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THE EFFECT OF NUCLEATION SITES FOR RECRYSTALLISATION ON ANNEALING TEXTURE AND EARING IN ALUMINIUM

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ABSTRACT

It is important to control the recrystallised texture in the aluminium alloy used for beverage cans. A model has previously been proposed which explains the recrystallised texture of the hot bands as a competition between grains nucleated either in transition bands or around coarse particles. Present work confirms that most recrystallised grains are nucleated around coarse particles and that these do not have any preferred orientation. Possibly the smaller of the coarse particles have a weak tendency to nucleate grains in a retained rolling orientation. Other recrystallised grains not associated with particles are preferably oriented on the (100)-fibre parallel to the rolling direction including the important cube and Goss orientations.

A light cold rolling of the hot bands prior to annealing can increase the final cube texture, but only if the hot band is slightly recrystallised. This is explained by a destruction of most small recrystallised grains while a few selected grains are conserved. Recrystallised grains in the vicinity of coarse particles are prone to destruction while grains oriented in the actual cube position for the applied cold rolling reduction are especially apt for conservation.

INTRODUCTION

The material generally used for beverage cans, DC-cast AA3004, is subject to severe and conflicting property requirements. One of the most critical requirements is to develop a strong cube texture with pronounced tendency for 0°/90° earing in the annealed state after hot rolling. A model has previously been proposed[1], which assumes that the texture developed during recrystallisation after hot rolling is a competition mainly between recrystallised grains nucleated either in transition bands or in the vicinity of coarse particles, particle stimulated nucleation (PSN). Transition bands will nucleate grains within the (100)-fibre parallel to the rolling direction. The desired cube orientation, (001)[100] is the most important one but the Goss orientation (011)[100] is also of importance.

Grains nucleated around coarse particles are supposed to have either a random spread or a retained rolling texture. They will suppress the development of a strong recrystallised cube texture and hence decrease the tendency for 0°/90° earing. The efficiency of PSN depends on the number of particles larger than a critical size which can be calculated from measured values of subgrain size together with fraction and radius of dispersoids. Fig. 1 shows the effect of the number density of efficient particles on the earing after recrystallisation[1]. The first part of this investigation was carried out to test if the particles are preferential nucleation sites for recrystallised grains and to determine which orientations these grains have. The orientations of recrystallised grains which are not connected with particles were also measured.

It has been reported[1,2] that a light cold rolling reduction (~8%) of the hot rolled strip can increase the level of the desirable 0°/90° earing after a subsequent anneal. Additional experiments were performed to explain the effect on final earing behaviour if a light cold rolling reduction is carried out prior to annealing of the hot bands.

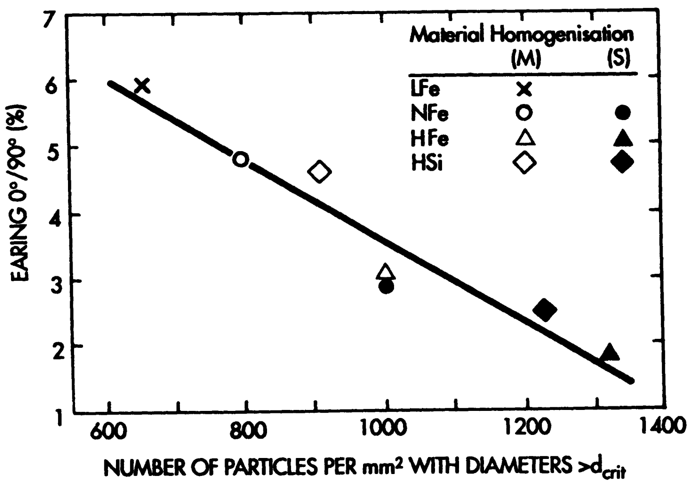


Fig. 1 Earing level in annealed hot bands as a function of number density of particles sufficiently large to initiate viable recrystallisation.

