[Article ID] 1003－6326(2002)06－1103－04

Development of high plasticity Al-Si alloy and its casting process[①]

GUO Guo-wen(郭国文), LI Yuan-yuan(李元元), CHEN Wei-ping(陈维平),
ZHANG Da-tong(张大童), LONG Yan(龙 雁)
(College of Mechanical Engineering, South China University of Technology, Guangzhou 510640, China)

[Abstract] Aiming to meet the challenge of the shape complexity and high plasticity demanded for the upper connective plate (UCP) in motorcycle, a high plasticity Al-Si alloy named HGZL-02 was developed by optimizing the chemical composition and casting process. Premium UCP castings were obtained by using optimized casting process. Results show that fine and dense microstructure are obtained in the UCP castings. An average of 224 MPa in ultimate tensile strength, 149 MPa in yield strength and 13.2% in elongation are achieved for T6 heat-treated UPS castings.

[Key words] high plasticity; Al-Si alloy; permanent mold casting
[CLC number] TG 146 **[Document code]** A

1 INTRODUCTION

Al-Si alloy has good castability, such as high fluidity, good air tightness, small contraction and low tendency in hot tearing. It has considerably good mechanical property, physical property, corrosion-resisting ability and acceptable machinability after modification and heat treatment. However, the plasticity of Al-Si alloys is rather low, and the elongation of Al-Si alloy casting is generally less than 5%. Low plasticity is the serious shortcoming of Al-Si alloy. Research on improving plasticity of Al-Si alloy is important and it is carried out in both China and abroad[1~4].

Upper connective plate(UCP) is an important part in motorcycle. It requires certain strength and high plasticity. Casting of UCP is difficult because of its complex shape and large difference in thickness at different positions. Al-Si alloy is a suitable material to produce UCP because of its good castability and physical property. However, research should be carried out on improving the plasticity of Al-Si alloy in order to fulfill the requirement for UCP. Mechanical property of UCP casting should be assured that the ultimate tensile strength is not less than 196 MPa and the elongation is not less than 10%.

Based on our experience in strengthening and toughness of copper and aluminum alloys[5~9], the authors have developed a kind of Al-Si alloy with high plasticity and successfully put it into UCP castings production with high comprehensive property by optimizing chemical composition, improving casting process and adopting suitable heat treatment condition.

2 COMPOSITION OPTIMIZATION OF HGZL-02 ALLOY

According to the mechanical requirement of the alloy as well as the strengthening and toughening principles of Al-Si alloy[10, 11], the main alloying elements of the objective alloy were designed as 4.5%~5.5% Si, 0.25%~0.35% Mg and 0.10%~0.20% Ti.

Orthogonal test was arranged to investigate the effect of Si, Mg and Ti on mechanical property of the objective Al-Si alloy (named HGZL-02 alloy thereafter), and obtain an optimized chemical composition of HGZL-02 alloy.

Alloys were melted in an electric furnace. About 5 kg of qualified molten metal was prepared and about 8 tensile bars were obtained in each batch. Pure aluminum, magnesium ingots, Al-35%Si master alloy, Al-5%Ti-1%B master alloy were used in smelting. Foundry returns, aluminum ingot and Al-Si master alloy were charged in sequence to the preheated crucible furnace at the beginning of smelting. The preheated magnesium ingot was charged into the bath when the temperature of the molten metal reached 700 ℃, and part of Al-Ti-B master alloy was charged when the temperature reached 720 ℃. Stirred the bath for 3 min. After charging the commercial refining flux, left the bath alone for 15~20 min and then discarded the floating slag. A little commercial covering flux was scattered on the surface of the molten metal to prevent oxidization and gas absorption. Modification was carried out by using Al-10%

① **[Foundation item]** Project(99J12.1.2.JW1606) supported by the National Defence Science and Technology Research Foundation; project supported by the Natural Science Foundation of South China University of Technology
[Received date] 2002－07－04; **[Accepted date]** 2002－11－08

Sr master alloy at 740 ℃. Left the bath alone for 10~15 min. After the Al-Ti-B master alloy was charged, stirred the bath for 3 min. When the temperature was 710 ℃ to 720 ℃, the molten alloy was ready for pouring.

