PHASE TRANSFORMATION STUDY OF TWO ALUMINIUM STRIP-CAST ALLOYS

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Abstract

The results of an investigation of second-phase transformations during high temperature annealing of AA 8006 and AA 8111 strip-cast cold rolled alloys are presented. The effect of temperature, duration and reduction preceding the heat treatment on the nature, size and number density of second-phase particles is evaluated.

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

1. Introduction

Second-phase particles in precipitate non-hardenable aluminium alloys play a crucial role in the processes of their recrystallization and texture formation and thus fairly influence alloy properties. Particles affect the stored energy and hence the driving force for recrystallization, can act as nucleation sites for recrystallization or contrarily, if they are small and closely spaced, they hinder recrystallization. Therefore, it is of primordial interest to have a good understanding of the technological processes and parameters that influence the size, spatial distribution and composition of second-phase particles. These are determined both by alloy composition and thermo-mecanical processing imposed to the material. The most important treatment, determining second-phase characteristics in continuously cast and cold rolled strips, is the high temperature annealing, usually involved at the beginning of the fabrication procedure. Appropriate particle characteristics can be obtained selecting properly the heat-treatment parameters.

Good formability and sufficient rigidity are required in applications of thin aluminium alloy sheets as fin-stocks in heat exchangers. The goal of the technological development, part of which results are presented in the paper, is to optimise the fabrication technology of strip-cast AA 8006 and AA 8111 alloys for fin-stock applications. Considering the primordial role of second-phase particles in alloy deformation and annealing response, the first investigation step was to obtain good knowledge about the kinetics of phase transformations during high temperature annealing. The results of the microstructure investigation carried out on samples subjected to different thermo-mechanical processing are presented in the paper.

2. Experimental

Two strip-cast aluminium alloys were investigated: AA 8006 and AA 8111. Alloy compositions are (in wt.%): 1.5 Fe, 0.4 Mn, 0.16 Si for the AA 8006 alloy; 0.7 Fe, 0.7 Si, Mn, Zn and Cu < 0.02 for the AA 8111 alloy. Both alloys were strip-cast and then cold rolled to different thickness. Rolled samples were subjected to high temperature annealing at 580°C, 550°C and 460°C with different duration. The detailed description of strip fabrication technology and the laboratory thermo-mechanical processing is presented in [1]. Microstructure evaluations were carried out in the longitudinal plane using optical and scanning electron microscopy. Particle volume fraction, size, shape and number density were determined using image analysis.

3. Results

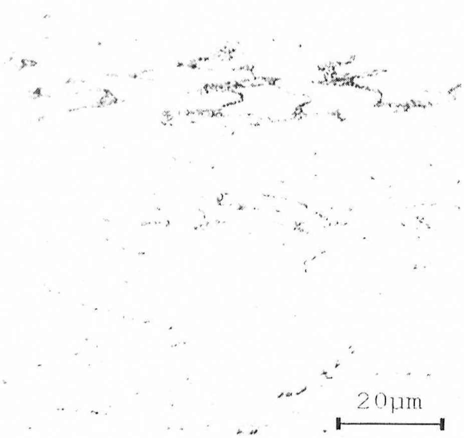
Very fine eutectic phases are observed on dendrite boundaries in both as-cast alloys (Fig. 1a,b and 2a). The strip surface layers exhibit more elongated dendrites with finer eutectic phase than in the bulk. The eutectic phases do not transform during the subsequent cold rolling with small reduction (35 % and 40 %, resp.) but their colonies are elongated in the rolling direction. The volume fraction of the eutectic phase in AA 8006 strips is more than two times higher than in AA 8111 strips. No attempt was made to exactly measure the eutectic phase volume fraction by image analysis because a considerable error was expected due to the phase nature and the limited resolution of the optical system.

During high temperature annealing a transformation of the eutectic phases in both alloys is observed. The resulting structure depends on the annealing temperature and cold rolling reduction preceding the heat treatment. The strips annealed at 460°C contain a great number of small particles and their arrangement is similar to that of eutectic phases in the as-rolled materials (Fig. 1c and 2b). The transformation process consists in partial dissolution and coagulation of the eutectic phase. Annealing at higher temperatures results in more complete transformation of the eutectic phase. The appearance of intermetallic particles in AA 8006 strips after heat treatment at 550°C is shown on Fig. 1d, after heat treatment at 580°C on Fig. 1e and 1f. The structure of AA 8111 strips annealed at 550°C is on Fig. 2c and annealed at 580°C on Fig. 2d. It is evident that during annealing at higher temperatures more intense dissolution of small particles occurs and coarser phases develop.

