Influence of Deformation Parameters on Deformation and Recrystallization Texture in Al-Mg-Si Alloys

Bruce Davis[1], F. John Humphreys[1], Kevin M. Gatenby[2], Carl P. Johnson[2]
[1] Manchester Materials Science Centre, Grosvenor Street, Manchester, M1 7HS.
[2] Alcan International Limited, Banbury Laboratory, Southam Road, Banbury, Oxon, OX16 7SP

Abstract A study of model Al-Mg-Si alloys has been carried out to investigate the rolling parameters that affect texture development following deformation and recrystallization. These included deformation temperature; strain rate; pre-deformation homogenization temperature; and dispersoid content. The material was hot deformed under plain strain compression (PSC) conditions, similar to those found in industrial rolling mills. Following deformation, the alloys were annealed to study their recrystallization behaviour. It was found that the CUBE component was increased by deforming at higher temperatures and lower strain rates. Altering the pre-deformation homogenization temperature had little effect, but it was found that the presence of dispersoids in the material caused a reduction in the intensity of the CUBE component.

Keywords: *Aluminium alloys, Hot deformation, Recrystallization, Texture.*

1. Introduction

Work has been carried out to investigate the influence of deformation parameters on texture development during the production of aluminium sheet from the 6XXX series alloys. These included alloy content; pre-deformation homogenization temperature; strain rate; and deformation temperature.

Texture development is important in the production of sheet metal because of its influence on formability and surface finish. Through a greater understanding of how deformation parameters affect texture it is hoped to improve the quality of the sheet products for the automotive industry.

2. Materials and Experiment Methods

The materials used in this study were aluminium-magnesium-silicon alloys. Three compositions were cast containing different levels of chrome and manganese, see Table 1. Due to the low solubility of Cr and Mn these elements form intermetallic dispersoid particles. The volume fraction of dispersoid particles increased from alloy A to C with increasing wt% of the elements.

Table 1. *Alloy composition.*

Alloy	Si	Fe	Mn	Mg	Cr	Ti	B
A	1.17	0.3	<0.001	0.45	<0.001	0.007	0.001
B	1.16	0.29	0.07	0.45	0.03	0.008	0.001
C	1.19	0.29	0.29	0.46	0.032	0.008	0.001

The cast ingots were scalped, homogenized at 560°C for eight hours, and hot rolled to a reduction of 50% to break up the existing dendritic microstructure. The material was then cut into blocks for plain strain compression (PSC). The PSC blocks were given a further homogenization at 350°C for eight hours and then water quenched. To investigate the effects of pre-deformation homogenization temperature samples were also annealed at 500°C, and 560°C.

PSC testing was used to simulate the deformation that occurs during rolling, and the strain rate and deformation temperature were varied to investigate their influence on texture. The development of recrystallization textures was studied by annealing the deformed material in a salt bath at 400°C for one hour.

amount of fine particles causes the recrystallized grain size to increase and also produces a stronger CUBE texture [3-6]. Other work suggests no effect [4]. This study has shown that although a higher number of dispersoids produces a larger grain size, it reduces the intensity of CUBE in 6XXX series alloys.

3.3 Effect of Temperature and Strain Rate on the Development of Texture

The effect of temperature and strain rate on the deformation of a material are closely linked, and therefore cannot be separated. These two parameters are often incorporated into a single variable; the Zener-Hollomon Parameter, Z, given as:- $Z=\dot{\varepsilon}\exp(Q/RT)$, where Q is the activation energy. Their influence on the development of texture is dealt with in the following sections.

3.3.1 Influence of Strain Rate

The effect of strain rate on the development of deformation and recrystallization textures was studied by deforming alloy A at 350°C to a strain of 0.8. Three strain rates were investigated, 1, 18, and 100 s^{-1}.

Figure 5a shows the intensity of the texture components found in the deformed samples. It can be seen that the sample deformed at 1 s^{-1} had a stronger intensity of CUBE compared to the samples deformed at 40 s^{-1} and 100 s^{-1}, i.e. as strain rate increased the CUBE intensity decreased.

Following recrystallization the CUBE texture became stronger in all the samples (Figure 5b). The specimen deformed at 1 s^{-1} was found to have a much more intense CUBE component than either of the other samples.