After different trials, T6 heat treatment was selected for HGZL-02 alloy in this investigation. Tensile bars were heat treated in a well-type electric furnace. They were solution heat treated for 6 h at 535 ±5 ℃ and rapidly quenched into warm water. 6 h after quenching, artificial aging was carried out at 140 ± 2 ℃ for 4~ 5 h, then the tensile bars were cooled in air.

Tensile testing was carried out on a computer-controlled CMT5105 material testing machine equipped with 100 kN load cell according to the Chinese Standard GB228. Diameter of the bar tested was 12 mm, and the surface was in as cast condition.

Results of the orthogonal test on mechanical properties are listed in Table 1. After data processing, influential trends of elements Si, Mg and Ti on mechanical property of the alloy are obtained and shown in Fig. 1.

In order to match the goal that UTS is not less than 196 MPa and elongation is not less than 10%, alloy with composition of 4.5%Si, 0.25%Mg and 0.20%Ti were selected for verification test. Results of verification test were 218 MPa in UTS and 11.5% in elongation for the tensile bars of HGZL-02 alloy.

3 CASTING PROCESS FOR UCP

3.1 Method

Considering the mechanical property and surface quality requirement on UCP casting and production cost, permanent mold casting was employed in the present research. The sketch of casting process is given in Fig. 2.

HGZL-02 alloy was melted in an electric furnace. 7 kg of qualified molten metal was prepared to produce 4 ~ 5 UCP castings and 3~ 5 tensile bars in each batch.

Tensile plate was cut from heat-treated UCP casting. Dimensions of tensile plate are shown in Fig. 3. All surfaces of tensile plate were ground by 800 grit sand paper prior to testing.

Samples for microscopic examination were prepared in accordance with the Chinese GB3246-82 specification. The etchant was a 0.5% hydrofluoric acid. An Olympus optical microscope was used to examine the microstructure of the castings.

Morphology analysis of fracture surface in tensile plates was performed in Philips XL-30 FEG

Table 1 Data of the orthogonal test (metal mold, T6)

Run	w(Si) / %	w(Mg) / %	w(Ti) / %	σ_b/ MPa	Elongation/ %
1	5.0	0.25	0.15	202	9.8
2	5.0	0.35	0.10	223	8.2
3	5.0	0.30	0.20	226	10.1
4	5.5	0.35	0.20	248	8.4
5	5.5	0.30	0.15	238	8.4
6	5.5	0.25	0.10	204	8.5
7	4.5	0.30	0.10	198	9.4
8	4.5	0.25	0.20	209	11.7
9	4.5	0.35	0.15	206	10.1
			Average:	217	9.4

