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Influence of Homogenizing and Ageing Practices on Microstructure and Dynamic Compression of Crash Relevant Al-Alloy Extrusions

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Crash relevant Al-alloys are extensively used in the automotive industry for their ability to absorb impact energy. The results of homogenization treatment, cooling rate after extrusion and ageing process parameters on the microstructure, tensile properties and crashworthiness of Al 6XXX alloys are presented in the present paper. Visual inspection, microhardness, tensile testing, light microscopy, along with dynamic compression testing are employed as the principal analytical techniques.
The findings of the investigation suggest that segmentation of the β-phase intermetallic blades was initiated after two hours soak and after 24h at 580°C homogenizing is completed leading also Mg_2Si eutectic phase to solid solution. Re-precipitation took place during air cooling.
Microstructure and grain structure evaluation of the extrusion showed no differences in the morphology of α-phase intermetallics and also in the mean grain size between water and air quenched samples. Submicroscopic Mg_2Si precipitation is more pronounced, tinting preferentially grain boundaries in air quenched samples compared to water quenched reducing toughness. Regarding artificial ageing, water quenching and double stage ageing for 8 and 12 h seems to result in improved crash tolerance and maximum strength of the aluminum alloy extrusion.

Keywords: *crash relevant, extrusion, ageing, dynamic compression*

1. Introduction

1.1 Background Information

Steel is the major construction material in automotive industry, but aluminum takes the second place and is becoming more frequent as it brings considerable weight reduction. In this way lighter cars are produced and pollutants emissions are reduced by 55% [1]. Automotive industry uses special alloys, known as crash relevant alloys, which have the potential to absorb impact energy.

Crash relevant extrusions production process:

Casting conditions are crucial in that as cast microstructure must be characterized by uniformity in distribution of intermetallic particles for maximization of product ductility. Iron has low solubility in aluminum and during solidification segregates at interdendritic regions where it combines with Al, Si and Mn to form intermetallic particles [1]. The iron intermetallics β-Al(Fe, Mn)Si have poor bond strength with the surrounding matrix and can lead to surface defects limiting extrudability. Adjacent to these particles a solute-depleted zone with no Mg_2Si precipitates is formed [2].

Homogenization aims to (a) dissolve Mg_2Si and (b) produce the smallest and roundest Fe-containing intermetallic particles (α-particles flow better in extrusion). Soaking conditions should exceed 550°C for 4 hours to initiate breaking up and spheroidizing of β-AlFeSi blades. Insufficient homogenization time leads to partial dissolution of Mg and Si and incomplete $\beta \rightarrow \alpha$ transformation [3].

Extrusion speed and billet temperature should be highly controlled to induce extrusion's recrystallization into very fine grains, especially at the surface. Coarse grain structure decreases significantly formability and limits ductility.

Ageing temperature-time curves show where most suitable properties are obtained and dictate selection of artificial ageing practices.

<u>Crash relevant extrusions composition</u>

6106-type alloys usually have close to balance (Mg:Si=1.73:1), or slightly excess Mg compositions, for better formability and bending. In case formability is not the major desirable property, excess Si is preferred since up to 25% stronger alloys can be obtained by means of solution hardening. However, ductility is sacrificed with excess Si alloys.

Mechanical strength increases with increasing wt% Mg_2Si. On the other hand, ductility will drop as wt% Mg_2Si exceeds 0.80%.

For increased formability Fe should be kept at or below 0.20% and Mn between 0.06 and 0.10%.

1.2 Experimental Procedure

The alloy for crash tolerance tested in this work is designed to have high $\%Mg_2Si$ to allow maximum strength potential, with slightly excess Mg that should eliminate ductility lowering tendency, inhibiting Si precipitation. The goal is to achieve such heat treatment conditions that an under-aged extrusion will still meet the minimum requirements for strength in combination with the maximum formability under compressive loads. The tested Al-6106 alloy extrusions, produced under different quenching and ageing conditions, were subjected to dynamic compression for evaluation of their crash tolerant properties. In addition, microstructure examination is conducted for air and water quenched (quenching refers to cooling rate after extrusion) extruded profiles.

