RESPONSE OF AA 8006 AND AA 8111 STRIP-CAST COLD ROLLED ALLOYS TO HIGH TEMPERATURE ANNEALING

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Abstract

The results of an investigation aimed at studying the influence of high temperature annealing on the structure and properties of AA 8006 and AA 8111 strips prepared by strip-casting and cold rolling are presented. The effects of the annealing temperature and duration and of the degree of reduction preceding the annealing on strip microstructure and properties are studied.

Keywords: *non-hardenable aluminium alloys, annealing, strip-casting, cold rolling.*

1. Introduction

Due to their relatively high strength combined with sufficient ductility the non-hardenable alloys Al-Fe-Mn-Si and Al-Fe-Si are largely used: in automotive industry, cooling systems, civil engineering. Thin aluminium sheets exhibiting good formability and sufficient rigidity are advisable in applications as fin-stocks in heat exchangers. Thus, fine grain size structure and a texture warranting low anisotropy must be achieved by alloy processing. The form in which the alloying elements are present is an important factor influencing recrystallization and texture development and in consequence alloy properties. Iron, manganese and silicon may be present in second-phase particles or dissolved in the matrix. Coarse intermetallic particles usually act as nucleation sites during recrystallization giving a random or retained rolling texture. Fine precipitates inhibit grain growth by pinning of grain boundaries. Thus, depending on dispersoid density and size, recrystallization can be accelerated or retarded. Alloying element in solid solution also affect structure and properties. Solid solution element contents and dispersoid distribution can be changed by heat treatments.

Manufacturing thin aluminium sheets by continuous casting and cold rolling is less expensive than the hot rolling technology. Unfortunately, the formability of continuously cast and cold rolled sheets is generally lower than that of chill cast and hot rolled sheets. High temperature annealing (also known as homogenisation), usually performed before strip hot or cold rolling, is aimed at improving the structure and properties of the final product. In order to optimise alloy structure with regard to subsequent softening processes the appropriate values of homogenisation parameters have to be selected for each alloy and casting technology. The above mentioned problems have been extensively studied in the case of chill cast and hot rolled aluminium sheets [1-4]. Strip-casting and cold rolling are not such frequently used and there is not enough information about the problems concerned.

The paper presents the results of an investigation aimed at studying the influence of high temperature annealing on the structure and properties of aluminium alloys prepared by strip-casting and cold rolling. The effects of the temperature and duration of annealing and of the reduction preceding the annealing on the microstructure and properties of AA 8006 and AA 8111 strips are studied.

2. Experimental

Two aluminium alloys were investigated - AA 8006 alloy containing (in wt.%): 1.5 Fe, 0.4 Mn, 0.16 Si and AA 8111 alloy containing (in wt.%): 0.7 Fe, 0.7 Si, Mn, Zn and Cu < 0.02. Both alloys were strip-cast to a thickness of 8.5 mm, cold rolled to a thickness of 5.4 mm, 4.2 mm and 3.3 mm, respectively. The strips were subjected to various heat treatments (Table 1). In all cases the annealing temperature was reached in 30 hours so as to simulate the industrial heating regime. Evaluation of size, shape and number density of second-phase particles was carried out and the results are presented in [5]. Grain size was measured in the three principal directions (L, T, S - Fig. 1) by conventional linear intercept method. Tensile tests in T direction were performed in order to assess the values of proof stress $R_{p0.2}$, strength R_m and elongation A_{50}. Vickers hardness *HV10* was measured in the rolling plane.

Table 1. Parameters of the thermo-mechanical treatments applied to both alloys.

Alloy	AA 8006			AA 8111		
Reduction [%]	61.4	52.3	35.2	61.2	50.6	40.0
Temperature [°C]	580 550 460	580 550 460	580 550 460	580 550 460	580 550 460	580 550 460
Duration [hours]	48 38	48 38	48 38	48 38	48 38	48 38

3. Results

Both alloys in the as-cast condition show a fine grained microstructure with elongated dendrites. Non-equilibrium eutectic phases on dendrite boundaries are stratified along the rolling direction during the subsequent cold rolling. Phase transformation and matrix softening occur during annealing at all temperatures tested. The structure changes of both alloys were found to depend on the temperature, duration and extent of reduction prior to heat treatment (see [5]). The phase transformation process at 460°C consists in partial dissolution and coagulation of the eutectic phase. Annealing at higher temperatures (550°C and 580°C) results in more complete transformation of the eutectic phase - intense dissolution of small particles occurs and coarser particles form.

