Effect of Si Content on the Properties of A356 Aluminum Alloy

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Abstract. The effects of different Si contents on the microstructure and mechanical properties of A356 aluminum alloy were studied by metallographic microscope analysis and tensile property test. The results show that when the silicon content is between 7% and 11%, with the increase of silicon content, the eutectic silicon in the matrix increases, and the tensile strength and elongation decrease. When the silicon content increased to 13%, the primary silicon structure appeared in A356 aluminum alloy, and its mechanical properties increased.

1. Introduction
At present, A356 aluminum alloy is used as the raw material to produce aluminum alloy automobile wheel hubs worldwide [1]. A356 aluminum alloy has good casting properties. After T6 heat treatment, the castings have excellent physical and chemical properties, good mechanical properties and machining properties, and achieve high strength, good plasticity, high impact toughness and corrosion resistance [2-3]. The effect of Si content on the properties of A356 aluminum alloy was investigated in this project.

2. Experimental scheme and sample preparation
2.1 Preparation of alloys

2.2.1 Test raw materials and smelting equipment
The main materials needed in the experiment are: aluminum block (99.5 %), Al-14 % Si master alloy, magnesium block (99.5 %), block hexachloroethane (degassing agent of aluminum liquid), coating (25 % ZnO powder, 15 % sodium silicate and 60 % water modulation). The main equipment required for the experiment include melting furnace, heating resistance furnace, thermometer, slag skimming tool, self-made clock cover, stirring rod, pouring tool, pouring mold, etc.
2.2.2 Adding scheme

Table 1 Test number of different Si content (wt %)

| serial number | Si content (%) | Mg content (%) | Al content |
|---------------|----------------|----------------|------------|
| group 1       | 7              | 0.4            | margin     |
| group 2       | 9              | 0.4            | margin     |
| group 3       | 11             | 0.4            | margin     |
| group 4       | 13             | 0.4            | margin     |

2.2.3 Alloy melting and casting

The pre-calibrated and pre-heated aluminum block was put into the melting furnace, and the melting temperature was adjusted to 730-750 °C. The Al-14 % Si alloy and magnesium block were added in turn, and the gas and slag were removed twice with hexachloroethane. The inclusions on the surface of the melt were removed with the slag skimming tool [4-5]. The melt was standing for 10-15 min before pouring, and finally was injected into the tensile sample mold.

3. Analysis of metallographic microscopic results

Fig.1 shows the metallographic diagram of A356 aluminum alloy with silicon content of 7 %. The main morphologies in the metallographic diagram are coarse α-Al matrix phase and coarse eutectic silicon structure [6]. Since the proportion of aluminum in the A356 alloy sample is high, and the sample is not subjected to heat treatment and modification, the dendrites of α-Al matrix phase in the microstructure are relatively coarse and adhered together, and there is a serious segregation of organizational components. The eutectic silicon is obviously passivated, and the grains are coarse, showing dendritic or acicular shapes. Due to the low silicon content, the distribution of eutectic silicon is relatively diffused and unevenly distributed in the alloy microstructure. At high magnification, the Mg₅Si phase is dendritic with uneven composition distribution.

Fig. 1 Microstructure morphology of as-cast A356 aluminum alloy with 7 % silicon content (X200)

Fig. 2 Microstructure morphology of 9 % Si A356 aluminum alloy (X200)
Fig. 2 is the metallographic diagram of A356 aluminum alloy with 9% silicon content. Due to the increase of silicon content, the eutectic silicon precipitated in the diagram increases, and the distribution in the microstructure is more concentrated. The distribution of eutectic silicon in the whole alloy structure is honeycomb, and the morphology of α-Al matrix phase is smaller. Fig. 3 shows the metallographic diagram of A356 aluminum alloy with 11% silicon content. Due to the continuous increase of silicon content, the metallographic structure shows more and more eutectic silicon. Some eutectic silicon grains are obviously rough and elongated, and the α-Al matrix phase is separated by the eutectic silicon phase, which is distributed in blocks. The Mg$_2$Si phase is dendritic at high magnification. Fig. 4 shows the metallographic diagram of A356 aluminum alloy with 13% silicon content. The silicon content of the sample exceeds the eutectic point (11.7%) in the binary phase diagram of Al-Si alloy, so the microstructure begins to precipitate the primary silicon with block irregular polyhedron. The primary silicon which is irregularly distributed plays a pinning role in the matrix, and the plastic deformation is inhibited [7]. Compared with Fig. 3, the microstructure of eutectic silicon has no obvious change. The α-Al matrix phase is separated by eutectic silicon and primary silicon, and the grain boundary is rougher. At high magnification, the grain size of Mg$_2$Si phase becomes finer and the shape is dendritic.

4. Tensile Properties Analysis

4.1. Tensile results
In A356 aluminum alloy, the fluctuation of silicon element composition will affect the tensile properties of the alloy.
### Table 2 Tensile properties of A356 aluminum alloy after adding different contents of silicon

| State       | Cast condition |
|-------------|----------------|
| Si content / % | 7   | 9   | 11  | 13  |
| Maximum tension /N     | 19713.78 | 18983.60 | 16863.22 | 17364.67 |
| Tensile strength /MPa | 174.46 | 168.00 | 149.23 | 153.67 |
| Elongation / %         | 4.8  | 3.8  | 3.4  | 3.2  |

#### 4.2. Tensile strength analysis
The average tensile strength of the first group (7 % silicon content) was 174.46 MPa, the average tensile strength of the second group (9 % silicon content) was 168.00 MPa, the average tensile strength of the third group (11 % silicon content) was 149.23 MPa, and the average tensile strength of the fourth group (13 % silicon content) was 153.67 MPa. It can be seen from Fig. 5 that when the silicon content is in the range of 7 % - 11 %, with the increase of the proportion of silicon in A356 aluminum alloy, the average loading force required for the tensile specimen decreases, so the calculated average tensile strength also gradually decreases. This is because with the increase of silicon content in A356 aluminum alloy, the precipitated eutectic silicon in the microstructure of A356 aluminum alloy also increases, and the eutectic silicon in the alloy microstructure is distributed in a network. The network eutectic silicon has a splitting effect on the α-Al matrix, which makes it easy to produce slight defects in the alloy microstructure, and affects the properties of the alloy. When the silicon content reaches 13 %, the primary silicon precipitates in the alloy structure form a second phase particle, the dislocation is pinned by the second phase particle, and the average tensile strength is slightly improved.

#### 4.3. Elongation analysis
The average elongation of the first group of samples (silicon content was 7 %) was 4.8, the average elongation of the second group of samples (silicon content was 9 %) was 3.8, the average elongation of the third group of samples (silicon content was 11 %) was 3.4, and the average elongation of the fourth group of samples (silicon content was 13 %) was 3.2. It can be seen from Fig. 5 that when the silicon content is in the range of 7 % - 13 %, the elongation of the alloy sample decreases gradually with the increase of silicon content in A356 aluminum alloy.

#### 5. Conclusions
The effects of different content of silicon on the microstructure and properties of A356 aluminum alloy were explored by metallographic microscopy and tensile test. The conclusions are as follows: When the silicon content of A356 aluminum alloy reaches 13 %, the bulk irregular polyhedron primary silicon begins to precipitate in the metallographic structure, and the eutectic silicon and primary silicon coexist. The primary silicon is not distributed, and the primary silicon precipitates in the matrix forms second phase particles. The dislocation is pinned by the primary silicon particle, and the mechanical properties are slightly improved. The alloy with 7 % Si content is the best in the range of 7 % to 13 % Si content.

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