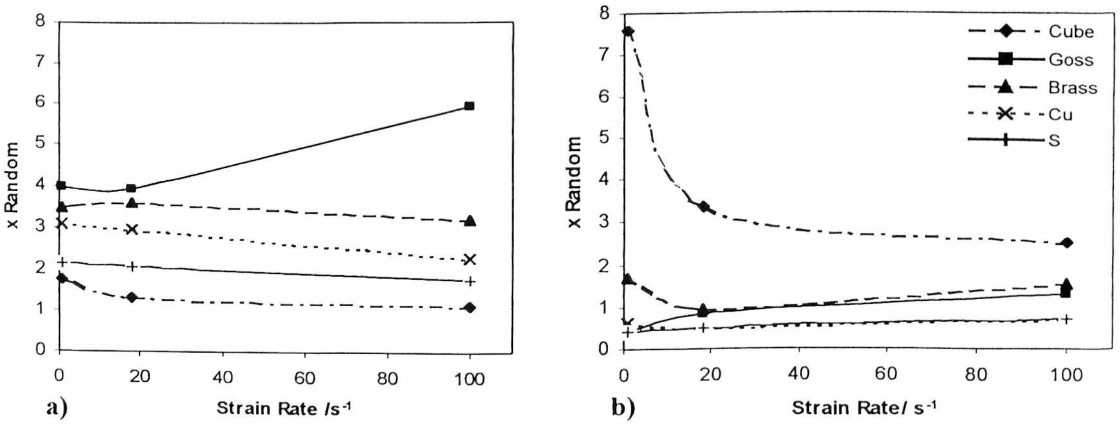

Figure 5. Graphs showing the intensity of the texture components of samples deformed at strain rates of 1, 18, 100 s^{-1}; a) Deformed material, b) Recrystallized.

3.3.2 Influence of Deformation Temperature on the Development of Texture

Samples of alloy A were deformed under PSC conditions to a strain of 1.6, at a strain rate of 18s^{-1}, and at temperatures of 350, 450, and 550°C.

The graph in Figure 6a shows the deformation texture components. It can be seen that the samples deformed at 350°C and 450°C contained predominantly rolling components i.e. GOSS, BRASS, CU, and S. However, the sample deformed at 550°C shows a low intensity of the rolling components. The intensity of CUBE is higher in the sample deformed at 450°C and 550°C when compared to the sample deformed at 350°C.

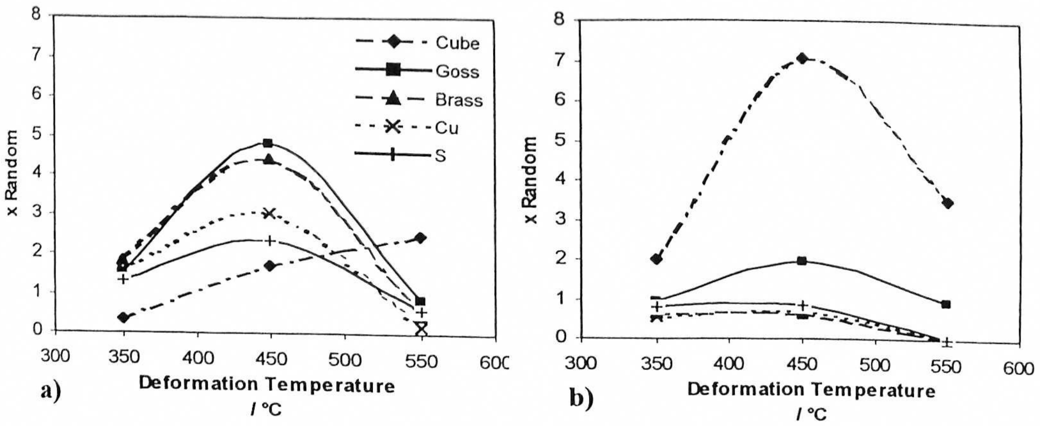

Figure 6. Graphs showing the intensities of the texture components found in the alloy. a) Deformation textures. b)Recrystallization textures.

3.3.3 Discussion

The results show that there was an increase in CUBE texture when the material was deformed at high temperature and low strain rates, i.e. low Z. This observation is consistent with work on AA3XXX alloys [8] and other dilute aluminium alloys [11]. There are two factors which maybe responsible.

The increased intensity of CUBE in the material deformed at lower strain rates may stem from the type of recrystallization nucleation sites that form during deformation. In competition with the CUBE orientation, are grains that originate from particle stimulated nucleation (PSN). These nucleate from deformation zones that form around large hard particles, such as constituent particles. The nuclei tend to be randomly orientated and hence generate a more non-specific texture. It is the formation of the deformation zones that is influenced by strain rate. Work carried out by Humphreys and Kalu [7] suggests that at low values of strain rate dislocations are able to climb around large particles. This prevents dislocation build up, and stops the formation of deformation zones. They have shown that at a given temperature there is a critical strain rate and particle size at which deformation zones begin to form. This is given by the equation below:-

$$\dot{\varepsilon}_c = \frac{K_1 \exp\left(-\frac{Q_S}{RT}\right)}{Td^2} + \frac{K_2 \exp\left(-\frac{Q_b}{RT}\right)}{Td^3}$$

Where K_1, K_2 are constants and Q_s, Q_b are the activation energies for volume and boundary diffusion. At a deformation temp. of 350°C and an average particle size of 1μm, as was found in the alloys used for this project, the critical strain rate is calculated to be 2 s^{-1}. This fits with the data, which suggests deforming at strain rates above 1s^{-1} increased the number of deformation zones.

The increase of the CUBE component in the samples deformed at 450°C and 550°C relative to the one deformed at 350°C is in agreement with previous work on aluminium and Al-Mg-Mn alloys [8,9,10]. The increase in the stability of the CUBE texture has been attributed to non-octahedral slip at high temperatures, i.e. low Z, [9].