Specimen preparation was conducted by wet grinding, using successive abrasive SiC papers, and fine polishing using diamond and silica suspensions. Immersion etching in HF solution was used for phase structure investigation while for grain structure examination electrolytic etching with Barker's solution was applied.

Metallographic studies were performed using a Nikon Epiphot 300 inverted optical microscope. Dynamic compression tests were conducted according to internal customer specification in a 1000 kN hydraulic testing machine; 300 mm high "tri-box" complex extrusion shapes (Fig. 1) were compressed down to 100 mm final height (≈67% nominal reduction) employing 100 mm/min testing speed. Tensile testing was performed to an 30 kN electromechanical testing machine. Finally microhardness test measurements were conducted using Vickers indentation technique under 0.1 kg applied load, according to EN ISO 6507-1 standard.

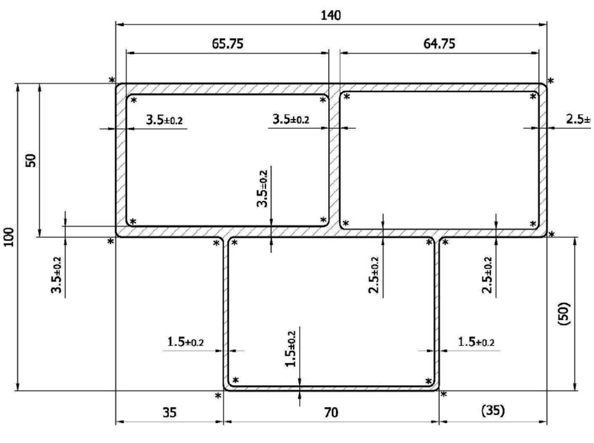

Fig. 1 Sketch showing dimensions of the extruded profile cross-section used for dynamic compression tests.

2. Investigation findings

2.1 Homogenization process

Two slices from an ø230 6106 alloy billet (with 0.05% excess Mg) were cut and furnace heat treated for 24 hours at 580°C and 560°C (homogenization) respectively and air cooled. Maximum temperature was reached in two hours. The completion of this process, evaluated by the degree of segmentation of β-blades and Mg_2Si dissolution, was examined with optical microscopy. As cast microstructure (Fig. 2) consisted of i) primary solid solution (Al), ii) α-phase intermetallics in the form of the binary (Al)+α-AlFeSi, iii) β-blades resulting from the relative fast cooling and iv) Mg_2Si and rosettes eutectics (quaternary eutectics containing h-AlFeSi, Mg_2Si, Si and Al-solid solution). Heat treatment for 24 hours at 580°C was found adequate for Mg_2Si eutectic particles to go into solution. In addition β-phase particles are segmented and rounded ($\beta \rightarrow \alpha$ transformation was completed, Fig. 3). Segmentation of the β-blades was initiated after two hours soak at 580°C and increased stepwise. Re-precipitation of submicron Mg_2Si eutectics, mainly in the interdendritic areas, took place during air cooling of the homogenized billet. Segmentation rate was much slower and not completed in 24h for 560°C homogenization temperature.