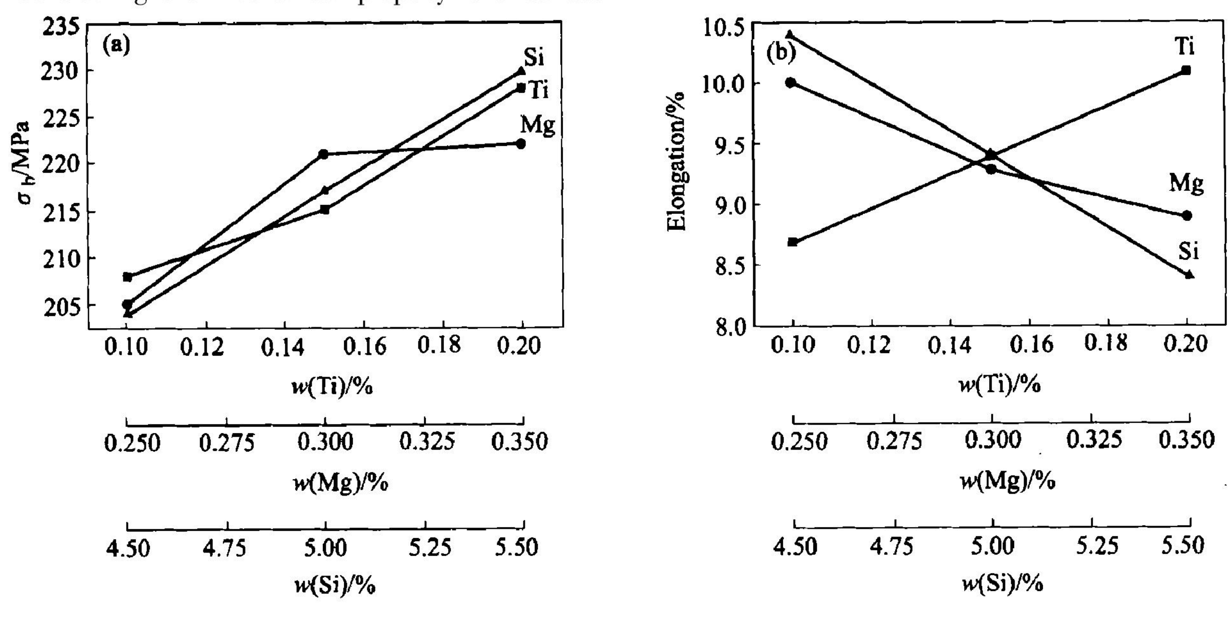

Fig. 1 Influence of Si, Mg and Ti on (a) σ_b and (b) elongation

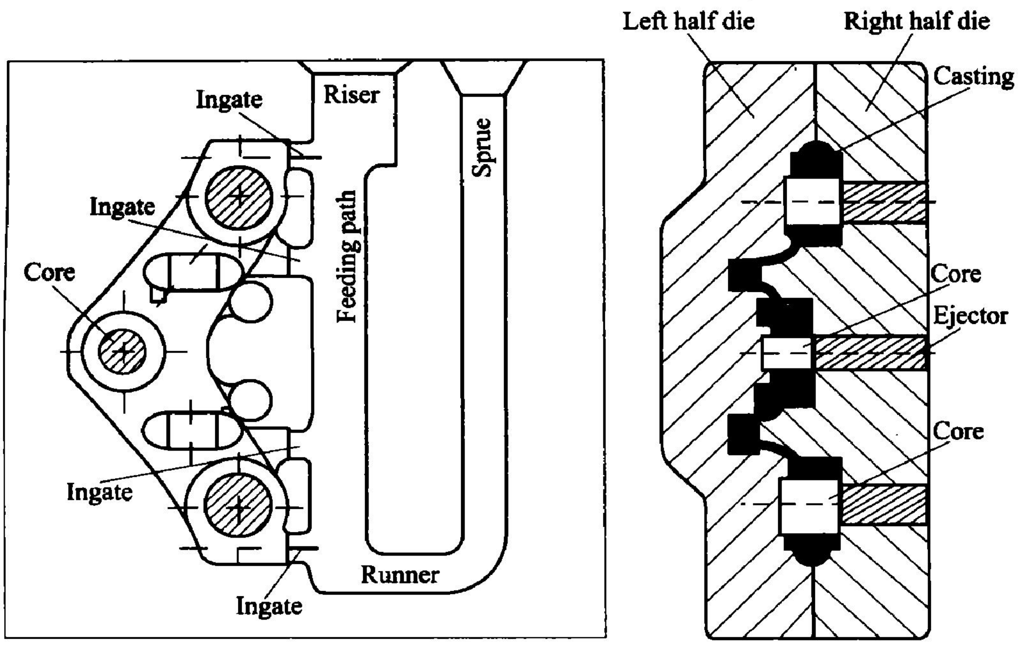

Fig. 2 Sketch of casting process

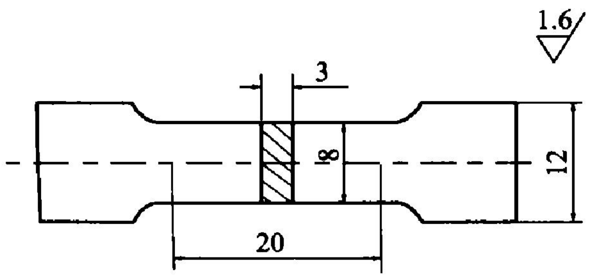

Fig. 3 Dimensions of tensile plate

scanning electron microscope(SEM).

3.2 Results

Four UCP castings from batch B8 and B9 were randomly chosen to inspect their mechanical property. Results are listed in Table 3, which indicates that all four specimens can successfully satisfy the predefined requirement.

Alpha solid solution, (α+ Si) eutectic and Mg_2Si are main phases in HGZL-02 alloy. The primary α is dendritic. After heat treatment the shape of eutectic silicon change to fine particulate. The effect of magnesium is to form Mg_2Si phase, which is a strengthening phase[12, 13].