The reduction of the rolling components in the material deformed at 550°C compared to the samples deformed at 350 and 450°C maybe caused by partial recrystallization between deformation and quenching.

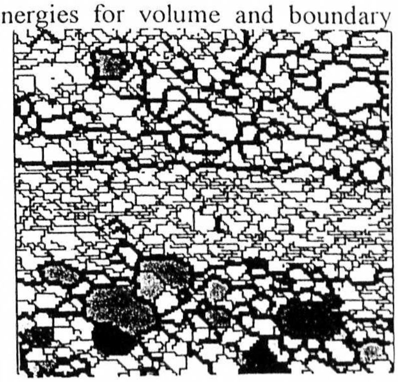

***Figure** 7. Orientation map of sample deformed at 350°C showing presence of partially recrystallized CUBE grains*

Analysis of a sample deformed at 350°C was carried out using Electron Back Scatter Pattern Analysis (EBSP) to show the orientation of the deformed structure. Figure 7 is an orientation map showing sub-grain and grain boundaries . At this much lower temperature there is evidence of the early stages of recrystallization. The shaded areas are CUBE or NEAR CUBE orientated grains. It can be seen that there are a number of CUBE grains surrounded by high angle boundaries and containing no sub grain boundaries, indicating that they are recrystallized grains.

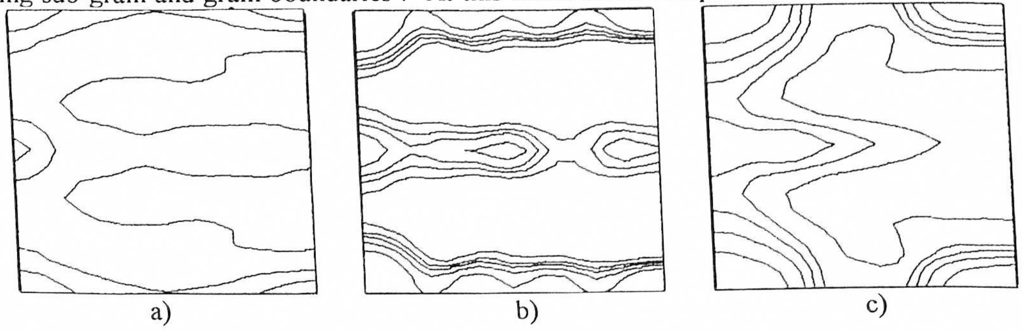
a) b) c)

Figure 8. *Orientation distribution cuts of $\phi_2=0$. The contours represent the intensity of the different texture components in the alloys following recrystallization. The alloys were deformed at:- a)350°C b)450°C c)550°C.*

Figure 6b shows the intensities of the texture components found in the recrystallized samples. It can be seen that recrystallization has caused an increase in the intensity of CUBE in all the specimens. This is common in recrystallized f.c.c. metals [11]. Figure 8 shows the $\phi_2=0$ ODF cuts of the recrystallized samples. It can be seen that the samples deformed at 450°C and 550°C contain a stronger CUBE component relative to the sample deformed at 350°C. If a larger amount of CUBE orientated grains survive deformation at higher temperatures, then this would lead to a greater number of CUBE nuclei being present in the material. Following recrystallization, this would result in a stronger CUBE texture.

4. Acknowledgements

The authors would like to acknowledge the financial support provided by the European Physical Science Research Council, and Alcan International. Thanks is also given to their colleagues for helpful discussions and contributions to the paper.

5. Bibliography

[1] F.J. Humphreys and M.Hatherly, Recrystallization and Related Annealing Phenomena, Pub. Elseiver Science Ltd. Oxford (1995)

[2] S.J. Lillywhite, F.J. Humphreys and P.B. Prangnell, Proc. THERMEC'97, Ed. Chandra, Wollongong, TMS, 1127

[3] O. Engler, A. Chavooshi, J. Hirsch, and G. Gottstein: Mater. Sci. Forum, 157 (1994) 939

[4] R.L. Higginson, M. Aindow, and P.S. Bate: Mater. Sci. and Eng A225 (1997), 9

[5] F.J. Humphreys, and I. Brough: Proc. Rex.'96, Ed (1996), 315

[6] O. Daaland and E. Nes, Acta.: Mater., 44 (1996), 1413

[7] F.J. Humphreys and P.N. Kalu: Acta. Mater., 35 (1987), 2815

[8] O. Daaland and E. Nes: Acta. Mater., 44 (1996), 1389

[9] C. Maurice and J.H. Driver: Acta. Metall. Mater., 41 (1993), 1653

[10] K.D. Vernon-Parry, T. Furu, D.J. Jensen, and F.J. Humphreys: Mater. Sci. & Tech., 12 (1996), 889

[11] R.K. Bolingbroke, T. Furu, D. J. Jensen, and K. Vernon-Parry: Mater. Sci. & Tech., 12 (1996), 897