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Toward a Recrystallized Microstructure in Extruded AA6005A Alloy

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Abstract

The correlation between extrusion processing parameters and chemical compositions on the one hand and the grain structure and mechanical properties on the other hand is studied for an extruded AA6005A alloy. Alloys with different chemical compositions and billet homogenization treatments have been extruded under different processing parameters. Optical microscope observations as well as hardness tests show that a wide range of mechanical properties and microstructures can be obtained. The grain structure can vary from a fibrous, deformed microstructure to a fully recrystallized microstructure. In some cases a mixture of the two is observed. The effects of processing parameters and chemical composition on the grain structure is discussed and used to find the optimized combination of homogenization treatment, pre-heating temperature, cooling rate after deformation, and chemical composition, in order to obtain a homogeneous recrystallized grain microstructure and optimum mechanical strength.

Introduction

Aluminum alloys are increasingly used in structural components in automotive and aerospace industries. They offer low weight, relatively high strength, corrosion resistance and good weldability [1-4]. Among different groups of aluminum alloys, the heat-treatable AA6xxx series aluminum alloys are the most widely used alloys in various medium-strength structural components, including automobile body sheet, pipes, welded structures, and aircraft components. Extrusion of aluminum alloys is a relatively cheap and fast method of producing complex shapes from Al-Mg-Si alloys. The flexibility of the extrusion method with respect to the alloy chemistry and profile shapes makes a unique technique for a wide range of components, used in building structures, offshore industry, furniture, aerospace applications, and automotive applications [2]. Control of grain structure in extruded Al-Mg-Si alloys structures is of critical importance in so many applications. For example in aerospace applications, presence of peripheral coarse surface grain size can significantly decrease the fatigue resistance of the components. In most applications for Al-Mg-Si alloys, a fibrous deformed grain structure is more desirable. This can be achieved by increasing the amount of dispersoid-forming elements (mainly manganese and chromium) in the Al-Mg-Si alloys. However, in most cases the higher the Mg and Cr contents, the higher the extrusion pressure, which could eventually increase the risk of the formation of peripheral coarse grain structure. Coarse recrystallized surface layer in alloy AA6005A could results in orange peel effect during cold forming and poor anodized appearance for decorative applications [3]. So, for some applications it could be more beneficial to have a fully recrystallized microstructure in Al-Mg-Si alloys rather than a deformed structure. However, changing the microstructure from a fibrous deformed one to a fully recrystallized one necessities a precise control of chemical composition as well as processing parameters. Non-homogeneous distribution of grain size and partially recrystallized structures are not desirable. Recrystallization behavior during extrusion can be controlled by the alloy chemistry, homogenization treatment and extrusion processing parameters. There is limited available literature regarding the correlation between the alloy chemistry and extrusion parameters in one hand and the grain structure of Al-Mg-Si extrudate in the other hand. This study aims at understanding the role of chemical composition, homogenization treatment, billet temperature, and quench rate on the grain structure of the alloy AA6005A. The information presented in this paper could be useful to control and optimize the grain structure in other grades of Al-Mg-Si alloys.

Materials and Methods

The chemical composition of the alloy AA6005A is shown in table 1. Two variants of the alloy AA6005A were DC-cast into ingots of length 300 mm and diameter 143 mm: one with Mn+Cr=0.13 (hereafter named 6005A_I) and the other one with Mn+Cr=0.4 (hereafter named 6005A_II). Mn and Cr are dispersoid-forming alloying elements, which inhibit the recrystallization and grain growth. The ingots were extruded with the speed of 3 mm/s to the profile shown in Figure 1. Two homogenization temperatures 530 and 570 °C were used to homogenize the as-cast ingots. Two pre-heating temperatures 480 and 520 °C were also chosen to pre-heat the ingots before extrusion. The ingots were either air- or water-quenched after extrusion, to study the effect of cooling rate after extrusion on the grain structure and mechanical properties of the alloy AA6005A. The grain structure of the extruded profiles was examined with a polarized optical microscope.

Table I. Chemical composition (wt%) of the alloy AA6005A

Elements	**6005A**	
	Min	**Max**
Si	0.5	0.9
Fe	-	0.35
Cu	-	0.3
Mg	0.4	0.7
Mn	-	0.5
Cr	-	0.3
Zn	-	0.2
Ti	-	0.1
Others each	-	0.03

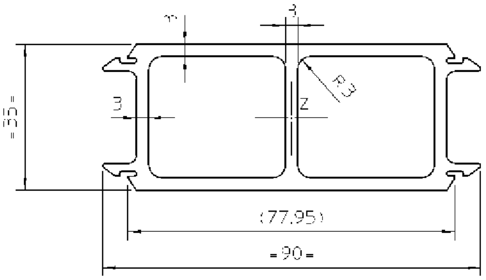

Figure 1. The drawing of the die, which is used for the extrusion (dimensions are in mm)

Results and Discussions

The grain structures observed after extrusion can be categorized into three categories: fibrous or deformed, fully recrystallized, and mixed recrystallized/deformed. Figure 2 shows examples of these three different microstructures.