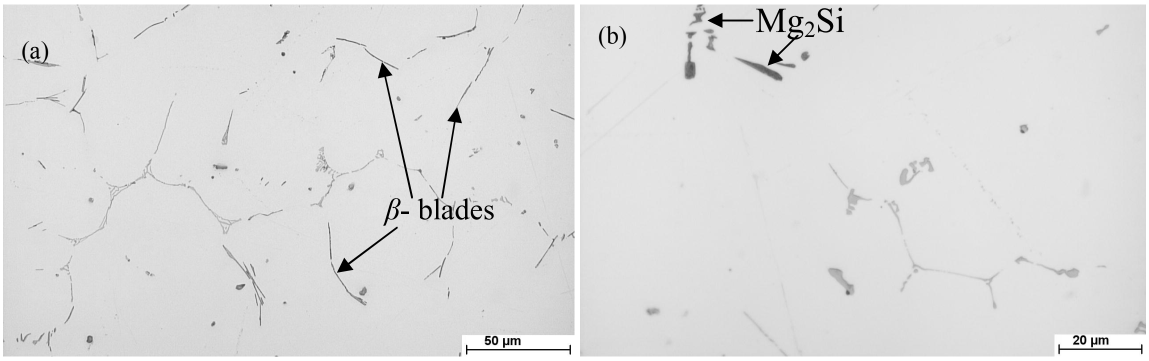

Fig. 2 (a), (b) Optical micrographs of the as cast billet (as polished) showing β-blades and Mg_2Si intermetallics.

2.2 Ageing process

The microstructure of air and water quenched, 6106 automotive hollow extrusions was examined and related to results from dynamic compression and mechanical properties data (microhardness, proof, tensile strength and elongation). The profiles were artificially aged with two different thermal cycles: single and double (or step) stage ageing (Table 1).

Table 1 Heat treatment conditions

Thermal Cycle "**A**" Double stage ageing	Heating from room temperature at ~ 70°C/hr to 100°C and soaking for 2 hours. Subsequently heating at 70°C/hr to 170°C, soaking time up to 12 hours followed by slow air cooling.
Thermal Cycle "**B**" Single stage ageing	Heating from room temperature at 50°C/hr to 170°C, soaking time up to 12 hours followed by slow air cooling.

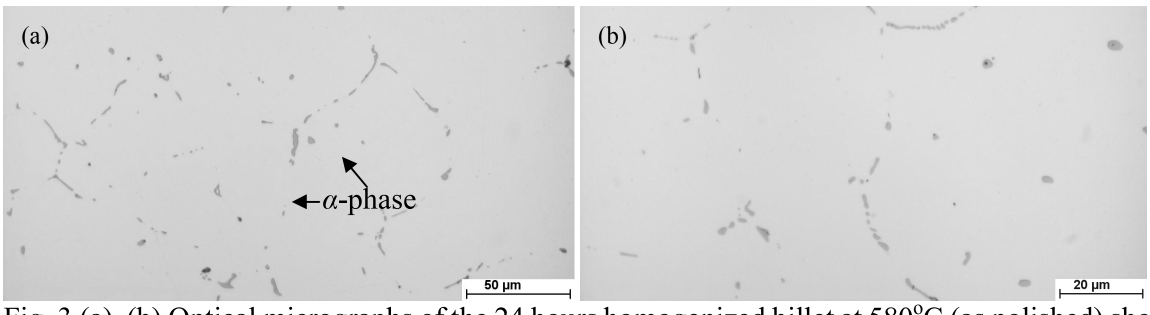

Fig. 3 (a), (b) Optical micrographs of the 24 hours homogenized billet at 580°C (as polished) showing that $\beta \rightarrow \alpha$ transformation occurred.

Optical micrographs are given in Figs. 4-6. Enhanced Mg_2Si precipitation was also observed in air quenched samples in conjunction to the soaking ageing time used. Besides, coarsening and coalescence into microscopic incoherent particles took place preferentially on grain boundaries creating weak neighboring areas, depleted in alloying elements. In water quenched samples no microscopic Mg_2Si precipitation was evidenced even for 12 hour soak (Figs. 4-5). Grain growth near the extrusions outer surface is observed after 12h soak in a higher degree in air quenched extrusions for both thermal cycles (Fig. 6). Fe-containing intermetallics of 11μm maximum length and 6μm maximum thickness were uniformly dispersed in the matrix in both water and air quenched extrusions.