MATERIALS AND EXPERIMENTAL PROCEDURE

The alloys used were 308 mm thick commercially DC-cast slabs. Their standard chemical composition was 1.2% Mg, 1.0% Mn, 0.45% Fe, 0.20% Si, 0.15% Cu and 0.03% Ti. Casts were made having lower iron ("LFe", 0.31% Fe), higher iron ("HFe", 0.58% Fe) and higher silicon ("HSi", 0.30% Si) contents. Different processing parameters were applied to the materials and their effect upon earing and texture are reported elsewhere[1].

Mechanical testing and microstructural investigations were carried out on the as coiled hot bands. Small recrystallised grains were examined in a SEM with the EBSP (Electron Back Scattering Pattern) technique. Four of the materials were given a light cold rolling reduction of 8% in a laboratory mill prior to the subsequent annealing. One of these materials was also lightly cold rolled at different angles to the original hot rolling direction. All recrystallised bands were examined optically and their earing behaviour measured. Textures of all annealed bands were determined from standard reflection pole figures and also using the orientation distribution function (ODF) method for a few selected samples.

OBSERVATIONS AND RESULTS

The degree of recrystallisation in the hot bands varied to some extent from one band to another but they all had a dominating deformed microstructure and texture with corresponding 45° earing behaviour. Complete recrystallisation occured during the subsequent annealing and the earing behaviour transformed to 0/90° type.

Texture measurements of pole figures showed the existence of a significant cube texture in all annealed bands although the textures were fairly inhomogeneous through the thickness. ODF's were determined for a number of annealed bands at a depth of 1/3 of the thickness. An example of such an ODF is shown in Fig. 2 for alloy LFe. The strongest texture component is the cube orientation with a spread about the rolling direction to the Goss orientation where another peak exists. Fig. 3 shows the existing texture peaks plotted versus the number density of viable particles capable of PSN. The cube component is the strongest single component in all bands. Both the Goss and R ~(123)[412] components are always present. These increase their strength in the same bands as the cube component increases at the expense of the volume fraction of material not associated with any particular component i.e. a random spread. The volume fraction of random spread orientations dominates (>50%) in all bands.

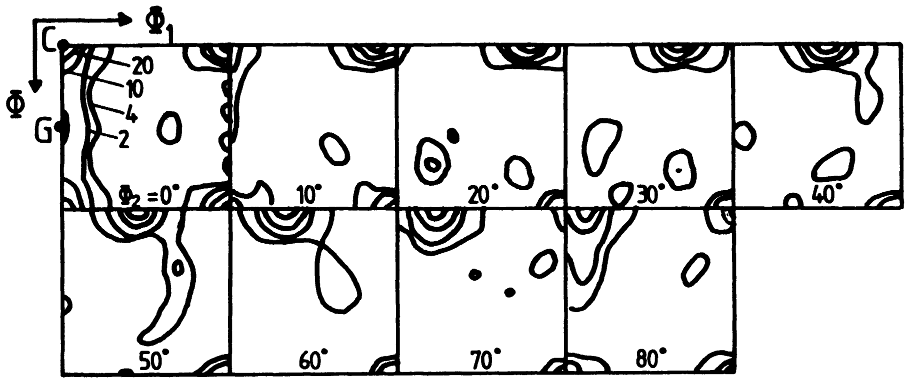


Fig. 2 Example of ODF for the annealed hot band with strongest texture (alloy LFe). Positions of cube and Goss components are at C and G respectively.

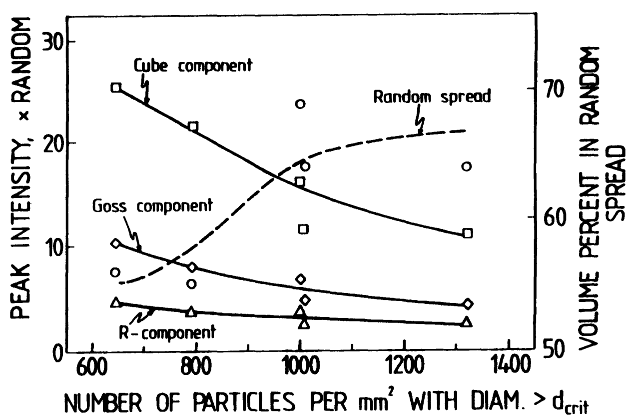


Fig. 3 Peak intensity of principal orientations and estimated volume percent of material not associated with major components for annealed bands as a function of number density of particles sufficiently large to initiate viable recrystallisation.

