to characterize recrystallization kinetics were obtained from a (linear) regression analysis between the ln[ln(1/(1-*X*))] and ln(*t*) as indicated in Figure 2.



(a)

Figure 2: (a) Variation of $\ln[\ln(\frac{1}{1-X})]$ Vs. $\ln(t)$ for scanned samples annealed at 375°C.

4. Application of GOS Criteria to Analyse Texture Evolution

The use of Grain Orientation Spread as a reliable criterion for obtaining recrystallization kinetics is clearly indicated by the similarity in JMAK parameters obtained from GOS analysis and microhardness variation obtained in a previous analysis [4] as indicated in Table 2.

Table 2: JMAK parameters obtained from two methods of analysis.

Annealing Temperature (^oC)	Microhardness		GOS	
	n	$k(s^{-1})$	n	$k(s^{-1})$
375	0.87	0.00814	0.91	0.00332
400	0.92	0.0356	0.96	0.0106

The relatively low values of JMAK exponent (*n*) can be attributed to the fact that the hot rolled sheet was obtained from a commercial rolling line and allowed to cool slowly and,

therefore, had undergone significant recovery. [4] This criterion can also be used to partition the interface between deformed and recrystallized regions. The scanned files were analysed to obtain the orientation spread in individual grains. The entire scan area was partitioned into deformed and recrystallized regions based on the orientation spread of all the grains in the scanned area. The partitioned regions of the sample were further analysed to characterize their texture. Figure 3 shows the variation of various texture components in the deformed and recrystallized regions of the scans. The main texture component in the recrystallized regions for samples annealed at 375^{o}C and 400^{o}C is the cube component whereas the brass and S components dominate the deformed regions, Figure 3. These observations correlate well with the texture evolution observed during the recrystallization of commercial purity aluminum alloys. [5]

