Evaluation of Microstructure and Mechanical Properties of 5182 Aluminum Alloy Ingots with Large-Sections

Youjun Guo, L. Shen and Z.M. Shi

ABSTRACT

The microstructure and mechanical properties of continuously-cast 5182 aluminum alloy ingots with large-sections are not uniform, which depends on the diameter of ingots and the position where the sample locates. For the Φ160 ingot, the outer layer and middle layer have fine and uniform α-Al grains, while the centre appears the coarse α-Al dendrite. In contrary, the middle and centre layers appear the coarse α-Al dendrite, only the outer layer has the fine α-Al grains for the Φ380 ingot. The (FeMn)Al$_6$ and Mg$_2$Si phases coexist in the primary α-Al grain boundaries and the Mg$_2$Al$_3$ phases precipitate in the α-Al grains. By homogenously annealing, the Mg$_2$Si and (FeMn)Al$_6$ phases are broken-up into dispersive islands and particles and the Mg$_2$Al$_3$ phases precipitate more sufficiently in the forms of fine particles and short flakes. The elongation is largely enhanced; while the yield strength, tensile strength and hardness receive much less influence by the heat treatment. However, the homogenous annealing at 495 °C for 24 h is not enough for adjusting the microstructure of the Φ380 ingot.

INTRODUCTION

5182 aluminum alloy has many advantages such as moderate strength, good corrosion resistance and excellent weldability, which has been widely used in modern transportations to meet the requirement of lightweight manufacturing and saving energy. A lot of researches have paid attentions to the casting and heat treatment techniques.

Thompson et al. [1] investigated the phase transformations and the evolution in solid fraction during solidification of 5182 alloy. The eutectic precipitates between 575 and 588°C, which corresponds to a solid fraction between 87-91%, and Mg$_2$Si phases precipitate between 551 and 560°C, which corresponds to a solid fraction of about 96-97%. Increasing cooling rate results in a slight increase in solid fraction for the eutectic precipitation and the highest cooling rate results in a drop in the solidus temperature from 500-510°C to 461°C. Flood et al. [2] reported the effects of casting
speed and grain refinement on structure and macrosegregation in AA-5182 alloy ingots. The structure and macrosegregation are insensitive to the casting speed; the grain refinement prevents “feather” grains and produces fewer but larger iron-bearing particles. The iron intermetallic type is insensitive to the casting parameters, which deteriorates the mechanical properties. Ratchev et al [3] found that two morphologies of rhomboidal and platelike (MnFe)Al₆ phases precipitated in the AA 5182 alloy; the platelike dispersoids have orientation relationships with the matrix of [100]//[210] and (011)/(001); while the rhomboidal precipitates do not follow any orientation relationship with the matrix, which has more harmful influence in recrystallization and hot ductility than the platelike ones. Baldacci et al [4] studied the break-up of large intermetallic particles during reversible hot rolling. The two types of particles of Al-Fe-Mn and Mg₂Si exhibit different behaviors; the iron-rich particles break up more quickly. Gao, et al [5] found that the tensile strength and yield strength of the 5182 aluminum alloy strips annealed at 250°C for 3 h is increased by about 10-15 MPa when compared with that annealed at 350°C for 3 h; the elongation of the strips is also improved. Wang et al [6] noticed that with increasing the annealing temperature and elongating the holding time, the tensile strength of the rolled 5182 alloy sheet decreases slightly, but its elongation and strain hardening exponent increase sharply, which reach up to 26.5% and 0.34 respectively. Annealed at 380°C for 24 h, the alloy accomplishes the recrystallization and obtains fine and homogeneous grains; the drawability of the alloy is also improved. Hollinshead [7] observed that the high temperature preheat followed by a slow cooling produces the coarse needlelike dispersoids; whereas a low temperature preheat produces a fine dispersion of low aspect ratio particles in AA 5182 alloy.