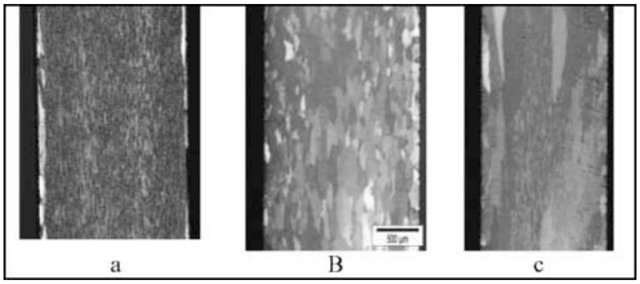

Figure 2. Examples of a) deformed, b) recrystallized, and c) mixed recrystallized/deformed grain structures

Figure 3 compares the microstructures of alloys AA6005A_I and AA6005A_II,. The microstructure of AA6005A_I, having lower amounts of Mn and Cr, is either completely recrystallized or mixed recrystallized/deformed depending on the process parameters. The microstructure of AA6005A_II, having higher amounts of Mn and Cr, is always fibrous. This can be rationalized in terms of the concentration of dispersoid forming elements, Mn and Cr. The dispersoids offer a resistance to grain boundary motion and can therefore inhibit the growth of grains during recrystallization. Decreasing the total Mn and Cr content reduces the volume fraction of particles and increases the inter-particle spacing, which decreases the grain boundary pinning effect, resulting in the easier recrystallization.

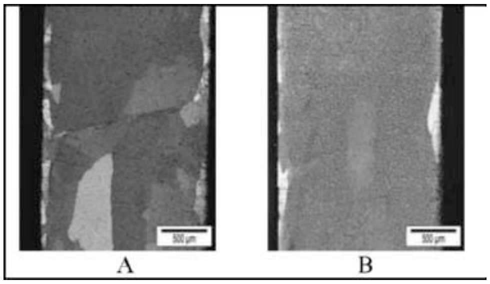

Figure 3. Effects of Mn+Cr contents on the grain structure in the a) alloy AA6005A_I and b) alloy AA6005A_II

Figure 4 shows the effects of cooling rate after extrusion on the grain structure of the alloy AA6005A_I. It is seen that the alloy, quenched in air (Figure 4a), has slightly larger grains, compared to the water-quenched sample (Figure 4b). During slow quenching, the exposure time of the profile at elevated temperatures, where further grain boundary motion could takes place, increases. This could be the main reason for the observed difference between grain size in the water-quenched and air-cooled samples. This effect is, however, minimal and obviously the grain structure of AA6005A alloy is relatively stable during elevated temperature exposure after extrusion. It is worth noting that the cooling rate after extrusion does not have any influence on the deformed fibrous structure of the alloy AA6005A_II either.

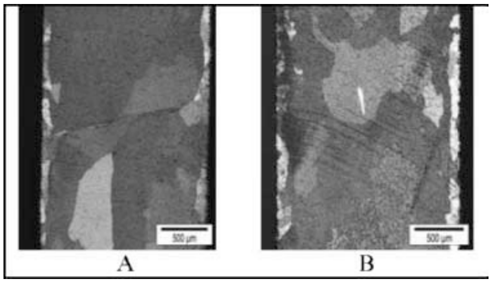

Figure 4. Effects of cooling rate on the grain structure of the alloy AA6005A_I after a) air cooling and b) water quenching

Figure 5 shows the effects of pre-heating temperature on the grain structure of the alloy AA6005A_II. Obviously, the pre-heating temperature does not have any significant influence on the grain structure. This is also the case for the alloy AA6005A_I. Billet temperature influences the stored energy and can drive or inhibit recrystallization. High billet temperatures promote high exit temperatures, allowing grain boundaries to move but also correspond to lower stored energy. In the current case it seems that the difference between pre-heating temperatures 480 and 520 °C is not high enough to make a difference in the grain structure of extrudates.

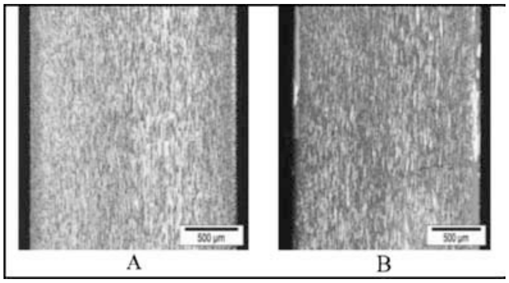

Figure 5. Effects of pre-heating temperature a) 480 °C and b) 520 °C on the grain structure of the alloy AA6005A_II

Figure 6 shows the effects of homogenization temperature on the grain structure of the alloy AA6005A_I. At homogenization temperature 530°C, in most cases a mixed deformed/recrystallized structure is observed (see Figure 6a). However, by increasing the homogenization temperature to 570 °C, a more homogeneously recrystallized microstructure is obtained. This could be attributed to the effects of homogenization treatment on the dispersoid size distribution. Further investigation on the effects of temperature on the dispersoid size distribution is, however, needed to postulate the effects of homogenization temperature on the structure of extrudates.