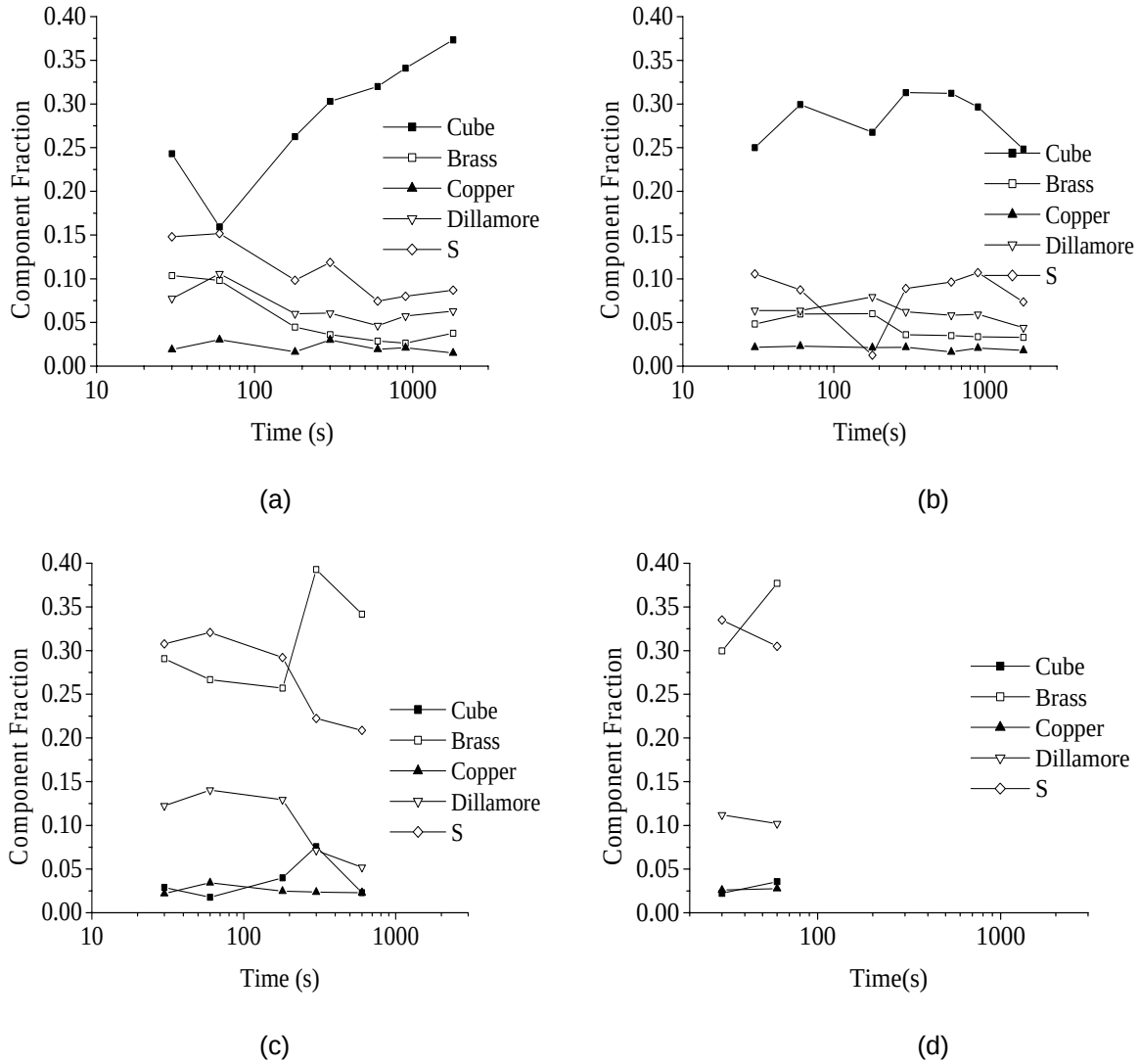


Figure 3: Variation of volume fractions of different texture components in partitioned samples. (a) Recrystallized regions for samples annealed at 375^{o}C. (b) Recrystallized regions for samples annealed at 400^{o}C. (c) Deformed region for samples annealed at 375^{o}C. (d) Deformed Regions for samples annealed at 400^{o}C.

5. Monte Carlo Simulation

Simulation of the recrystallization process was undertaken in order to understand the annealing response of the materials and to provide, ultimately, a predictive model. The simulation domain for generating the microstructure was a 3D regular grid (100x100x100

sites). EBSD maps of the as-deformed Al1050 were used to generate microstructures for simulation. Orientation maps were obtained on two orthogonal observation planes using electron back scattering diffraction (EBSD). Figure 4 shows the experimental geometry arranged such that the sample axis e_1 is aligned parallel to the rolling direction, sample axis e_2 is parallel to the transverse direction and the sample axis e_3 is parallel to the normal direction. A distribution of overlapping ellipsoids was obtained using the geometry information from the orientation maps. Out of the distribution a subset of ellipsoids was selected to maximize the space filling and minimize overlap. Next, a Voronoi tessellation was performed on a random sample of points selected from the simulation domain. Each of the Voronoi cells thus obtained was assigned to an ellipsoid. This procedure ensured a microstructure that was space filling with no overlap between the grains. [6]

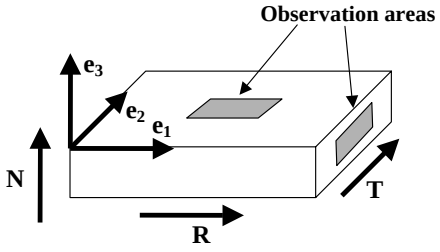


Figure 4: Experimental Geometry.

