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Development of High-strength Aluminum Extrusion Alloy for Automobile Bumper

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In recent years, high strength aluminum alloys with 350MPa in tensile strength have been applied for automobile bumper as request of lightening. However, most attempts were focused on AA7XXX alloys of Al-Mg-Zn. These Al-Mg-Zn alloys had many disadvantageous such as low productivity (extrudability, Z), increasing inferiority, expensive equipment. The aims of present study are focusing on development of automobile bumper by using AA6XXX alloys with higher extrudability over 70. Furthermore, feasibility of solid-solution elimination during T6 heat treatment was also investigated through an application of CNC based rapid extruded bar quenching techniques

Keywords: *Aluminum extrusion, AA6082, High-Strength, Automobile bumper, CNC based rapid cooling*

1. Introduction

The high-strength AA7xxx alloy restrictively used for highly stressed structural components such as bumper in the automobile industries since it is generally acknowledged that the alloy is very difficult to extrude, especially when the cross-section shape of the extrudate is complex. These difficulties induce some disadvantageous such as low productivity(etrudability, Z), increasing inferiority, expensive equipment. Extrusion speed applicable to AA7xxx (up to 10 m/min) is only a small fraction of that for a medium-strength 6xxx series alloy such as AA6061 (5–25 m/min). The low extrudability of AA7xxx is related to its chemical composition with zinc and magnesium as the main alloying elements.

The aims of present study are focusing on development of automobile bumper by using AA6xxx alloys with higher extrudability over 70. Furthermore, feasibility of solid-solution elimination during T6 heat treatment was also investigated through an application of CNC based rapid extruded bar quenching techniques. The present study was intended to demonstrate for the first time that, in the case of extruding the AA6082 alloy into an automobile bumper profile with varied wall thicknesses, the design of extrusion lay out and the choice of process parameters could be integrated to achieve optimum product quality and maximum throughput. In order to achieve this goal, the effect of process parameters such as cooling variant after extrusion, storing time prior to artificial ageing and aging conditions affecting desired mechanical strength for automobile bumper were investigated.

2. Experimental Procedures

Table. 1 indicates chemical composition of commercial AA6082 alloy billet used in this study.

Table. 1 Chemical composition of investigated AA6082 alloy (wt. %)

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
6082	1.19 ~ 1.25	0.18 ~ 0.24	0.1	0.46 ~ 0.5	0.67 ~ 0.76	0.12 ~ 0.16	0.04	0.03	Bal.

The homogenization treatment was carried out at 570±10^{o}C for 8 hours and subsequently cooled to room temperature at a rate greater than 4^{o}C /min. The billet thus produced was pre-heated to 500^{o}C and were extruded into automobile bumper profiles, respectively, at a rate of 97.5 mm/sec. The exit temperature was fixed at 520 ~ 530^{o}C and the profiles were immediately cooled by CNC based rapid extruded bar quenching. After extrusion, the effect of different cooling modes after extrusion (water, air and slow cooling in the furnace) on mechanical properties and micro-structure was investigated. The effect of storing time of 24 and 720 hours at room temperature on mechanical strength was also investigated. The mechanical properties of AA6082 alloy extruded bar were measured with ASTM E subsize specimen which was selected parallel and perpendicular to extrusion direction, respectively.

3. Results and discussion

The metallographic investigations of AA 6082 alloy were performed on the as-cast samples. It has been observed that the microstructure of as-cast AA6082 alloy has various components such as Mg_2Si, α-Al(Fe,Mn)Si and β-$Al_8Fe_2Si_2$ phase as shown in Fig 1. The typical as-cast structure of examined alloys consisted of a mixture of β-AlFeSi and α-AlFeMnSi intermetallic phases distributed at cell boundaries, connected sometimes with coarse Mg_2Si.

