EFFECT OF MELT SUPERHEATING ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A357 ALLOY①

Li Peiyong[1, 2], Jia Jun, Guo Jingjie, Li Peijie, Shao Gaoliang
1 School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001
2 Beijing Research Institute of Aeronautical Materials, Beijing 100095

ABSTRACT The effect of superheating from 750 to 1 000 ℃ on A357 alloy were investigated. The results show that there exist three characteristic temperature ranges: 750～ 800 ℃, 800～ 900 ℃ and 900～1 000 ℃, which are correspondent to the variations of chemical composition, microstructure and mechanical properties. When A357 alloy superheated from 750 to 800 ℃, most of its mechanical properties are remarkably improved.

Key words melt superheating microstructure mechanical property A357 alloy

1 INTRODUTION

A357 alloy, as a premium cast aluminum alloy, is widely used in aerospace and aircraft indurstry[1, 2]. Generally, in order to obtain the premium casting, the optimum melt state is the first need condition. In recent years, it[3- 5] was found that melt superheating could affect the micro-inhomogeneous aluminum alloys, as a result, the iron-rich phase, grain size, physical properties (e g resistivity and viscosity.) and mechanical properties would change.

In this paper, the effect of melt superheating on A357 alloy was investigated in detail. The goal of this study is to ascertain whether or not the melt superheating may be applied to improve the mechanical properties of A357 alloy.

2 EXPERIMENTAL

2.1 Materials

A357 alloy was prepared by putting pure magnesium (99.95%), pure silicon(99.7%), Al-3.37% Be and Al-5% Ti-0.2% B master alloys into super pure aluminum (99.99%) in a resistance furnace. The alloy was modified with the flux of 0.5% (40% NaF+ 40% NaCl+ 10% KCl + 10% Na_3AlF_6), its analysis results is listed as follows:

Si	Mg	Be	Ti	Fe	Al
6.9	0.62	0.06	0.15	0.055	Balance

2.2 Melt superheating treatment

The prepared A357 alloy was heated to 750, 800, 850, 900, 950, 1 000 ℃, respectively. After each superheated, the melt was cooled naturally in the furnace. When the temperature of melt decreased to the range of 750～ 760 ℃, 0.5% flux (30% NaCl + 36% KCl + 14% Na_3AlF_6+ 20% Na_2SiF_6) was injected into the melt for degassing and inclusion removal by a flux injection equipment[6]. After the flux injection treatment, the melt was kept in the range of 750～ 760 ℃ for 5 min, and then was poured into the permanent mould preheated to 200 ℃ for test bars.

2.3 Heat treatment

① Supported by the Aeronautical Science Foundation of China Received May 13, 1996; accepted Sep. 17, 1996

One part of the test bars was heat treated in T_6 state:

Solid solution at 540 ℃ for 8 h;

Quenching into water at room temperature;

Natural aging for 12 h;

Artificial aging at 175 ℃ for 10 h.

2.4 Mechanical test and microstructural analysis

All the test bars in as cast and T_6 state were tested at Instron-1186 electron tension machine, the deformation rate was 2 mm/min. Samples were taken from the tested bars for chemical (by EDXA), OM and SEM analyses. The etchants for the samples of OM and SEM were 0.5% HF and 5% HF, respectively. Grain was revealed by Tucker etchant (45 mlHCl + 15 mlHNO$_3$ + 15 mlHF + 25 mlH$_2$O).

3 RESULTS AND DISCUSSION

3.1 Effect on chemical composition

Fig. 1 shows the effect of melt superheating on the chemical composition of A357 alloy. From 750 to 900 ℃, Si and Ti increase; from 900 to 1 000 ℃, they decrease. In other words, at 900 ℃, there exist peak values for Si and Ti. With superheating, Mg decreases continuously. This phenomenon might result from their different burning-loss rates. From 750 to 900 ℃, the burning-loss rates of Mg and Al are much higher than those of Si and Ti. Apparently, in order to keep the chemical composition in the range of A357 alloy, the superheating temperature should be controlled below 850 ℃.