Tensile testing was performed parallel to extrusion direction, for the different wall thicknesses as demonstrated by the profile geometry, and the average value was extracted. Specimens were tested for 2.5, 4, 6, 8 and 12h soak for both thermal cycles, A and B. Results showed progressive strengthening of the profiles, but with decreasing rate, as a function of ageing soaking time, mostly independent of the quenching conditions and thermal cycle applied. Regarding thermal cycle "A", water quenched samples were slightly stronger as compared to air quenched. From preliminary tensile tests, it was evident that water quenched samples exhibited slightly faster age hardening rates, as compared to air quenched samples, for soaking durations up to 6h, while this is reversed for soaking times between 6 and 12h. Maximum proof and tensile strength were achieved for both types of samples after 12h soak, i.e. 250 and 275 MPa respectively. Correspondingly, fracture elongation was constantly 2% higher for air quenched samples (as compared to water quenched samples) and ageing durations up to 8h, while their difference is eliminated for 12h soaking time (A=13%). Profiles thermally treated using cycle "B" exhibited lower mechanical properties and often below the specified limits.

Microhardness testing was also carried out to understand the ageing curves (Table 2). Water quenched samples exhibited consistently almost identical hardness values compared to the air quenched samples. Additional sampling at 10h soak showed that peak hardness, corresponding to T6 condition, was probably reached after 10h soak. Double stage ageing procedure produced higher hardness extrusions than single step ageing. These results are consistent with tensile tests data.

Crash relevant response was evaluated via dynamic compression of the extruded profiles according to internal customer specification and subsequent visual examination. Damage assessment criteria involve mainly the identification of deformation mode (folding) and cracking phenomena that took place due to dynamic loading. Air quenched profiles (Figs 7-8) showed destructive fracture (quasi-brittle behaviour, early cracking and severe splitting) and unaccepted folding for 4, 8 and 12 h soaking time and for both thermal cycles. On the contrary, water quenched profiles demonstrated accepted crash tolerance properties. Limiting conditions were achieved for 12h soak time (Thermal Cycle A, B), since no improvement in crash tolerance behaviour has been recorded by employing further thermal treatment (ageing at 170°C for 14h); a deterioration in deformation mode was rather induced resulting in severe cracking and fracture phenomena. Double and single step ageing did not cause noticeable differences in crash tolerance behaviour.

Table 2 Microhardness measurements ($HV_{0.1}$). Mean of 10 measurements.

		Air Quenched	**Water Quenched**
As extruded		57	57
Cycle "A", double stage ageing	4h soak	78	78
	6h soak	85	87
	8h soak	85	90
	10h soak	88	89
	12h soak	87	87
Cycle "B", single stage ageing	4h soak	76	80
	6h soak	84	86
	8h soak	86	88
	10h soak	88	89
	12h soak	89	89

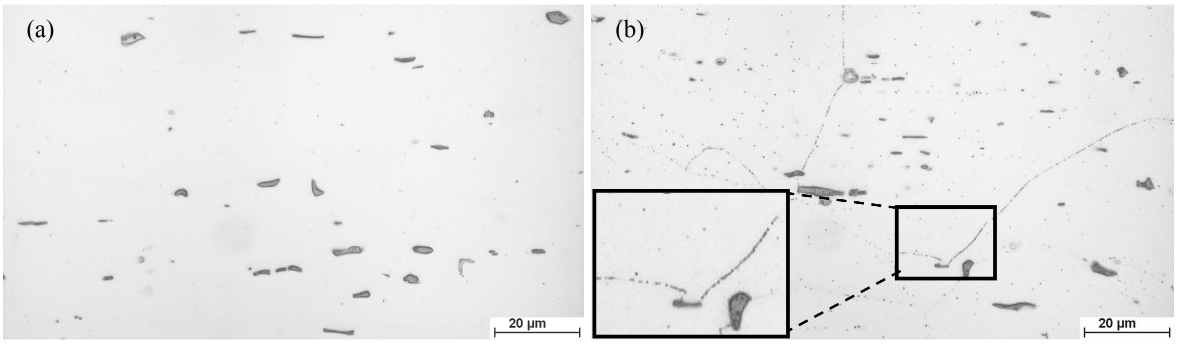

Fig. 4 Optical micrographs of (a) water quenched and (b) air quenched extrusion profile after double stage ageing for 12 hours (HF etch). Grain boundary precipitation of Mg_2Si intermetallics is observed in air quenched sample.