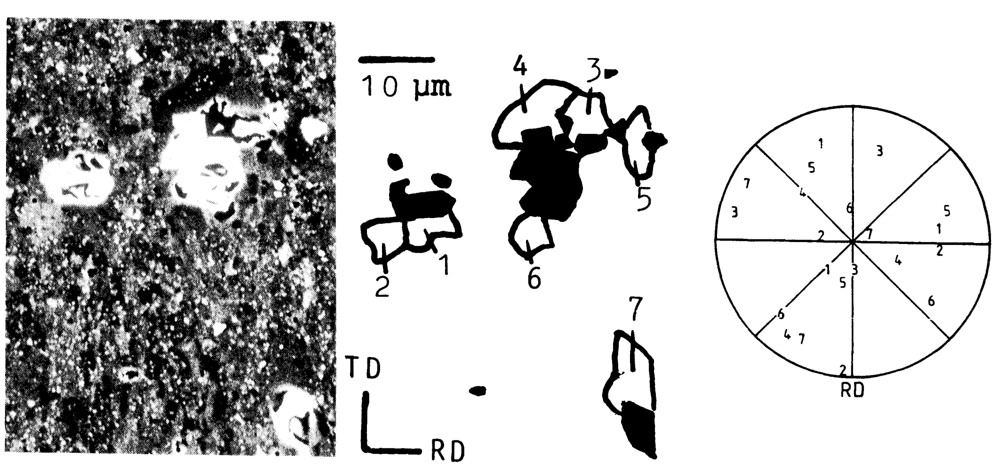
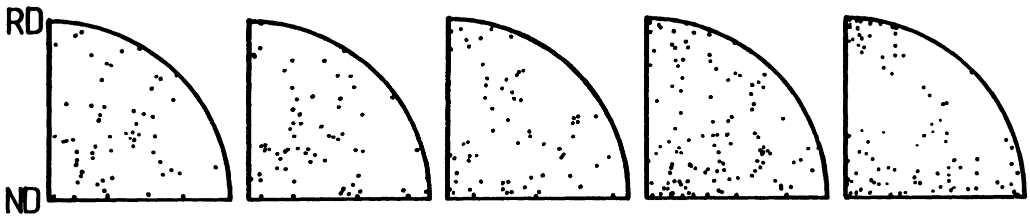


Fig. 4 Small recrystallised grains and their orientations around coarse particles. Mn-rich dispersoids show up as white dots.

Examination of coiled bands by optical microscopy, SEM and TEM showed that in the very early stages of recrystallisation most recrystallised grains were associated with coarse particles. An example of this is shown in Fig. 4 from SEM/BSE where the orientations for the recrystallised grains are indicated in a (100) stereographic projection. The coarse particles often appear in cluster when viewed as here in the rolling plane at 1/3 thickness. Such clusters are prominent sites for recrystallisation. Small Mn-rich dispersoids visible as white dots are sparce in certain regions, especially around some coarse particles. These regions seem to be most efficient for nucleation of recrystallised grains. The EBSP often changes from one particular pattern to a completely different pattern in the vicinity of coarse particles whereas it is fairly constant when visible in the subgrain matrix away from particles. This indicates that subgrains or small recrystallised grains often have large misorientations around coarse particles.