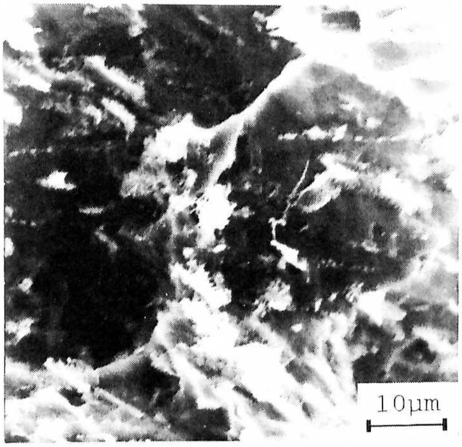
The metallographic etching identification of the intermetallic phases in samples annealed at temperatures higher than 540°C showed that AA 8006 strips contain particles of three different types: 1) coarse darker particles of irregular shape, 2) elongated rod or plate like particles, 3) equiaxed small particles. The small size of the particles does not allow the exact quantitative determination of their composition by SEM X-ray microanalysis, however the ratio (Fe+Mn)/Si can be easily measured. Microanalysis results indicate that the first two phase types do not contain silicon whereas the last one contains silicon and the (Fe+Mn)/Si ratio is 5.2 ± 1.8. In AA 8111 strips two kinds of intermetallic particles were distinguished: 1) coarser particles of irregular shape, 2) small nearly globular particles. SEM X-ray microanalysis showed that the Fe/Si ratio for the coarse phases is 3.3 ± 0.3 and 1.8 ± 0.4 for the small particles.

The second-phase volume fraction V_V in AA 8006 strips annealed at 550°C and 580°C is in the range from 5.0 to 6.0 % and from 7.5 to 9.5 % in strips annealed at 460°C. The second-phase volume fraction in AA 8111 strips is lower and ranges from 1.7 to 2.5 % for all samples investigated. The results of particle size and number density evaluation in the AA 8006 strips subjected to different heat treatments are presented on Fig. 3. The mean area of particle sections A and the mean number of sections per unit surface N_A (measured on the longitudinal strip plane) for all samples investigated are compared. The corresponding results for AA 8111 strips are on Fig. 4.

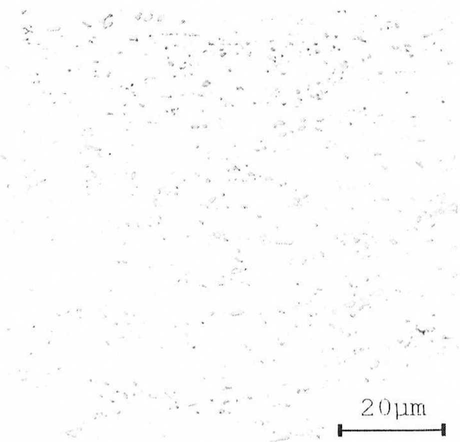
The results of the quantitative evaluation of second-phase particle characteristics indicate that these are significantly influenced by heat treatment parameters. It is evident that for both alloys the number density of particles increases and the mean particle size decreases with decreasing annealing temperature. Heat treatment duration affects particle size and number too - almost in all cases longer annealing results in a reduction of the number density and in corresponding increase of the mean particle size. For AA 8006 strip the extent of reduction preceding annealing influences also the particle size and number per unity of volume - for higher prior reduction smaller and more numerous particles are present in the annealed strip structure. The effect of prior reduction is not so pronounced in AA 8111 annealed strips.