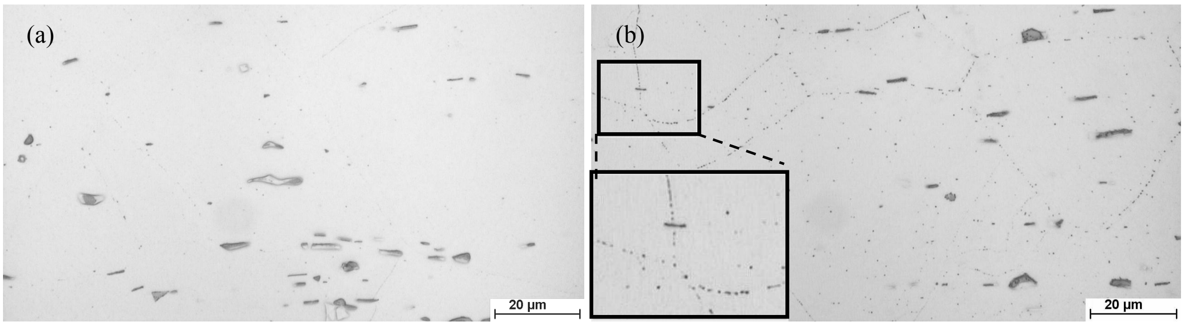

Fig. 5 Optical micrographs of (a) water quenched and (b) air quenched extrusion after single step ageing for 12 hours (HF etch). Grain boundary precipitation of Mg_2Si intermetallics is observed in air quenched sample.

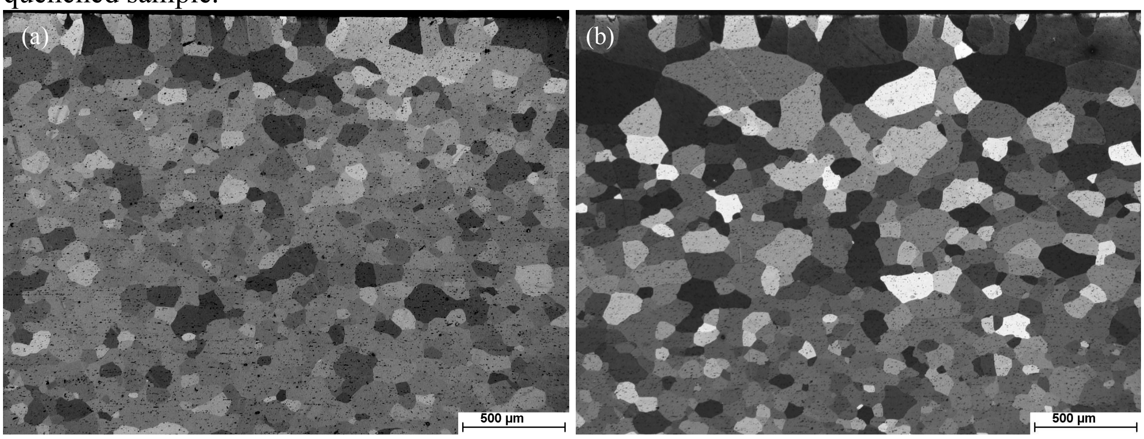

Fig. 6 Optical micrographs of (a) air quenched extrusion and (b) air quenched + single stage aged for 12 hours soak (Barker's etch). Grain growth near the surface is evident. Longitudinal cross-sections.

