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The variation of earing and texture components during annealing treatments of a 3003-type aluminium alloy

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Abstract. In this research work the effect of manufacturing parameters on the relationship between the developed crystallographic texture and the anisotropy characteristic earing was studied for a 3003 aluminium alloy, which alloy is broadly applied worldwide. The parameters of the cold rolling subsequent annealing heat treatments were varied and the developed texture and earing were studied. The initial material was a hot rolled sheet, which was cold rolled to the final thickness (ε≅1.94), then the samples were heat treated at 190°C, 280°C and 380°C, for 1 to 5 hours. Afterwards XRD examinations were used to evaluate the crystallographic texture. The earing numbers were determined by an industrial partner. The low-temperature annealing resulted in increased rolling texture due to the recovery of the sheet. At temperatures of 280°C the time-dependence of the recrystallization can be seen. Thus, on these temperatures the recrystallization was PSN. At 380°C the classic high-angle boundary movement involved recrystallization occurred. It can be seen altogether that raising the temperature, or the time duration of the annealing generally causes the 45°-type earing index number to gradually decrease. The results provide a good base for the optimization of the given technology, moreover it provides data for the simulation based researches.

1. Introduction

In the most cases the aluminium sheets, these semi-products are deep-drawn. Therefore, the critical property of the sheets, is the deep-drawability. This is defined explicitly by the crystallographic texture. The crystallographic texture describes the crystallographic orientation of all grains in the material, thus it defines the degree of anisotropy. This is an important aspect, because currently, in most industrial environments, the effectivity of the annealing is characterized by the hardness, which does not completely describe the behaviour of the material.

The main alloying component in the 3003 aluminium alloy is the manganese. During heat-treatments, raising the temperature causes the dissolution of the manganese from the solid solution, forming compounds. These precipitations have effect on the recrystallization occurring during annealing, hence they are nucleating sites

This aim of this research is to characterize the kinetics of the physical metallurgical processes and to link it to the earing, the index number of the formability.

2. Examinations

During experiments a 7 mm thick hot-rolled sheet was cold-rolled to 1 mm thickness. This was followed by annealing heat treatments at three different temperatures (190°C, 280°C, 380°C) for five different time durations (1-5 h). On Figure 1. the route of the examinations can be seen. The heat treatments were carried out in an air atmosphere furnace: The sheets were put into the furnace, heated up to the annealing temperature and after the heat treatments the sheets were taken out and cooled down in room temperature air.

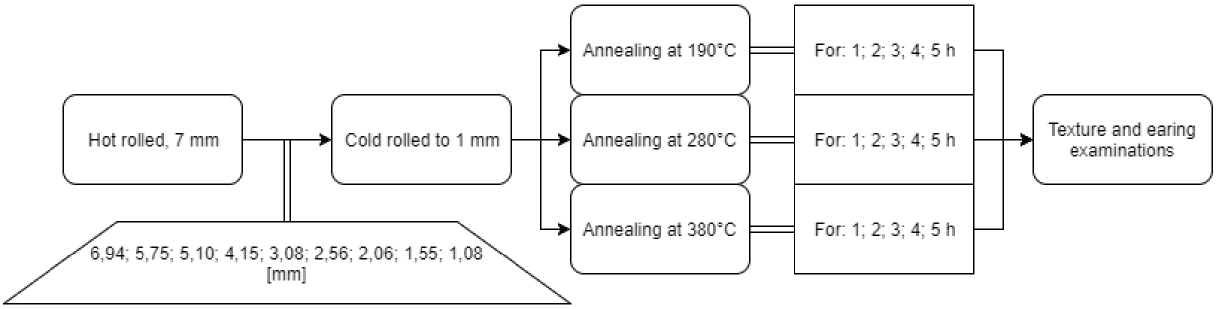

Figure 1. Route of the examinations.

The texture examinations were carried out on the Bruker D8 Advance X-ray diffractometer equipped with an Eulerian cradle. The parameters of the measurement were: 40mA, 40kV. The radiation is CoKα. The samples cut from the sheets were 30x30 mm in dimensions. During the examinations, the Bragg angles of the {111}, {200}, {220} lattice planes were measured and the corresponding pole figures were recorded. The texture evaluations were carried out with the TexEval program. The pole figures of the prementioned lattice planes were recalculated and provided the base for the Orientation Distribution Function calculation. ODF cuts were made at constant φ_2 values with 5 degree steps. The texture component volume fractions were defined by φ_1, Φ and φ_2 angles.