The softening response of the alloys investigated is different: AA 8111 strips are fully recrystallized after annealing at all tested temperatures whereas AA 8006 strips do not recrystallize at 460°C. The biplanar optical micrographs of samples annealed for 18 hours at 580°C after 35 % and 40 % prior reduction (Fig. 1 for AA 8006 and Fig. 2 for AA 8111 strips) illustrate the grain structure in two principal planes (L-S and T-S). In all recrystallized strips the grain structure is homogeneous excepting the AA 8111 strip rolled to a thickness of 3.3 mm and annealed at 580°C for 18 hours. This sample exhibits fairly heterogeneous grain structure with a few coarse grains surrounded by fine grained structure which gives an evidence of the occurrence of secondary recrystallization.

The results of grain size assessment for AA 8006 strips are presented on Fig. 3 and for AA 8111 strips on Fig. 4. The grain shape in the alloys is different: the grains in AA 8006 are markedly elongated in the L and T direction whereas AA 8111 grains are less elongated. The shape factor SF(L/S), calculated as the ratio of the mean intercept lengths in L and S directions, ranges from 2.1 to 3.5 for the AA 8006 strips and from 1.3 to 2.0 for the AA 8111 strips. A difference of the grain size in L and T directions was observed and is more pronounced in AA 8006 strips - the shape factor SF(L/T) for AA 8006 strips ranges from 1.0 to 2.0 whilst for AA 8111 strips is from 1.0 to 1.4.

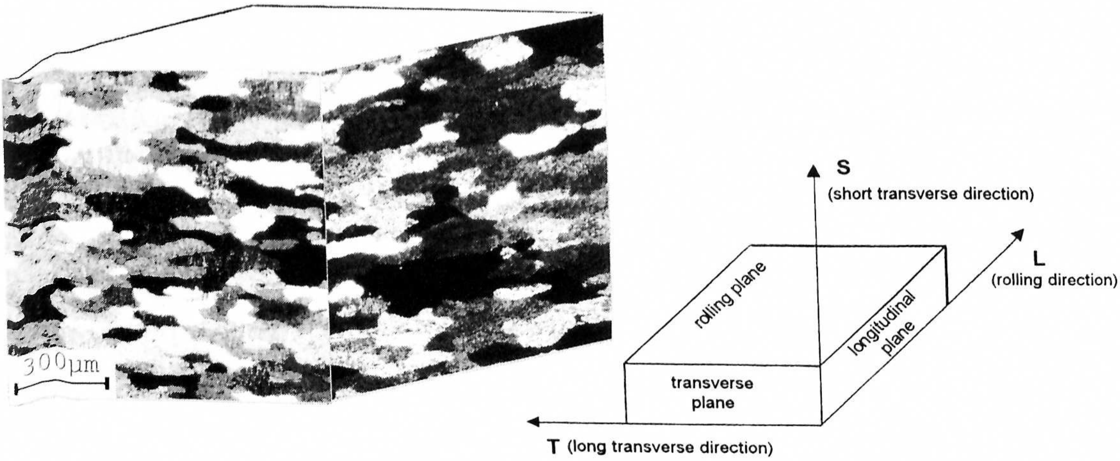

Figure 1. Biplanar optical micrograph illustrating the grain structure of the AA 8006 alloy - strip annealed for 18h. at 580°C after 35,2 % reduction.