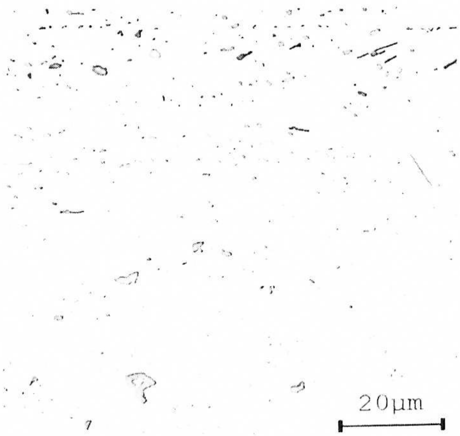
a) as-rolled - 35.2% reduction



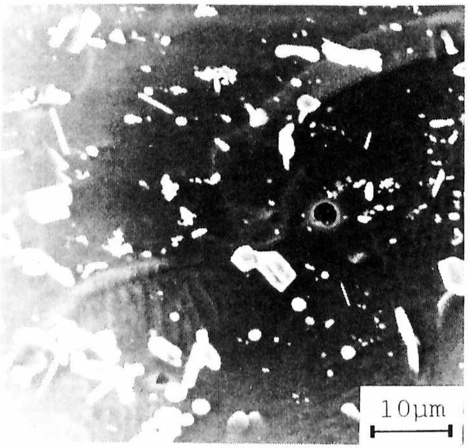
b) as-rolled - 35.2% reduction



c) annealed 460°C/18h - 52.3% reduction



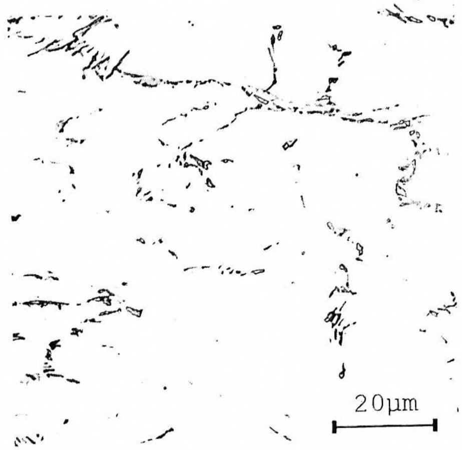
d) annealed 550°C/8h - 52.3% reduction



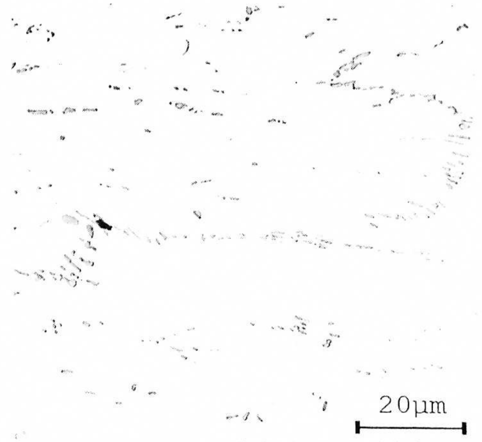
e) annealed 580°C/18h - 35.2% reduction

f) annealed 580°C/18h - 35.2% reduction

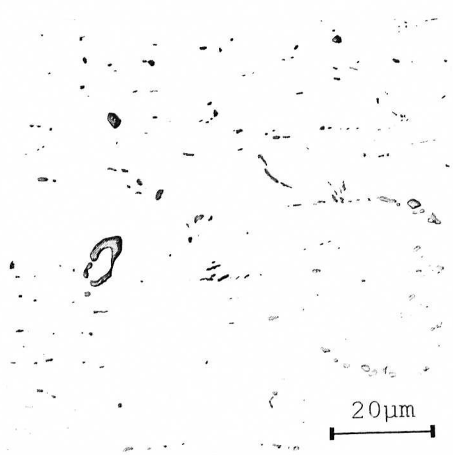
Figure 1. Intermetallic phases in the AA 8006 strips: a), c), d) and f) - optical micrographs; b) and e) - SEM micrographs of deep etched samples.



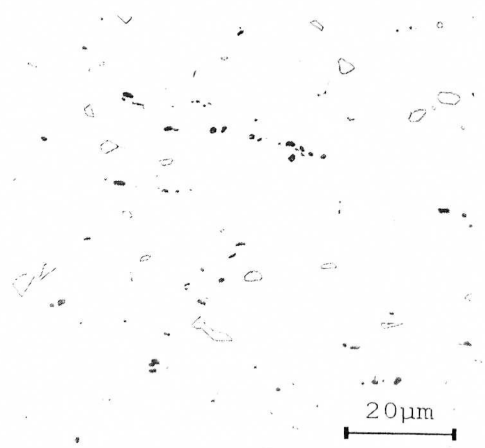
a) as-rolled - 40.0% reduction



b) annealed 460°C/18h - 50.6% reduction



c) annealed 550°C/18h - 50.6% reduction



d) annealed 580°C/8h - 40.0% reduction

Figure 2. Intermetallic phases in the AA 8111 strips - optical micrographs.