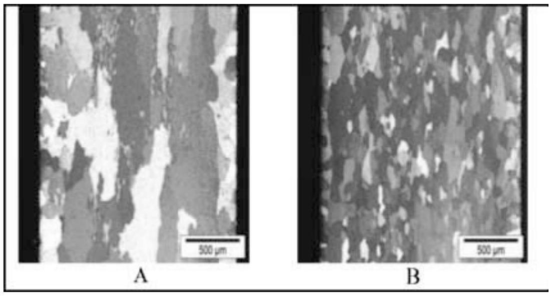

Figure 6. Effects of homogenization temperature a) 530 and b) 570 °C on the grain structure of the alloy AA6005A_I

Figure 7 shows the microhardness of the alloy AA6005A_II after extrusion and a few days of natural ageing and after 6 hours ageing at 180 °C. Obviously, when the alloy is water-quenched, the hardness is higher compared to the case when the alloy is air-cooled. Furthermore, the hardness increase during artificial ageing is also higher for the water-quenched material than the air-cooled one. Besides, pre-heating at 520 °C could slightly increase hardness compared to the pre-heating at 480 °C and has negligible effect on the hardness increment during artificial ageing. The overall strength and hardness of Al-Mg-Si alloys mainly depend on the microstructure, the solute content, and the distribution of precipitates, in the present case the metastable phases of Mg_2Si [5]. Since pre-heating temperature and cooling rate were found to have minimum effects on the microstructure, the difference of hardness observed in figure 7 can be attributed to differences in solute content and precipitate distribution. During ageing precipitates nucleate from the supersaturated solid solution. These nuclei are small and, therefore, cut through by moving dislocations during deformation. The contribution of these nuclei to the strength is usually weak or moderate. The higher the temperature at which the nucleation takes place, the lower the nucleus number density. By increasing the ageing time, the precipitates become larger and stronger. Precipitates larger than a transition radius cannot be sheared any more and dislocation can only bypass by looping around them. This leaves an Orowan loop around the precipitates that enhances the mechanical properties of the alloy. However, the density of precipitates simultaneously decreases during ageing so that a maximum strength is obtained for an intermediate average precipitate size. When precipitates become bigger, their number decreases and the overall strength as well. During air-cooling after extrusion, precipitates have time to nucleate and grow when the material is still at high temperature. These precipitates have a low number density, and therefore have limited contribution to the strength, but could still consume significant amounts of Mg and Si. As a result the supersaturation will be low after cooling and the hardening potential of the material during artificial ageing is limited. In comparison, no precipitation is expected during water-quenching and the supersaturation is maintained. A high density of precipitates can nucleate during subsequent natural ageing and artificial ageing and contribute to the observed strength increase. The higher hardness for the material pre-heated at 520 °C compared to the one pre-heated at 480 °C can be related to the higher amount of Mg and Si in solid solution at higher pre-heating temperature. During water-quenching this difference is conserved. The higher supersaturation for the material pre-heated at 520 °C provides a higher potential for precipitate strengthening during ageing.

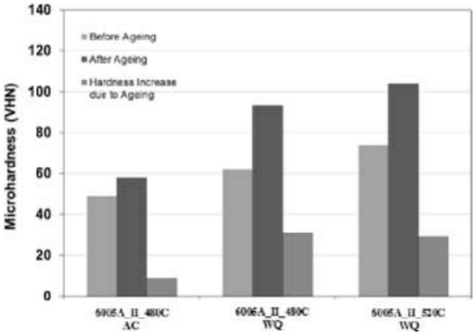

Figure 7. Effects of pre-heating temperature and quenching rate on the hardness of the alloy AA6005A_II

Conclusions

The correlation between extrusion processing parameters and chemical compositions on the one hand and the grain structure and mechanical properties on the other hand was studied for an extruded AA6005A alloy. Alloys with different Mn+Cr contents, billet homogenization treatments and extrusion processing parameters have been extruded. The following conclusions can be drawn:

- The grain structures observed can, depending on the composition and processing parameters, be fibrous, fully recrystallized, or mixed recrystallized/deformed.
- By decreasing the amounts of Mn and Cr, the microstructure is normally either completely recrystallized or mixed recrystallized/deformed.
- The effect of cooling rate on the grain structure is minimal and obviously the grain structure of AA6005A alloy is relatively stable during elevated temperature exposure after extrusion. However, hardness of the aged alloy is very much influenced by the cooling rate after extrusion. Slow quenching in the air promotes the formation of large Mg_2Si particles, and therefore decreases the hardness of T6 alloy.
- At homogenization temperature 530°C, in most cases a mixed deformed/recrystallized structure is observed. However, by increasing the homogenization temperature to 570 °C, the microstructure is more homogeneous. This could be attributed to the effects of homogenization treatment on the dispersoid size distribution.

Acknowledgments

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