Earing examinations were carried out by the ARCONIC-Köfém Kft. The earing examinations were carried out at the laboratory at Szekesfehervar and results were sent back to evaluation. Besides the industrial measurement of earing, the earing tendency was also calculated with a method proposed by the authors and described in detail in Ref. [1]. Briefly, the method is based on defining the individual texture component poles as the vectorial combination of the (+) and (-) directions.

3. Results

On Figures 2-4. the volume fractions of the texture components are shown at constant annealing temperatures as the function of annealing time. The texture components resulting from the forming are: C, S, B; while the texture components resulting from the annealing are: G, Cube, R, P. The index numbers of the earing are also shown with an „x" on the same diagrams for comparison. The texture components of the rolled state can be seen at 0 h annealing.

Fig. 2. shows the samples annealed at 190°C. The texture components resulting from the forming unequivocally dominate the texture. It can be seen that the time duration of the heat treatment at this temperature causes no significant change in the texture or in the index number of the earing (rolled).

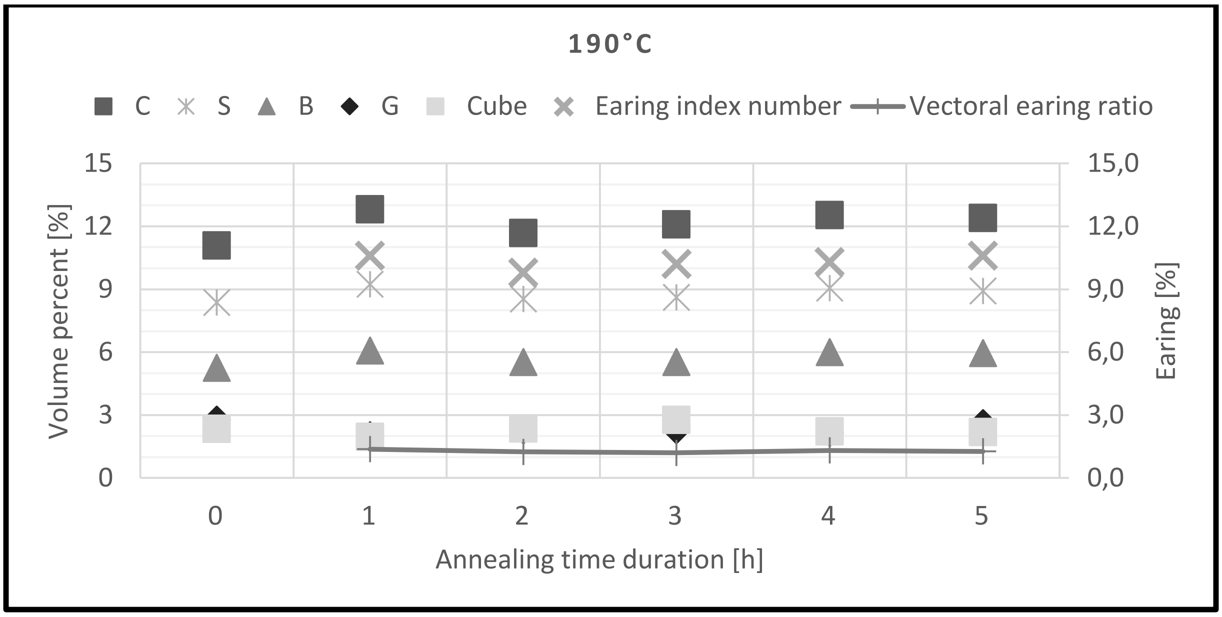

Figure 2. The texture components and earing index numbers of the 1 mm cold-rolled and 190°C annealed samples.

Fig. 3. shows the results of the samples annealed at 280°C. It can be seen that changing the duration of the annealing causes substantial change (contrary to Fig. 2.) in the texture of the samples. After one hour annealing, the rolling components dominate, furthermore, they are increased compared to the rolled state. Accordingly, the degree of earing (rolled) is high. The samples annealed for two and three hours show a considerable decrease in the rolling components and parallelly an increase of the recrystallization components. Proportionately, the index number of the earing decreases. After annealing of four and five hours compared to the three hours state no change is visible in the earing and in the texture components.