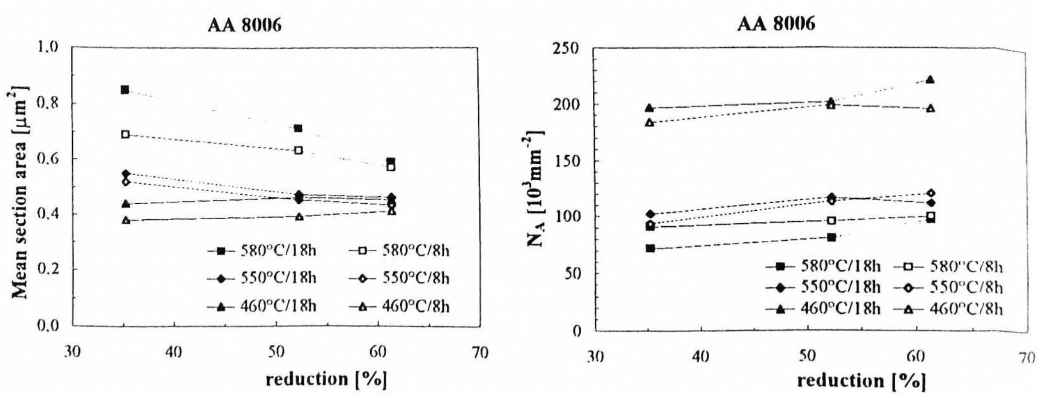


Figure 3. Mean particle section area and number density N_A measured on AA 8006 strips cold rolled to different reductions and annealed at different temperatures with two different durations.

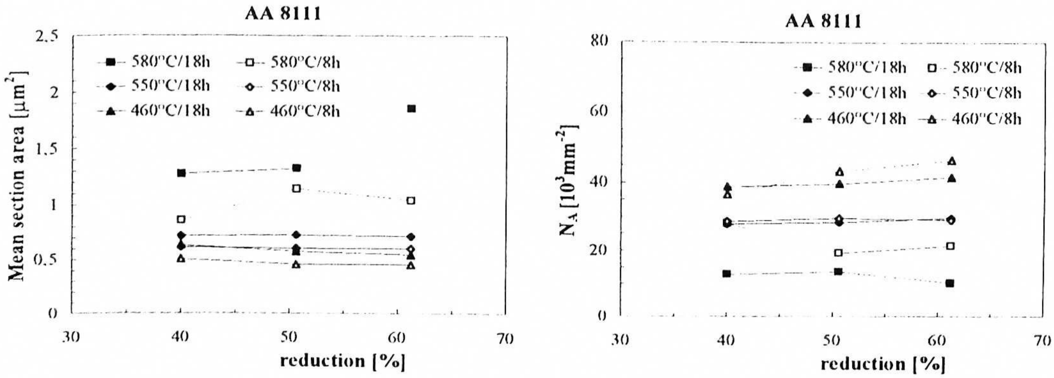


Figure 4. Mean particle section area and number density N_A measured on AA 8111 strips cold rolled to different reductions and annealed at different temperatures with two different durations.

4. Discussion

Due to the high cooling rate during solidification of strip-cast alloys a very fine non-equilibrium phases form and it is very difficult to determine their composition. Metastable $Al_6(FeMn)$, α-AlFe(Mn)Si and β-AlFeSi phases can be expected to form in AA 8006 alloy [2], α_c-AlFeSi, Si and β-AlFeSi phases in AA 8111 alloy [6]. Several other metastable phases of the ternary system Al-Fe-Si have been observed in rapidly crystallising aluminium alloys [6], a hexagonal or rombohedral α-AlFeSi phases are described in [3]. The same authors state that the formation of the cubic phase is stabilised by the presence of manganese.

The particles in annealed AA 8006 alloy were found to have a composition only approximately corresponding to known phases such as $Al_6(FeMn)$, $Al_3(FeMn)$ and α-$Al_{12}(FeMn)_3Si$. The microanalysis in SEM indicates that the rod shape particles do not contain silicon and their composition is in the range of $Al_3(FeMn)$ phase. Rod shape Al_3Fe particles were observed in an AlFeSi alloy [7] after similar annealing conditions. The composition of the fine globular particles lays in the composition range of the α-Al(FeMn)Si phase. Particles with composition corresponding to the $Al_6(FeMn)$ phase were also observed. The microanalyses performed by TEM [5] confirmed that annealed AA 8006 strips contain particles with composition corresponding to the α-Al(FeMn)Si and $Al_3(FeMn)$ phases, containing also a small amount of Cu. No match with crystal lattice type and parameters cited in literature [2,6] was found by electron diffraction evaluation of individual particles [5]. To all appearance AA 8111 annealed alloy contains mainly β-AlFeSi particles which composition cited in [3,6] is Al_5FeSi or $Al_9Fe_2Si_2$ and α'-Al_8Fe_2Si particles [6].