As is well known, to meet the need for energy-saving and environment-protection, the configuration size of transportations is gradually increasing, so the size of original aluminum alloy ingots is accordingly increased. However, the increase in the size brings about changes in microstructure and mechanical properties because of the change of solidification process, which further influences the subsequent heat treatment and plastic processing. Up to now, few of researches have paid attentions to the changes in microstructure and mechanical properties. Therefore, this paper aims to disclose the changes in the 5182 aluminum alloy ingots with different diameters so as to accurately control the casting, heat treatment and plastic deformation processes.

EXPERIMENTAL PROCEDURES

The 5182 aluminum alloy ingots, φ160×2500 mm and φ380×2500 mm, were fabricated by a continuous casting technique, hot top mould casting [8], as shown in Fig. 1. The primary pure aluminum ingot was added into an electric furnace to be melt at 750 °C, and definite amounts of intermediate alloys of Al-Si, Al-Fe, Al-Mn, Al-Cu, Al-Cr, Al-Ti, Al-Mg and Al-Zn were put into the melts. After remelting, the melts was purified by adding tetrachloroethane flux. The composition of the melts was shown in Table 1. When the temperature dropped to 720 °C, the melts was introduced into the water-cooled graphite crystallizer through a porous ceramic filter. After staying for 40-60 s, the ingot was drawn down at a speed of 40-50 cm/min and wassecondly cooled by the water jet. By changing the diameter of the graphite
crystallizer, the ingots with different diameters can be prepared. The ingots were further annealed at 495 °C for 24h.

![Figure 1. Sketch map of crystallizer.](image)

![Figure 2. Sampling positions.](image)

**TABLE 1. **CHEMICAL COMPOSITION OF 5182 ALUMINUM ALLOY, WT%.

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.20</td>
<td>0.32</td>
<td>0.14</td>
<td>0.30</td>
<td>4.2</td>
<td>0.11</td>
<td>0.23</td>
<td>0.14</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

Three ringlike layers with a thickness of 20 mm and a longitudinal length of 150 mm were cut down by an electric spark processing method as shown in Fig. 2. For every layer, five samples were cut uniformly along the ring and were machined into standard tensile samples with a diameter of 10 mm. Table 2 listed the D1, D2 and D3 value for the ingots with diameters of 160 mm and 380 mm.

**TABLE 2. **SAMPLING DIMENSIONS, MM.

<table>
<thead>
<tr>
<th>Ingot</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
</tr>
</thead>
<tbody>
<tr>
<td>φ160</td>
<td>60</td>
<td>110</td>
<td>160</td>
</tr>
<tr>
<td>φ380</td>
<td>60</td>
<td>220</td>
<td>380</td>
</tr>
</tbody>
</table>

The microstructure was observed by a metallurgical microscope (OLYMPUS-GX51). The surfaces of the samples were polished and etched by an HF (5 wt%)-alcohol solution. The mechanical properties were measured using a material test machine (Jinan SHT4605) with a loading speed of 0.2 mm/min.

**RESULTS**

**Microstructure and Mechanical Properties of Different Layers for φ160 Ingot**

*As-cast state.*

Fig. 3 shows the microstructure of cross-section in different layers for the as-cast Φ160 ingot. The D2 and D3 layers are composed of fine α-Al dendrites, however, some coarse α-Al dendrites present in the layer D1 (Fig. 3a). This indicates that the cooling rate has a great influence in the microstructure, i.e., higher cooling rate reduces the granularity of the α-Al dendrites. Moreover, the Mg$_2$Al$_3$ phases precipitate in the α-Al grains in forms of fine particles. The dark clawlike and bulks are Mg$_2$Si phases; the gray bulks are (FeMn)Al$_6$ phases, which locate in the α-Al grain boundaries (Fig. 4a).
Annealed State.