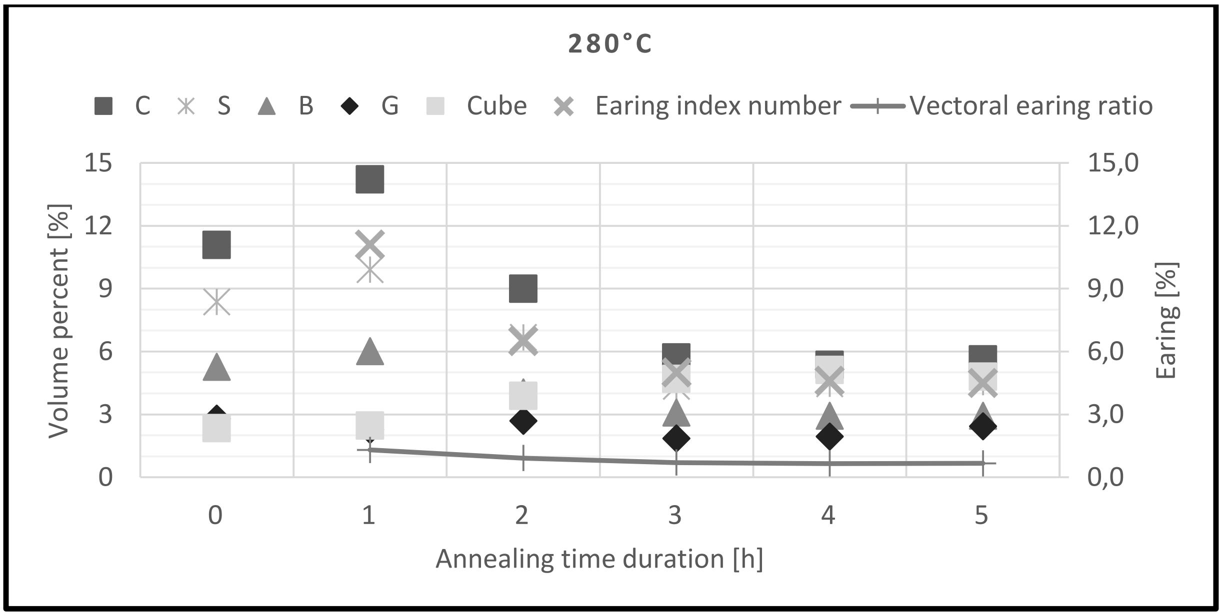

Figure 3. The texture components and earing index numbers of the 1 mm cold-rolled and 280°C annealed samples.

Fig. 4. shows the results of samples annealed at 380°C. It can be seen that at all annealing durations, the recrystallization texture-components have the highest volume percentage and the texture does not change significantly. The earing index number also does not show significant change in function of annealing time and reaches the lowest number (around 3%) throughout the study.