The hot band of alloy LFe with low iron content was suitable for further studies of grain orientations at a very early stage of recrystallisation. An area of 0.25 mm² was examined and totally 135 recrystallised grains were found of which 103 were in contact with one or more particles. The results in Fig. 5 show that the recrystallised grains which nucleated around coarse particles have no preferred orientation. Possibly there is a weak tendency for a retained rolling texture in grains around the smaller of the coarse particles. Recrystallised grains not associated with particles show a clear tendency to be oriented in the (100)-fibre parallel to the rolling direction, i.e. the orientation fibre found in the annealed band between cube and Goss components.



a) d<3µm b) 3<d<4µm c) 4<d<5,5 µm d) d>5,5 µm e)

Fig. 5 (100) pole figures for small recrystallised grains at particles (a-d) and small grains nucleated elsewhere (e).

The effect of a light cold rolling reduction prior to annealing on earing after complete recrystallisation is plotted in Fig. 6 for four different bands. The amount of recrystallisation in these hot bands is here visualised as the proof stress where 220 MPa corresponds to no recrystallisation and 140 MPa to about 10% recrystallisation. An increased amount of recrystallisation up to ~10% increased the effect of maximising the 0°/90° earing while the material with no recrystallisation prior to the light cold rolling was not affected. The final recrystallised grain size always increased considerably in the hot bands which had started to recrystallise but did not change for the hot band with no recrystallisation. One of the hot bands was lightly cold rolled at different angles Ø about the original hot rolling direction before annealing. The results in Fig. 7 show a great influence of the direction of the light cold rolling upon earing and texture. The earing and (200)-texture decreases with increasing angle Ø to a minimum at 45°. There are actually 8 ears at $Ø^1$ = ±15° away from the original hot rolling direction for the 45° cups. Notable is also that the maximum height of the ears for the 15° and 30° cups are found at an angle $Ø^1$ away from the original hot rolling direction towards the applied cold rolling reduction. All these cold rolled samples showed a similar and considerably coarser grain size than the sample without cold rolling.

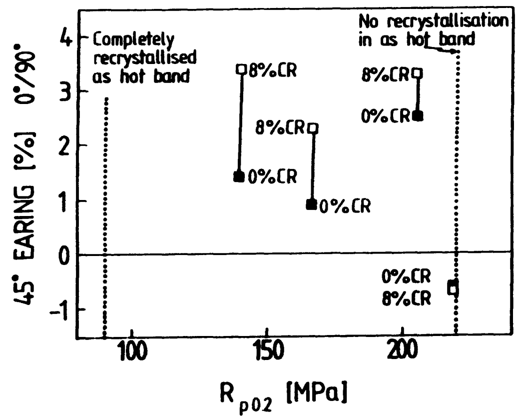


Fig. 6 The effect of a light (8%) cold reduction applied to hot bands on final earing behavior on fully annealed material. Different hot band conditions are indicated by their proof stresses.

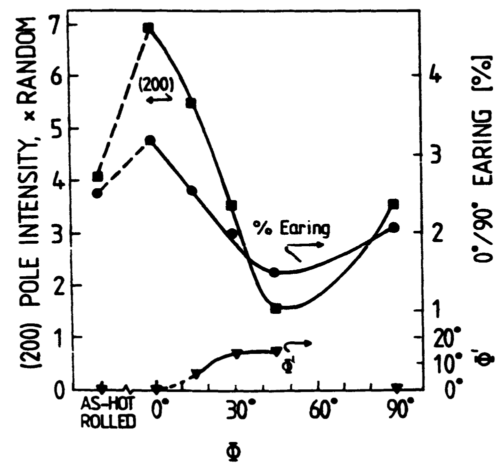


Fig. 7 (200)-texture, earing height and position Ø'as a function of angle Ø between hot and cold rolling directions.

DISCUSSION

No preferred orientation was found for the recrystallised grains connected with the coarse particles. This combined with the preferred texture for other grains on the orientation fibre between cube and Goss supports the previously proposed model[1]. The orientations of the grains at this very early stage of recrystallisation also agree well with the ODF for the annealed band. It is therefore reasonable to assume that the first existing recrystallised grains make a major contribution to the annealed texture in this material after the applied batch annealing process.