Annealed at 495 °C for 24 h, the Mg₂Si and (FeMn)Al₆ phases are broken-up into fine particles that distribute uniformly in the α–Al grain boundaries and their contents are reduced (Fig. 5). This indicates that the Fe, Mn and Si atoms in the intermetallics partially dissolve into the α–Al grains. Moreover, the Mg₂Al₃ phases sufficiently precipitate in the α–Al grains in the forms of fine particles and short flakes (Fig. 4b).

Mechanical Properties.

Table 3 shows the mechanical properties of different layers for the Φ160 ingot. The centre layer D1 has the lowest tensile strength and elongation in both states. By an annealing treatment, the tensile strength and elongation are enhanced; however, the yield strength and hardness are slightly decreased. The improvements can be related to that, the particles and short flakes of Mg₂Al₃ phases paticipated in the α-Al grains produce a good collocation for strength and plasticity; the annealing
eliminates the inner stress and the isolated Mg$_2$Si and (FeMn)Al$_6$ phases reduce the stress concentration.

**TABLE 3. MECHANICAL PROPERTIES OF DIFFERENT LAYERS OF ANNEALED Φ160 INGOT.**

<table>
<thead>
<tr>
<th>State</th>
<th>As-cast state</th>
<th>Annealed state</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D1</td>
<td>D2</td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield strength, MPa</td>
<td>141.7</td>
<td>142.2</td>
</tr>
<tr>
<td>Tensile strength, MPa</td>
<td>258.8</td>
<td>266.8</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>19.8</td>
<td>25.8</td>
</tr>
<tr>
<td>Hardness, HB</td>
<td>70.2</td>
<td>71.2</td>
</tr>
</tbody>
</table>

**Microstructure and Mechanical Properties of Different Layers for φ380 Ingot**

**As-cast State.**

Fig. 6 shows the cross-section microstructure of different layers for the as-cast Φ380 ingot. It is obvious that the grain size is greatly influenced by the sampling positions. With the change of D3, D2 and D1 positions, the sizes of α-Al grains, as well as the Mg$_2$Si and (FeMn)Al$_6$ phases are largely increased. This indicates that the diameter of an ingot greatly affects uniformity of the microstructure, which is dominated by the solidification behaviors.

![Figure 6](image)

**Figure 6.** Cross-section microstructure of different layers of as-cast Φ380 ingot, (a) D1; (b) D2; (c) D3.

**Annealed State.**

Fig. 7 illustrates the microstructure of different layers for the annealed Φ380 ingot. Even though the intermetallics are isolated, the Mg$_2$Al$_3$ phases mainly precipitate along the grain boundaries for the D1 and D2 samples. This is because that, there exists a temperature gradient in the radial direction of the ingot. With an increase of the diameter, the temperature gradient will get greater. Therefore, the actual soaking temperature and time are less than that of the small section ingot, resulting in the poor annealing effect.
**Mechanical Properties.**

Table 4 shows the mechanical properties of different layers. Comparing with that of the Φ160 ingot, it can be seen that the mechanical properties of the ingot are lower in general. The annealing can not adjust the mechanical properties to a high level as that of the Φ160 ingot.

### CONCLUSIONS

The Φ160 ingot roughly has the uniform microstructure and mechanical properties in as-cast and annealing states, while they are greatly dependent on the sampling positions for the Φ380 ingot.

By homogenously annealing at 495 °C for 24 h, the (FeMn)Al₆ and Mg₂Si phases are broken-up into dispersive islands and particles; the Mg₂Al₃ phases precipitate more sufficiently in the forms of fine particles and short flakes for the Φ160 ingot. However, the annealing is not enough for adjusting the microstructure of the Φ380 ingot because of the insufficient precipitation of Mg₂Al₃ phases in D1 and D2 samples.

The Φ160 ingot has higher tensile strength and elongation than those of the Φ380 ingot in both states, and they are further enhanced by the annealing, especially for the Φ160 ingot, the yield strength and hardness are slightly decreased; the elongation and tensile strength are increased. However, annealing at 495 °C for 24 h is not enough for adjusting the microstructure of the Φ380 ingot.

### REFERENCES