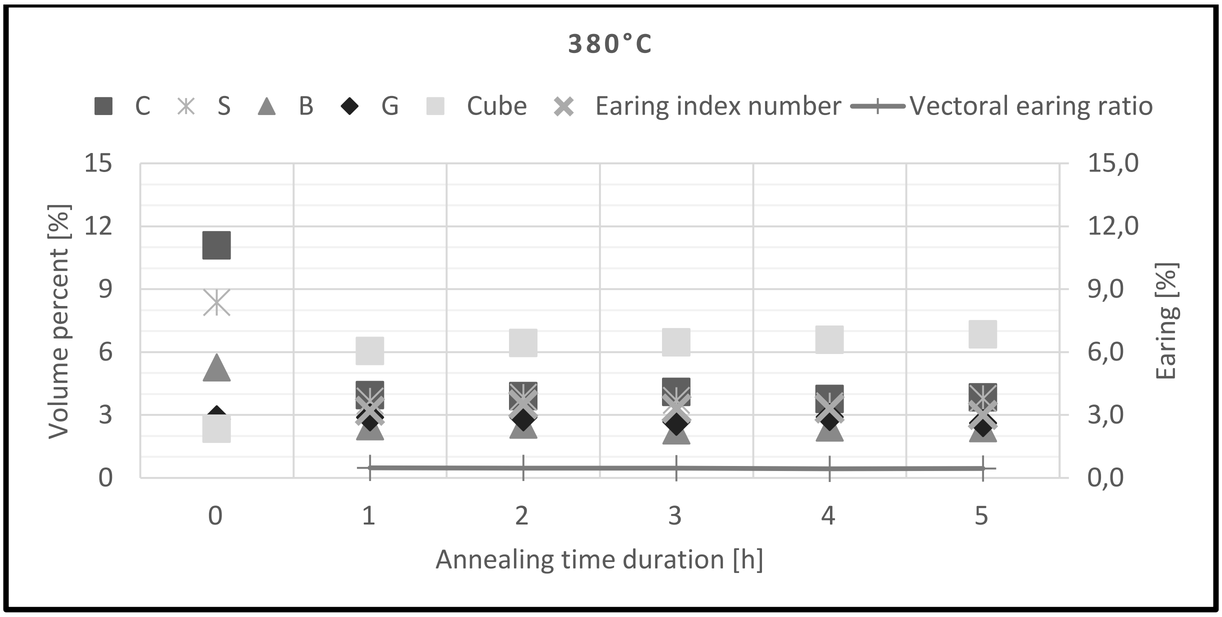

Figure 4. The texture components and earing index numbers of the 1 mm cold-rolled and 380°C annealed samples.

4. Discussion

It can be stated that during the annealing of the 3003 aluminium alloy at 190°C only recovery occurred. It is based on that even after five hours of annealing, the rolling texture-components remained the strongest and were larger compared to the rolled state, while the recrystallization texture-components remained at low values. The reason behind this is that during recovery, the dislocations are arranged to form tilt boundaries (polygonization) thus forming subgrains. This arrangement also yields a close to dislocation-free volume inside the formed subgrain, oriented more uniformly. It means that after recovery, the rolling texture-components have higher volume percentage than before annealing. Furthermore, it was observed that the earing values are in agreement with the texture-components and they were characteristic of rolling.

At 280°C, the rolling texture evolved into an almost isotropic texture during in annealing. The process can be followed in detail with the variation of the volume fraction of the texture-components as a function of annealing time: First, the rolling components increased after one hour annealing due to recovery, then they decreased and the recrystallization components slightly increased. Hence, even after five hours of annealing the recrystallization texture was not dominant. Thus, it can be stated that at 280°C the recrystallization mechanism produced an almost texture-free structure. This mechanism is the Particle Stimulated Nucleation (PSN). The analysis of the texture components results very detailed and quantitative outcome of this process. The volume fraction of the components in between three and five hours did not change notably. This data shows, that at 280°C the PSN type recrystallization peaks at three hours. The earing values decrease in between one and three hours of annealing, afterwards their value stagnates.

At 380°C annealing, the sheets recrystallized at all annealing time durations, even after one hour. The recrystallization texture-components dominate, which indicates that at this temperature, the classic high-angle boundary movement involved recrystallization was activated. Hence, the recrystallization components are not too high (~6-7%), which suggests that besides high angle recrystallization, the PSN mechanism was also activated. The texture-components show, that at 380°C after one hour of annealing, recrystallization takes place and no notable change can be observed in the texture at longer time durations (2-5 h). Comparing the sheet annealed for one hour with the sheet annealed at 280°C for five hours, it can be seen that the recrystallization texture components are higher and the rolling components are lower in the 380°C annealed sample. It can be concluded that the effect of annealing temperature cannot be compensated with longer annealing durations at a lower temperature. The earing values were the lowest in the samples annealed at 380°C. This corresponds well to that the rolling components were the lowest at the 380°C samples.

5. Conclusions

In this research, the evolution of texture and earing were characterized at three different temperatures in the function of annealing time in the 3003 aluminium alloys. The chosen temperatures are based on industrial heat treating temperatures. The conclusions of the texture and earing development, influenced by the annealing heat treatment are the following:

- At 190°C, at all the practical annealing time durations, only recovery occurs, which causes rolling texture and strong earing.
- At 280°C, recovery occurs after one hour annealing, which is followed by PSN recrystallization, which causes a texture-free structure and homogeneous formability after three hours of heat treatment.
- At 380°C annealing, even after one hour, classic recrystallization, involving high angle grain boundary movement is the dominant process, although PSN still occurred at a lesser extent. The texture and earing do not change with increasing annealing time. The result is a weak recrystallized texture and a marginally inhomogenity of the forming. Considering the deep-drawability, the annealing at 380°C results the most favourable structure and properties.

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