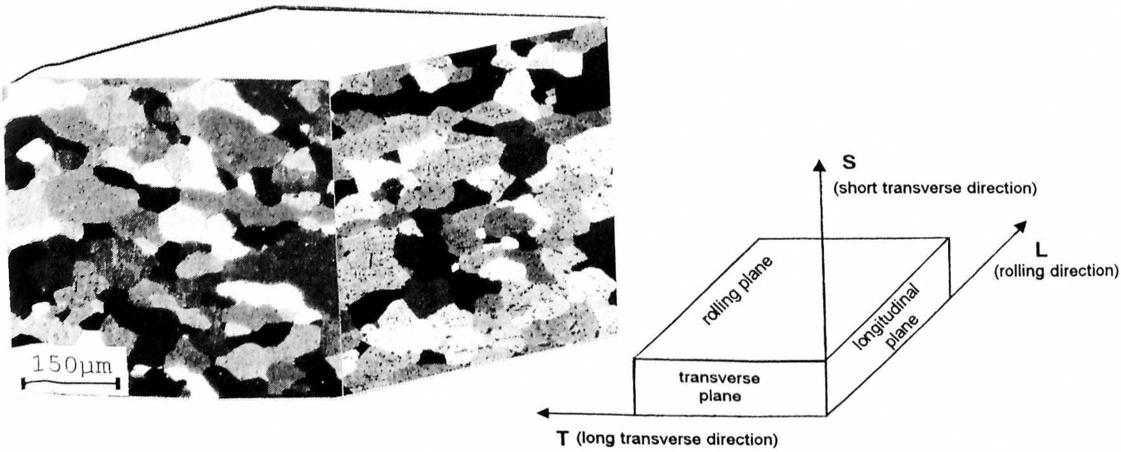

Figure 2. Biplanar optical micrograph illustrating the grain structure of the AA 8111 alloy - strip annealed for 18h at 580°C after 40,0 % reduction.

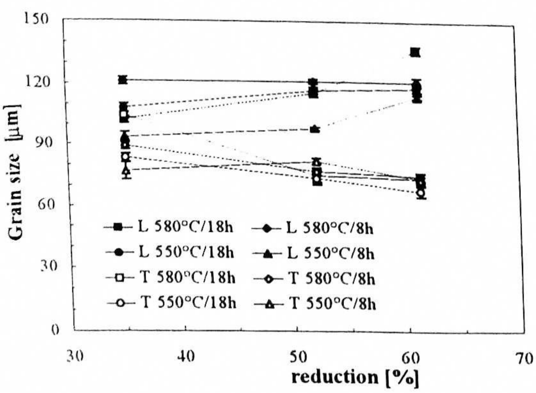

Fig. 3. Grain size of AA 8006 strips in L and T directions.

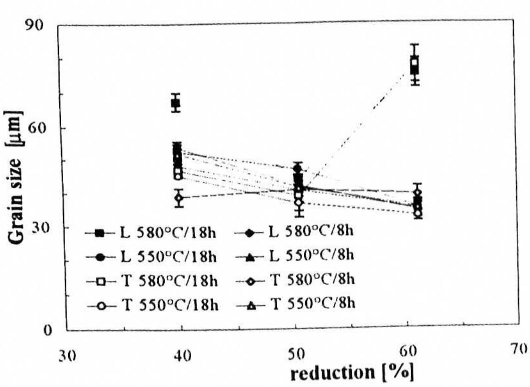

Fig. 4. Grain size of AA 8111 strips in L and T directions.

The mechanical properties after annealing depend on the parameters of the thermo-mechanical treatment imposed to the strips. The dependence of the mechanical properties ($R_{p0.2}$, R_m and A_{50}) and hardness *HV10* on the extent of prior reduction and on temperature for strips annealed for 18 hours is shown on Figure 5 for both alloys. The mechanical properties of AA 8006 strips annealed at 460°C are influenced by annealing duration, whereas they are not reduction dependent for AA 8111 strips annealed at this temperature. As an illustration, the proof stresses of AA 8006 and AA 8111 strips, annealed for 18 and 8 hours, are shown on Figures 6a and 6b, respectively.