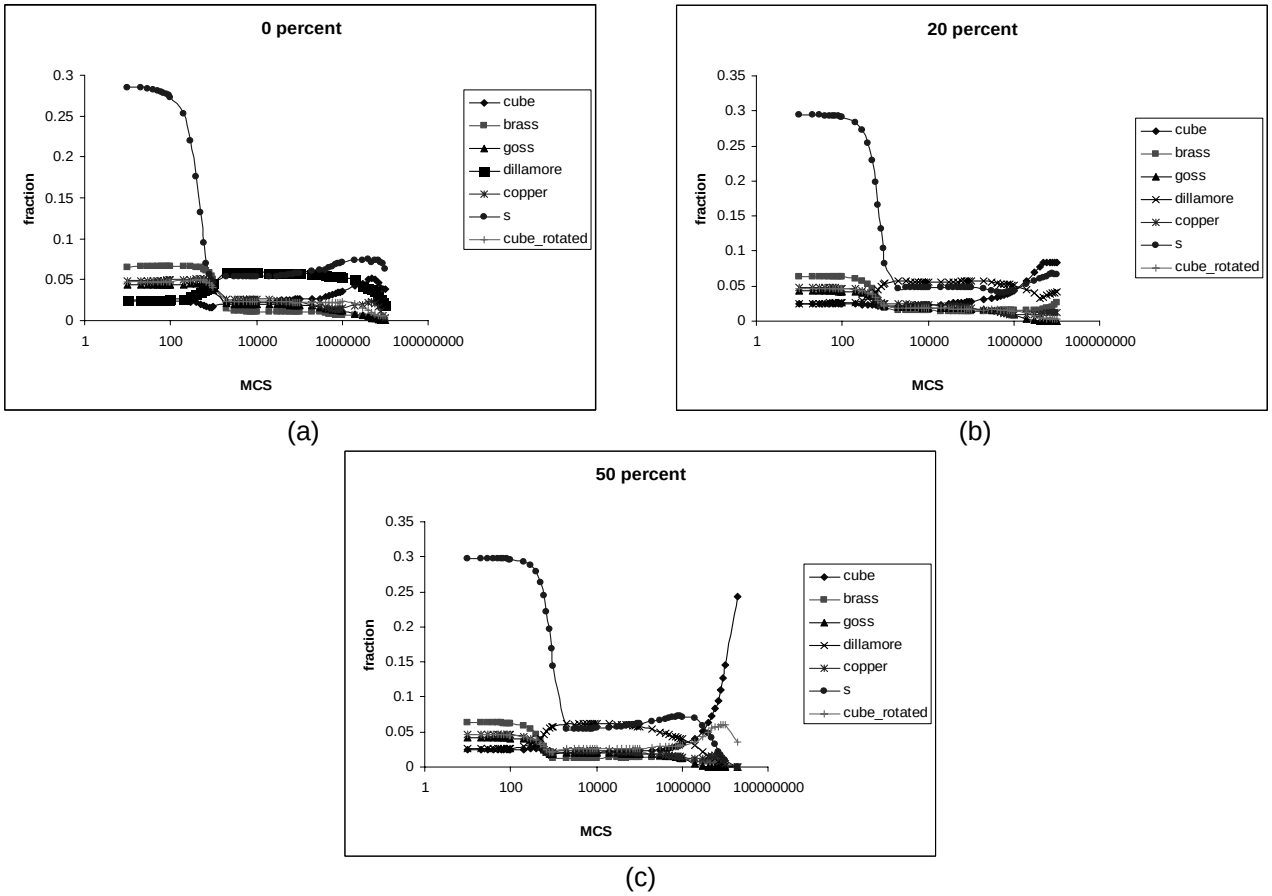


Figure 5: Effect on evolution of various components due to nucleation scheme. P is (a) 0, (b) 0.2, (c) 0.5.

Once the microstructure had been generated, orientations were assigned to the grains taking into account the nearest neighbour relationships. This was done in following manner. The grains were assigned random orientations. Then error between the assigned orientations and the observed orientations was minimized to arrive at the final assignment of texture. Both orientation distribution function, ODF, and misorientation distribution function, MDF, were used for the assignment. Monte Carlo models, used commonly to describe grain growth and recrystallization [7–9], were used. In particular the Potts model

was used because of the flexibility it offers in terms of assigning materials properties such as energy and mobility, and because of its computational efficiency.

Simulations were carried out on a microstructure containing pancake like grains (corresponding to the observed grain shapes in the experiments). Nuclei were introduced at the start of simulations, i.e. time *t=0*. A substantial fraction of the deformation texture did not correspond to any of the standard texture components commonly used for texture analysis in FCC metals. For the purposes of this paper, this part of the texture is referred to as the 'undefined components' whose centre of gravity is approximately (90, 0, 15) and (35, 0, 5) in (Bunge) Euler angles. Three independent simulations were carried out by changing the probability, P, of insertion of nuclei next to these dominant components. The initial volume fraction of nuclei was held constant at 0.02. In the three simulations discussed, the probability P was varied from 0 to 0.2 to 0.5. Figure 5 shows the evolution of the different texture components in the three simulations. Table 3 summarizes the results. Evidently the cube component depends strongly on the probability P.

Table 3: Change in the volume fraction of cube as we change the probability of nuclei occurring next to the "undefined" texture

Probability(P) %	Volume fraction of cube
0	0.05
20	0.085
50	0.243

6. Conclusions

The kinetics of recrystallization have been analysed for hot rolled AA1050 annealed at 375^{o}C and 400^{o}C using the Grain Orientation Spread (GOS) criterion to partition EBSD maps. A GOS value of 3° was chosen as a cutoff for orientation spread for differentiating between deformed and recrystallized grains. The scanned samples partitioned on the basis of GOS criterion were also analysed for texture evolution in deformed and recrystallized regions. The main texture component in the recrystallized regions is cube where as the main texture components in deformed region are brass and S component. The textural evolution during simulation of recrystallization yields comparable results to the texture evolution observed during recrystallization of commercial purity aluminum alloys.

Reference

[1] M.H. Alvi, B.S. El-Dasher, and A.D. Rollett, Hot Deformation of Aluminum Alloys III, p.3-12 ed. Z. Jin, A. Beaudoin, T. Bieler, and B. Radhakrishnan (2003).

[2] J. Tarasiuk, P. Gerber and B. Bacroix, Acta Mater., 50, 1467-1477, (2002).

[3] V. Randle and O. Engler, Introduction to texture analysis, Gordon & Breach Science Publishers, Amsterdam, p.229 (2000).

[4] M.H.Alvi, S.Cheong, H.Weiland and A.D. Rollett, 1st International Symposium on Metallurgical Modelling for Aluminium Alloys, p.191-197 ed. M. Tiryakioglu, L.A. Lalli (2003).

[5] K.D. Vernon-Parry, T. Furu, D.J. Jensen and F.J. Humphreys, Mat. Sci. & Tech.,10, 889-896, (1996).

[6] D.M. Saylor, J. Fridy, B.S. El-Dasher, K. Jung, and A.D. Rollett, Metall. Mater. Trans., *in press* 2004.

[7] M. Miodownik, A.W. Godfrey, E.A. Holm, and D.A. Hughes, Acta Mater. 47, 2661-2668, (1999)

[8] M.P. Anderson, G.S. Grest, D.J. Srolovitz: Phil. Mag. *B*, 59, 293, (1989).

[9] G.N. Hassold, E.A. Holm: Computers in Physics, 7, 97 (1993).