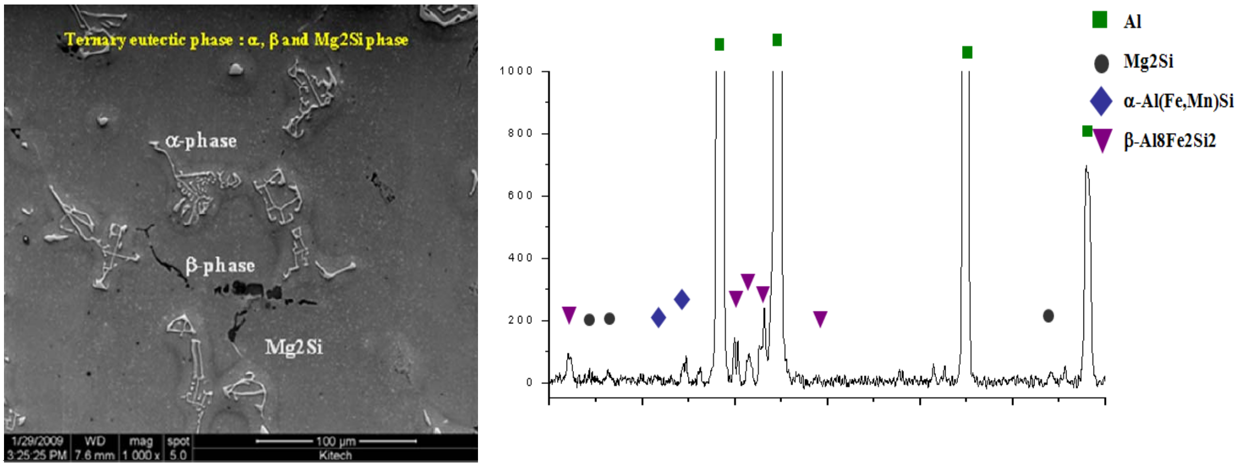

Fig 1. SEM Image and EDX analisys result of as-cast AA6082 alloy

During casting of 6*xxx* aluminum alloys a wide variety of Fe-containing intermetallics such as Al–Fe,Al–Fe–Si and Al–Fe–Mn–Si phases are formed between the aluminum dendrites. Type of these phases depends mainly on the cooling rate and the Fe to Si ratio in the alloy. These intermetallic phases have different unit cell structures, morphologies, stabilities and physical and mechanical properties[6]. During this homogenization treatment several processes take place such as the transformation of interconnected plate-like β-Al_5FeSi intermetallics into more rounded discrete α-$Al_{12}(FeMn)_3Si$ particles and the dissolution of β-Mg2Si particles [7]. Transformation of β-Al_5FeSi to α-$Al_{12}(FeMn)_3Si$ intermetallics is important because it improves the ductility of the material. Dissolution of β-Mg_2Si is also important since it will give maximum age hardening potential for the extruded product [7]. The precipitation of the metastable precursors of the equilibrium β-(Mg_2Si) phase occurs in one or more sequences, which are quite complex. The precipitation sequence for 6*xxx* alloys, which is generally accepted in the literatures [8], is:

$$\text{SSSS} \rightarrow \text{atomic clusters} \rightarrow \text{GP zones} \rightarrow \beta'' \rightarrow \beta' \rightarrow \beta \ \ (\text{stable}) \qquad (1)$$

where SSSS is the super saturated solid solution.

To obtain maximum strength, the exit temperature must be above the solution temperature of Mg_2Si and the cooling fast enough to depress precipitation. For AA6082 alloy this means that cooling with forced air is usually satisfactory on open profiles with a thickness up to 3mm. In the present study, in order to investigate a feasibility of solid-solution elimination after automobile bumper extrusion, an application of CNC based rapid extruded bar quenching techniques was attempted with different cooling modes after extrusion (water, air and slow cooling in the furnace). As show in Fig 2, the tensile strength of the investigated 6082 alloy was generally sensitive to cooling conditions. The highest tensile strength was obtained in the samples cooled in water of 1.2liter/extruded bar-m^3.