Fig. 4 shows the microstructures at hot spots in UCP casting. Fig. 4(a) reflects the position around the upper hole with the thickness of about 15 mm; Fig. 4 (b) reflects the position around the middle hole with the cross-section of 18 mm × 18 mm. It can be proved from Fig. 4 that the microstructures of hot spots are fine in grain size, no porosity and shrinkage exist and no needle or flaky phase appear.

Typical fracture surface of T6 heat-treated tensile plate is shown in Fig. 5. It is a typical ductile fracture, and the material is proved to be of high plasticity by big and deep dimples.

3.3 Means to improve plasticity of UCP

Difficulties in casting of UCP include:

1) The complex shape of UCP, which contains curved surfaces and long filling path that cause high filling resistance. In addition, the solidification time is short because of high cooling rate of permanent mold. Therefore, misrun, cold shut or shrinkage may take place.

2) The large difference in thickness. The cross-section of the thickest position is 18 mm × 18 mm, and the thinnest position is only 3 mm. It is difficult to guarantee that no misrun or cold shut exists in thin position and no shrinkage or porosity exists in thick position.

3) Aluminum alloy is easy to be oxidized, and gas entrapping and slag formation may occur in the case of unsmooth filling process.

The following means are taken to improve the plasticity of UCP casting:

1) Fine grain size and particulate-shaped silicon phase are achieved by adopting strontium as long effective modifier, Al-Ti-B alloy as grain refiner, and some processing parameters, such as low pouring temperature, high cooling rate, well-distributed molten metal, reasonable heat treatment.

2) Oxidation and entrapped gas may be diminished by adopting stepped gating system and an additional feeding path.

3) Gas content and amount of inclusion in molten metal would be lowered by strict controlling the degassing and refining process.

4) Float slag are prevented to enter mold cavity by adopting three actions: (a) slag would be de –

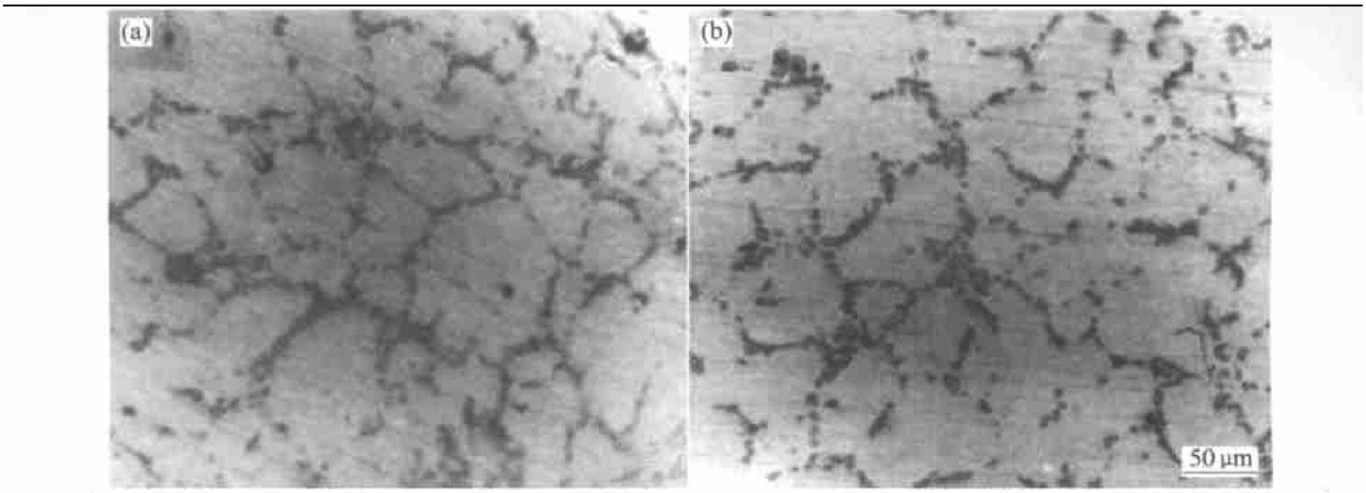

Fig. 4 Typical microstructures of UCP casting around upper hole(a) and middle hole(b)