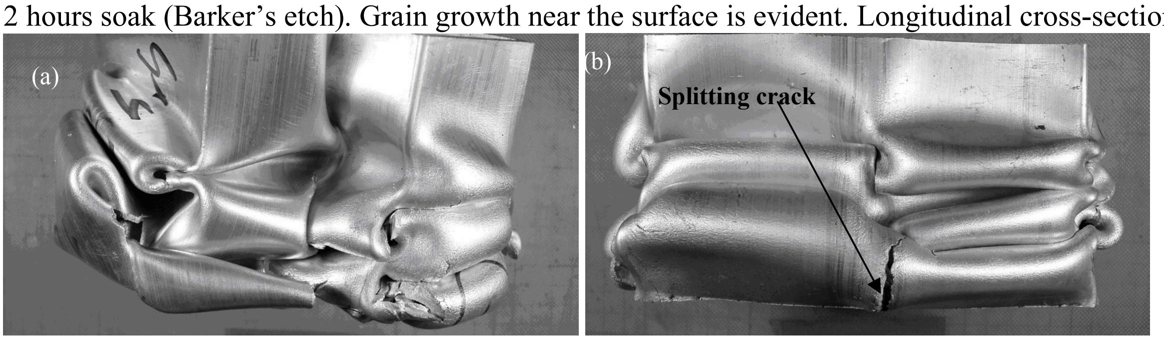

Fig. 7 Macro images showing non-symmetrical folding, severe cracking and splitting in air quenched extrusions. (a) Double stage aged profile for 8 hours and (b) single step aged for 4 hours.

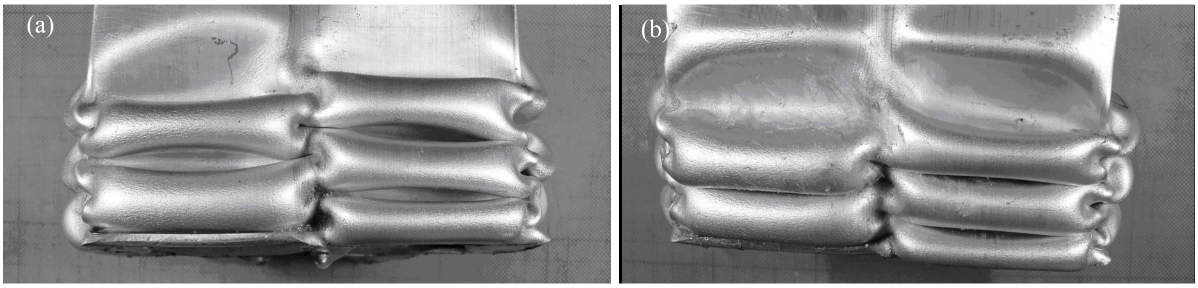

Fig. 8 Macro images showing symmetrical folding in water quenched extrusions after. (a) Double stage aged (profile for 12 hours and (b) single step aged for 8 hours.

3. Conclusions

From the above results it can be deduced that:

1. Homogenization treatment for 24 hours at 580°C leads to progressive segmentation of the β-blades with a direct contribution on extrudability and toughness of the final component.
2. Poor crash performance exhibited by the air quenched samples could be attributed to the presence of coarse intermetallic particles on grain boundaries, which became more evident as ageing time increased. Weakening of the extrusions predominantly close to these areas has an adverse effect on the crash behavior, as manifested also by the reduction of the tensile fracture elongation after ageing.
3. Tensile properties requirements are succeeded by air and water quenched samples after double stage thermal treatment due to primary precipitation of GP coherent zones which are nucleation sites for semi-coherent phases.
4. As a result of the present investigation, the optimum combination in toughness and strength is fulfilled in the case of water quenched and double stage aged sample for 8 and 12 h soaking time.

References

[1] ASM SPECIALTY HANDBOOK, *Aluminum and aluminum alloys*.

[2] Dietrich G. Altenpohl: *Aluminum: technology, applications, and environment, a profile of a modern metal*, TMS, 1998.

[3] F.O.Traenkner: *Factors affecting the physical characteristics of aluminum magnesium silicon alloy extrusions*, National Aluminum, Proceedings of the second International Aluminum Extrusion Technology Seminar.