The differences observed in the phase transformation rate of both alloys is due to their different composition. AA 8111 alloy contains a smaller amount of alloying elements than AA 8006 alloy and does not contain manganese. Due to these differences the diffusivity and solubility of iron and silicon atoms in the aluminium matrix are rather different. It is known that manganese increases the solubility of iron in Al and that iron diffusivity in Al is much smaller than silicon diffusivity. The AA 8111 alloy contains about four times more silicon and about two times less iron than the AA 8006 alloy. Therefore, the formation of coarse intermetallic particles during high temperature annealing is expected to be more easier in AA 8111 strips than in AA 8006 strips.

The particles in the AA 8111 alloy heat treated at temperatures higher than 540°C are about two times coarser than particles in the AA 8006 alloy. The volume fraction of second phases in AA 8111 strips is about three times smaller than in AA 8006 strips and the particle number density is three to five times smaller in the former. The size and number of second-phase particles in both alloys investigated were found to depend on the parameters of the thermo-mechanical treatment imposed to the strips. The phase transformation response of the AA 8006 alloy is influenced significantly by all parameters investigated, whereas the AA 8111 alloy is not sensible to prior reduction. The volume fraction and size, respectively the number density of second-phase particles determine the mean interparticle spacing and therefore both the deformation behaviour and recrystallization response of the alloys. Particles affect recrystallization directly but also through the mediation of their effect on the formation deformation structure prior to annealing. The influence of particle characteristics on the recrystallization kinetics of both alloys is discussed in [1].

Second-phase dispersion is one of the most important parameters influencing work hardening rate in dispersion hardened alloys to which category belong both alloys investigated. AA 8006 seems to be apt to exhibit higher work hardening rate than AA 8111 alloy due to the smaller interparticle spacing. Second-phase dispersion is of great importance for the formability of final thickness strips and its influence on strip deformation behaviour will be the subject of further investigations.

5. Conclusion

The results of identification of intermetallic phases in AA 8006 and AA 8111 strip cast aluminium alloys subjected to high temperature annealing indicated that even a relatively long heat treatment at 580°C does not lead to total transformation of the non-equilibrium eutectic phases in equilibrium ones. Further analyses are necessary in order to determine more precisely the composition and crystallographic characteristics of the phases present in the alloys investigated. The particles in AA 8006 alloy have a composition approximately corresponding to the $Al_6(FeMn)$, $Al_3(FeMn)$ and α-$Al_{12}(FeMn)_3Si$ phases. AA 8111 alloy contains particles corresponding approximately to the β-Al_5FeSi and α'-Al_8Fe_2Si phases.

The phase transformation response of the AA 8006 alloy is influenced significantly by all parameters investigated, whereas the AA 8111 alloy is not sensible to prior reduction. The size and number density of second-phase particles in both alloys depend on the parameters of the thermo-mechanical treatment imposed to the strips. The alloys investigated differ by volume fraction, size and number density of second-phase particles - AA 8111 alloy contains coarser and less numerous particles than AA 8006 alloy. Particle volume fraction in AA 8111 strips is three times smaller than in AA 8006 strips.

The differences in the phase transformation rate of both alloys is explained considering their composition and the influence of alloying element content and nature on iron and silicon solubility and diffusivity in Al matrix. The formation of coarse intermetallic particles during high temperature annealing is more easier in AA 8111 strips than in AA 8006 strips.

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References:

[1] Slámová M., Očenášek V., Dvořák P. and Juřicek Z.: *Response of AA 8006 and AA 8111 Strip-Cast Cold Rolled alloys*....., submitted to these proceedings.
[2] Dons A.L.: Z. Metallkde **81** (1990), 484.
[3] Griger A., Stefaniay V, Lendvai A. and Turmezey T.: Aluminium **65** (1989), 1049.
[4] Turmezey T., Stefaniay V. and Griger A., Key Eng. Mat. **44&45** (1990), 57.
[5] Slámová M., Cieslar M., Dvořák P. and Juřicek Z.: submitted to Proc. 10th Metallogr. Symp., High Tatras (1998).
[6] Dons A.L.: Z. Metallkde **76** (1985), 609.
[7] Shoji R., Fujikura C.: Key Eng Mat. **44&45** (1990), 163.