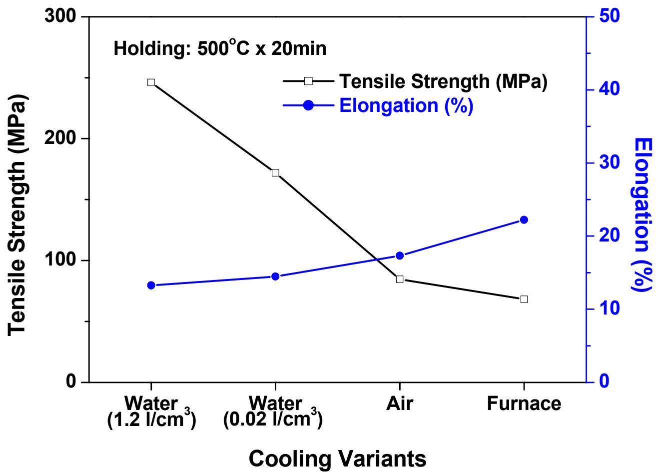

Fig 2. Variation of tensile strength and elongation of AA6082 alloy with different cooling variants after extrusion

Microstructures of the 6082 alloy after different modes of cooling after extrusion are shown in Fig 3. It is likely that during homogenization of the alloy at temperature 570 ◦C, the transformation β -AlFeSi phase in more spheroidal α-Al(FeMn)Si phase may occur. It is supposed that the very fine dispersed precipitates shown in rapid cooling condition by water as shown in Fig 3 (a). The dissolved particles of β-Mg_2Si phase precipitates during slow cooling after extrusion.

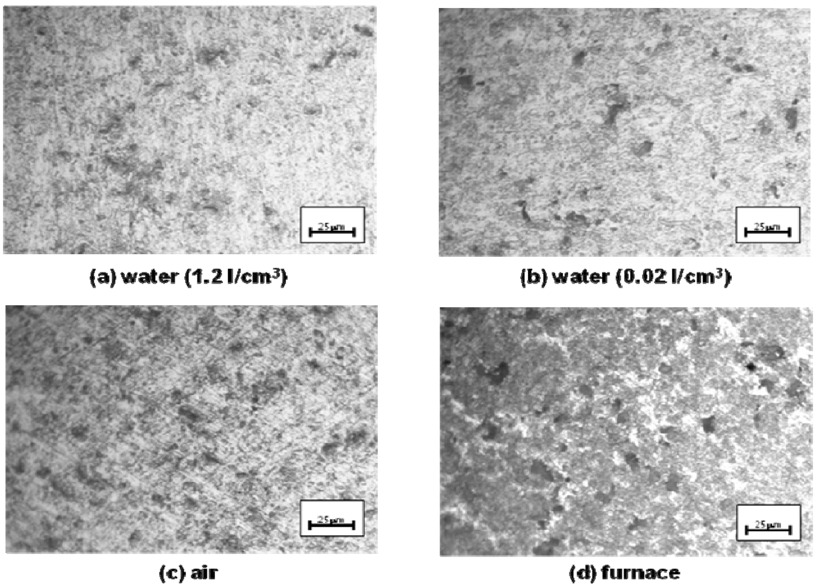

Fig 3. Optical microstructure of AA6082 alloy with different cooling variants after extrusion

As shown in Fig 2 and Fig 3, the enough cooling by water after extrusion may induce both higher strength and finer precipitates in extruded AA6082 alloy. Fig 4 shows the variation of tensile strength of aged AA6082 alloy with different aging time after extrusion. The tensile strength increases with increasing aging time although quenching(water cooling after extrusion) was not performed. It can be mentioned that ageing at high temperature gives higher strength than ageing at low temperature when ageing time is similar. Furthermore, in the present study, the CNC based rapid extruded bar quenching techniques were applied to minimize tolerance during cooling. The tolerance of extruded bar with/without quenching shows similar up to 3%.