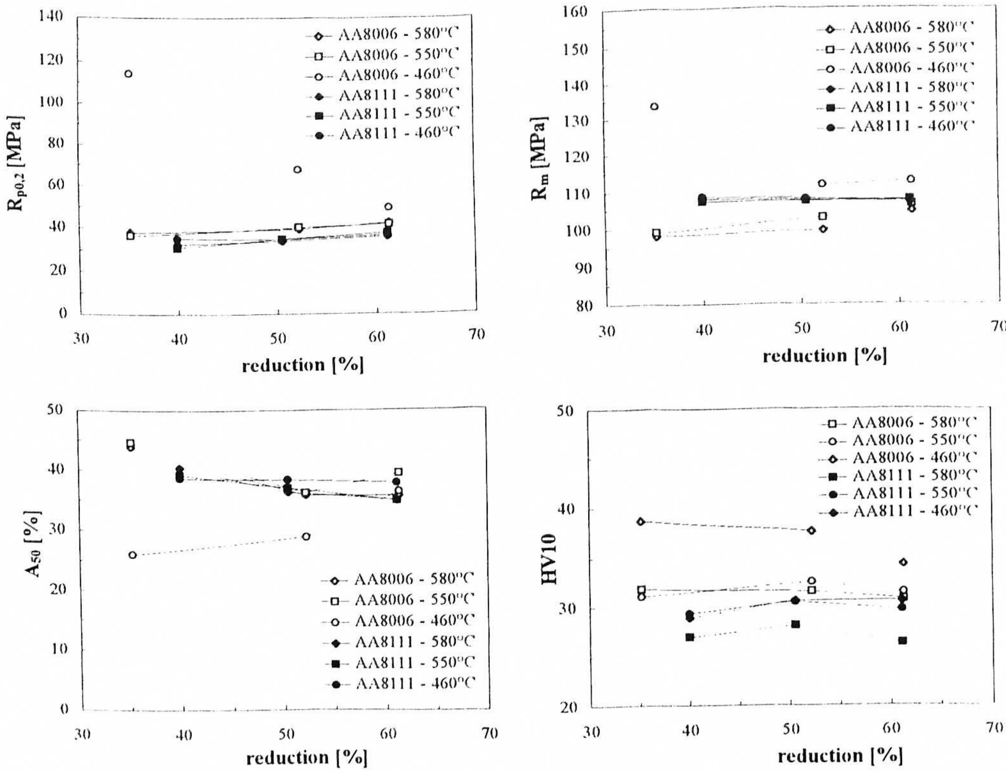

Figure 5. Comparison of the mechanical properties and hardness of AA 8006 and AA 8111 strips subjected to different thermo-mechanical treatments - the annealing duration is 18 hours.

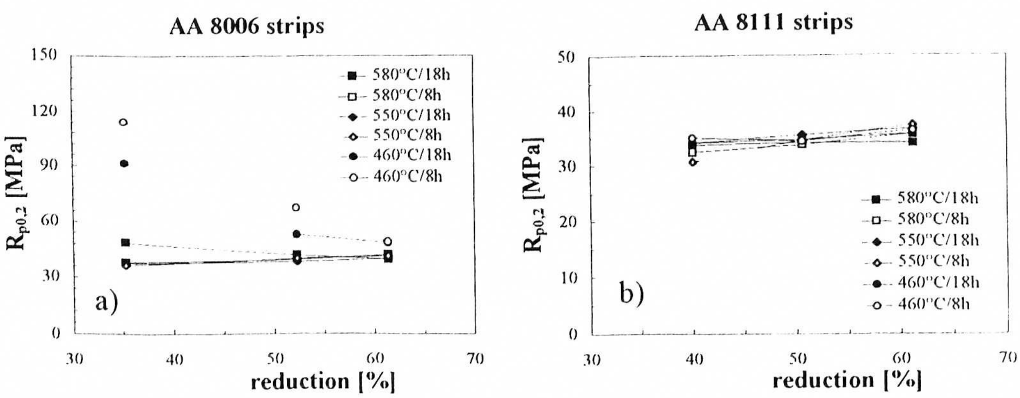

Figure 6. Proof stress dependence on reduction, temperature and duration for both alloys.

4. Discussion

The results of microstructure evaluation as well as mechanical property values indicate that the response to high temperature annealing of the alloys investigated is different. For example AA 8006 strips are not recrystallized at 460°C even after annealing during 18 hours whereas AA 8111 strips are fully recrystalized at this temperature after 8 hours. The grain size and shape differ too - AA 8006 grain structure is coarser and more anisotropic than AA 8111 structure. These differences can be explained by the differences of the size and spatial distribution of second-phase particles and the effect of particles on recrystallization kinetics. As it is shown in the accompanying paper [5] the second-phase dispersion in both alloys is rather different - AA 8006 alloy contains much more particles in unity of volume than AA 8111 alloy after all thermo-mechanical treatments investigated. The particles in the former alloy are in the average more finer. Even after a heat treatment at the highest temperature (580°C) the particles in AA 8006 strips are not uniformly distributed but are found preferentially on former dendrite boundaries. This is not the case of AA 8111 strips. In the AA 8111 alloy the particles are coarser, therefore there are more potential cites for particle stimulated nucleation of recrystallization and the grain structure is finer than in AA 8006 strips. The interparticle distances in the short transverse direction of AA 8111 strips are larger, thus the pinning effect on grain boundary migration in this direction is weaker than in AA 8006 strips. Due to particle interactions both with grain nucleation and grain boundary migration AA 8006 strip grain structure is coarser and more anisotropic. The presence of a great number of small particles involves an increase of the critical particle diameter required for nucleation in AA 8006 strips because the particles block some of the potential nucleation sites. The particle alignment on dendrite boundaries in AA 8006 strips and the flattening of dendrites parallel with the rolling plane explain the uneven grain size in L, T and S direction - growing grain boundaries are pinned by these particles. The drag pressure of iron, silicon and manganese atoms dissolved in the matrix must be taken also into account when describing the recrystallization kinetics of AA 8006 alloy because Mn is known to increase Fe and Si solubility in Al matrix.