PSN has recently been reviewed by Humphreys[3] and the observations in this investigation agree with previous ones. Large misorientations were often found in subgrains surrounding coarse particles. At some particles, a few of these subgrains had grown enough to become small recrystallised grains. Especially groups of particles were efficient for PSN even if each individual particle was rather small. The Zener drag effect of dispersoids included in the model has also been observed by others[4] [5] to decrease the efficiency for PSN. In this investigation some very coarse particles were observed not to initiate PSN while other smaller particles did. The efficiency was observed to decrease if the matrix close to the coarse particle contained dispersoids as shown in Fig. 4.

Ørsund and Nes[6] have proposed and shown that PSN may lead to a retained rolling texture after recrystallisation. This happens if a subgrain in the surrounding matrix consumes the deformation zone and hence the orientation of the recrystallised grain is inherited from the deformation texture. This is not the situation in present material apart from possibly PSN around the smaller coarse particles, compare Fig. 5. The results of the EBSP measurements also show some areas with very low density of poles which indicates that some orientations may not be formed around particles.

The majority of the measured recrystallised grains, 76%, are connected with particles at the very early stage of recrystallisation. This figure is higher than the 55% of the volume within the random spread calculated from ODF's for the annealed material. This may be explained by a preferred growth effect for cube grains compared to other orientations or by the fact that not all PSN recrystallised grains are able to grow. There is a risk of overestimating the percentage of grains nucleated at particles, since some of the nuclei may be originated elsewhere. The areas around particles were investigated more carefully than other areas.

A consequence of the model is that the annealed grain size is decreased by an increased number of active nucleation sites as previously shown[1]. Destruction of small active growing grains at an early stage of the recrystallisation would therefore increase final grain size after annealing. Recrystallised grains are probably more affected than deformed material when a light deformation is applied. New dislocations substructures build up fast in the recrystallised regions leading to a less favourable situation for further growth during a subsequent anneal. In particular, recrystallised grains in the vicinity of hard second phase particles ought to be susceptible to such destruction. This can explain why a light cold reduction prior to annealing only increases the final grain size in those hot bands which had started to recrystallise.

EBSP measurements show that other recrystallised grains exist within the [100]//RD fibre texture which are not associated with particles. A cold reduction will also tend to eliminate these nuclei. However, cube oriented grains have a lower deformation hardening than others for plain strain compression and they recover faster due to the weak interaction of the dislocations[7]. It has been shown that a strong initaial cube texture is rather stable for plain strain compression[8] and not very easily rotated towards the more stable rolling orientations. These grains are therefore expected to be more stable and easily conserved the closer they are to the ideal cube position for a certain cold rolling. These conditions apply for light cold rolling with $\emptyset = 0°$ and $90°$. A light cold rolling at different angles, $\emptyset$, to the original direction will therefore give maximum cube texture after annealing when $\emptyset = 0°$ and minimum when $\emptyset = 45°$. This explanation is supported by the earing height and (200)-texture results. For cold rolling directions between 0° and 90° the maximum earing heights will lie between the hot rolling direction and the applied cold rolling direction. This is a consequence of both the number of nucleation sites and their ability to be conserved during the light cold rolling.

CONCLUSIONS

(i) Coarse particles and especially groups of particles provide nucleation sites for recrystallised grains. Their efficiency is decreased if they are surrounded by a matrix containing dispersoids.

(ii) The grains nucleated around coarse particles have no global preferred orientation. Possibly there is a weak tendency for a retained rolling texture in grains surrounding the smallest coarse particles (<~4μm diameter).

(iii) Other recrystallised grains, nucleated supposedly in transition bands, have a preferred texture along the fibre between the cube and Goss orientations.

(iv) The annealed texture, earing behaviour and grain size are only influenced by a light (8 %) cold rolling reduction if the hot band has started to recrystallise.

(v) Most small recrystallised grains are destroyed by a light cold rolling and impeded from further growth in a subsequent annealing.

(vi) Cube oriented grains in the actual cold rolling direction are more apt than others to be conserved.

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