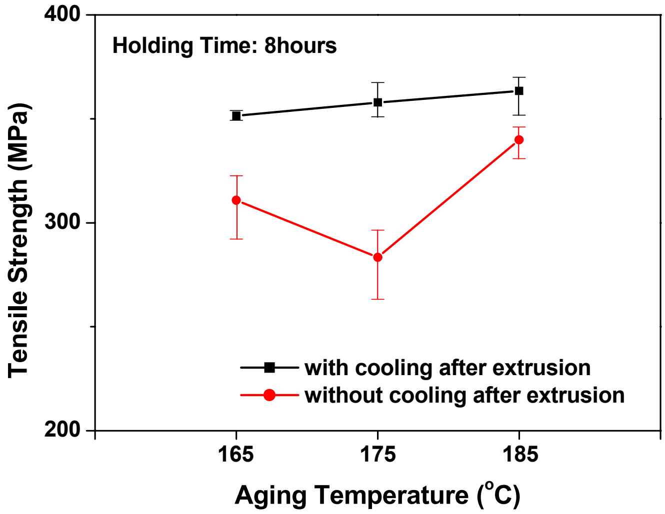

Fig 4. Variation of tensile strength of aged AA6082 alloy with different aging temperature

It is generally well known that mechanical strength of AA6082 alloy depends upon the intermediate storing time prior to artificial ageing. The effect of storing time before ageing on mechanical strength was also investigated quantitatively.

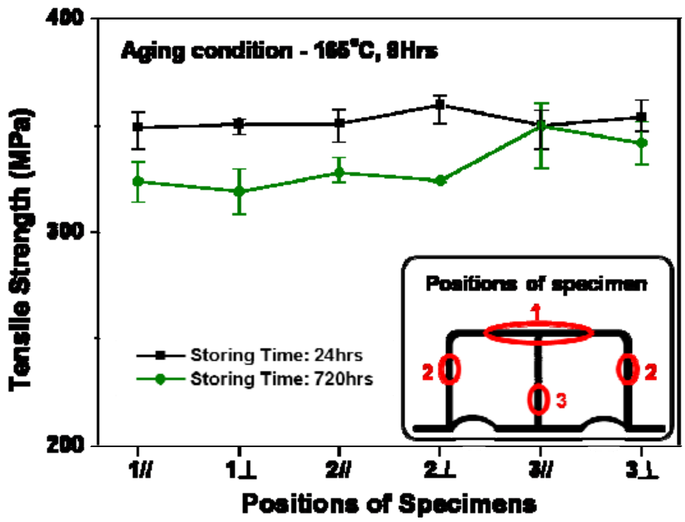

Fig 5. Variation of tensile strength of aged AA6082 alloy with different storing time afer extrusion

Fig 5 shows the variation of tensile strength of aged AA6082 alloy with different storing time before ageing. In the figure, digit on X-axis indicates strength measurement position in extruded bar of AA6082 alloy. The symbols such as // and ⊥ indicate parallel and perpendicular to extrusion direction, respectively. Even though details of dependence on the storage time at room temperature (RT) are not fully understood, it can be mentioned that the mechanical strength may decrease with increased intermediate storing time. In the present study, storing time much than 24 hours prior to artificial ageing will decrease the tensile strength with approximately 3%.

4. Conclusions

The following conclusions are drawn from this work:

1. The tensile strength of the investigated 6082 alloy was generally sensitive to cooling conditions after extrusion. The highest tensile strength was obtained in the samples cooled in water.
2. It can be mentioned that optimum ageing parameter of AA6082 alloy for automobile bumper was 185°C x 5hours in a view point of tensile strength and elongation.
3. It was also found that storing time much than 24 hours prior to artificial ageing may induce the decreased tensile strength with approximately 3%.

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