Grain size depends on the degree of reduction preceding the annealing: the grain size in T and S directions in both alloys and in the rolling direction of AA 8111 strips decreases with increasing reduction. The effect of prior reduction on grain size in the rolling direction of AA 8006 strips makes an exception - the grain size increases with increasing reduction. In this case, due to the higher density of second-phase particles on dendrite boundaries parallel to the rolling plane, the pinning effect of particles on growing grain boundaries is more pronounced. As a result the grains in AA 8006 strips grow more easily in the rolling direction. The nature of particle number density and distribution therefore determines the effect of deformation texture on recrystallized grain structure.

Strip mechanical properties after annealing were found to depend on the parameters of thermo-mechanical treatment in correspondence with grain size dependence. The recrystallized grain size in T direction decreases with increasing prior reduction and this tendency corresponds to the small increase of proof stress and strength (more pronounced for AA 8006 alloy). Annealing at higher temperature results in slightly coarser grain structure for AA 8006 strips and in the corresponding lower strength. Annealing temperature does not influence AA 8111 mechanical properties in a significant way excepting strips rolled with the largest reduction and annealed at 580°C where secondary recrystallization resulted in coarse heterogeneous grain structure and the worst properties. The influence of particle coarsening with increasing temperature on strength and ductility in both alloy is to be taken into account too [5]. These two features, grain structure and second-phase particles, mutually interact both during annealing and in their effect on alloy deformation behaviour. For the partially recrystallized AA 8006 alloy (annealed at 460°C) the mechanical properties are dependent on annealing duration - longer annealing results in higher degree of recrystallization and in the corresponding lower proof stress and strength and higher elongation. The differences of mechanical property values of the recrystallized materials are much more smaller and reflect the smaller differences of grain size in the T direction.

5. Conclusion

The investigation of the response to high temperature annealing of AA 8006 and AA 8111 stip-cast and cold rolled alloys showed that:

1. The recrystallization temperature of AA 8006 strips is higher than of AA 8111 strips.
2. The grain structure of both alloys is different - AA 8006 grain structure is coarser and more anisotropic than AA 8111 structure.
3. Particle number density and distribution influence alloy recrystallization response - the difference of second-phase volume fraction and distribution between the alloys investigated reflects in their different grain structure. The different particle distribution determines the effect of deformation texture on recrystallized grain structure.
4. The grain structure is influenced by thermo-mechanical treatment parameters - in AA 8006 strips this influence is more pronounced.
5. The mechanical properties of annealed strips depend on treatment parameters in correspondence with grain size dependence.

The results of the investigation of the structure and property response of AA 8006 and AA 8111 alloys to different high temperature treatments will be used for the optimisation of the technology of thin sheet fabrication for applications requiring a combination of good formability in combination with sufficient strength.

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References:

[1] Oscarsson A., Hutchinson W.B., Ekström H.E.: Mat. Sci. Techn. **7** (1991), 554.
[2] Usui E., Inaba T., Shihano N.: Z.Metallkde. **76** (1985), 786.
[3] Simielli E.A., Plaut R.L., Padiha A.F.: Z.Metallkde. **78** (1987), 771.
[4] Kamat R.G. and Saimoto S.: Mat.Sci. Techn. **10** (1994), 215.
[5] Slámová M., Očenásek V., Dvořák P. and Juříček Z.: *Phase Transformation Study of Two Aluminium Strip-Cast Alloys*, submitted to these proceedings.