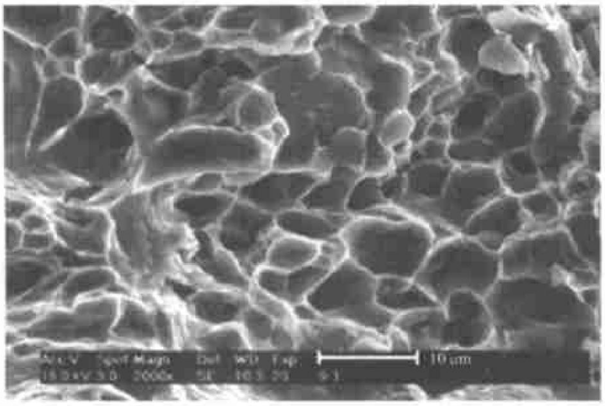

Fig. 5 SEM morphology of T6 heat-treated tensile plate's fracture surface

tained on the top of sprue by bottom gating system with a decreasing sprue area; (b) an additional feeding path gives entered slag a way to escape; (c) reasonable gating system design.

5) Solidification rate at hot spot is enhanced to obtain fine grain size and dense microstructure. Hot spots of UCP casting are located around the holes and these holes are formed by steel cores with a temperature of 50 ℃ instead of 150~ 250 ℃ in general.

6) Impurities such as iron, lead, nickel and antimony are strictly controlled at low contents.

[REFERENCES]

[1] Sutton T L. Alumnium castings —a step forward into the next century[J] . Foundryman, 1997, 90(6) : 217~ 226.

[2] Pan E N, Hu J F. Fluidity of Al-Si(Cu) alloys as affected by alloy solidification modes[J] . AFS Trans, 1998, 106, 609 - 617.

[3] SI Nai-chao, WU Jing. The measures and theoretical analysis of the crack failure elimination for Al-Si ingot[J] . Special Casting & Nonferrous Alloys, (in Chinese) , 1997 (6) : 17 - 19.

[4] Andersen U. High volume production of thin-walled aluminium castings[J] . Foundryman, 1999(3) : 69 - 70.

[5] LI Yuan-yuan, GUO Guo-wen, ZHANG Wei-wen, et al. Effects of alloying elements on hot tearing trends of Al-Cu alloy[J] . The Chinese Journal of Nonferrous Metals, (in Chinese) , 2001, 11(2) : 791 - 795.

[6] LI Yuan-yuan, Ngai T L. Grain refinement and microstructural effects on mechanical and tribological behaviours of Ti and B modified aluminium bronze[J] . Journal of Materials Science, 1996, 31: 5333 - 5338.

[7] LI Yuan-yuan, LUO Jun-ming, LUO Zong-qiang, et al. The microstructure and wear mechanism of a novel high-strength, wear-resistant zinc alloy (ZMJ) [J] . Journal of Materials Processing Technology, 1995(55) : 154 - 161.

[8] CHEN Wei-ping, LI Yuan-yuan, GUO Guo-wen, et al. Squeeze casting of Al-Cu alloy[J] . Journal of Central South University of Technology, 2002, 9(3) : 159 - 164.

[9] LI Yuan-yuan, XIA Wei, Ngai Tungwai Leo, et al. Microstructures of a novel high strength and wear-resisting zinc alloy[J] . Trans Nonferrous Met Soc China, 1995, 5(4) : 84 - 88, 132.

[10] Easton M, St John D. Grain refinement of aluminum alloys: Part Ⅰ. The nucleant and solute paradigms —a review of the literature [J] . Metallurgical and Materials Trans, 1999, 30A: 1613 - 1623.

[11] Easton M, St John D. Grain refinement of aluminum alloys: Part Ⅱ. [J] . Metallurgical and Materials Trans, 1999, 30A: 1625 - 1633.

[12] HUANG Hui-yuan. Foundry Handbook(Vol. 3 Cast Nonferrous Alloy) [M] , (in Chinese) . Beijing: Mechanical Industry Press, 1993.

[13] Lee Y W, Lin Y L, Yeh C H. Correlation of feeding and mechanical properties of A206 aluminum alloy plate casting [J] . AFS Trans, 1990, 98: 935 - 941.

(Edited by PENG Chao-qun)