3.2 Effect on grain size

Fig. 2 shows the change of the grain size of A357 alloy with the superheating temperature. It indicates that the grains first become fine when superheated from 750 to 800 ℃, then coarsen gradually from 800 to 900 ℃, and become fine again from 900 to 950 ℃, at last, coarsen sharply from 950 to 1 000 ℃. This phenomenon may be related to the variation of the chemical composition, especially the titanium content. Ti in the melt forms TiAl$_3$ as the nucleant of Al during solidification process, and thus TiAl$_3$ plays the role of grain refinement. Apparently, the smaller the size and the larger the amount of TiAl$_3$ are, the better the grain refinment effect is. As shown in Fig. 1, when superheated from 750 to 900 ℃, Ti content increases sharply from 0.15% to 0.37%. This may lead to TiAl$_3$ with larger size, which resluts in the larger grain size. When superheated from 900 to 950 ℃, Ti content slightly decreases, so the

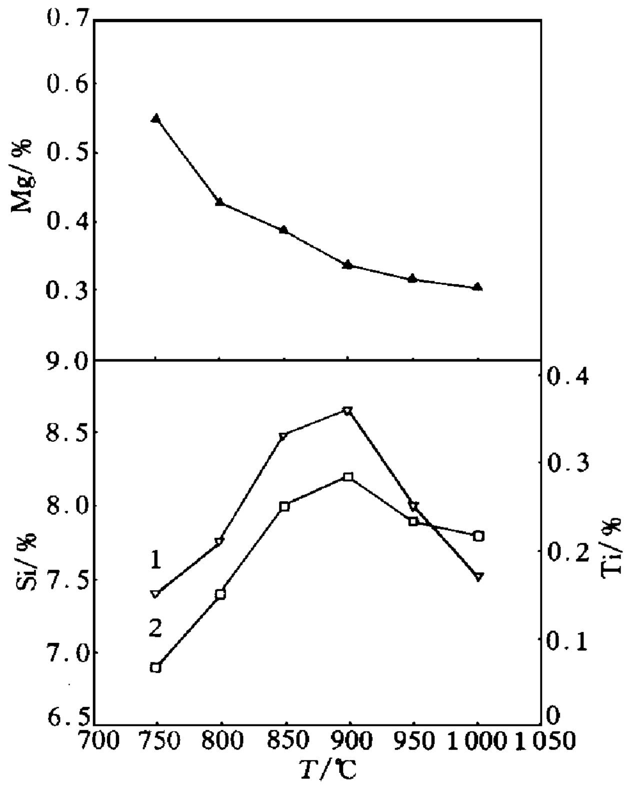

Fig. 1 Effect of melt superheating on the chemical composition of A357 alloy

1—Ti; 2—Si

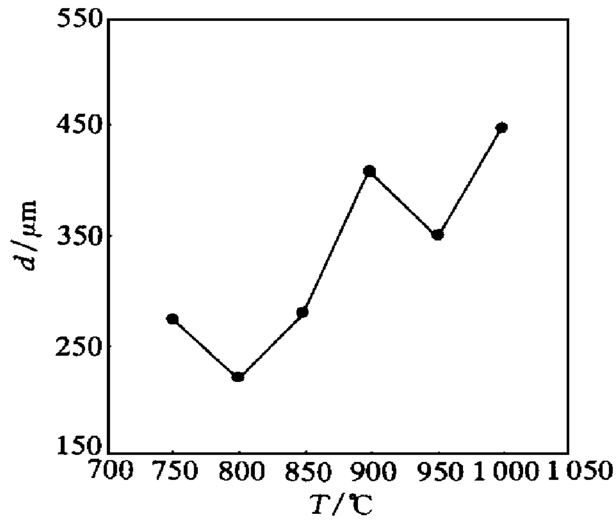

Fig. 2 Relationship of grain size (*d*) of A357 alloy with superheating temperature

grain size becomes finer somewhat. These indicate that much higher Ti content is contributed to grain refinement.

3.3 Effect on morphology of eutectic silicon

Fig. 3 shows the variation of the morphology of eutectic silicon during melt superheating. Apparently, From 750 to 800 ℃, eutectic Si becomes finer fibre, i e the modification effect is improved. From 800 to 950 ℃, eutectic Si becomes coarser and has less branches, i e the modification effect is fading. From 950 to 1 000 ℃, eutectic Si granulates. These changes indicate the variations of Na content and melt-structure. When superheated from 750 to 800 ℃, the melt is of homogeneous, thus, Na dissolves in the melt more completely. This is beneficial for Na to playing the role of modification—to suppress the nucleation of eutectic Si and to precipitate on the $(111)_{Si}$, thus to induce its twinning and branching. When superheated from 800 to 900 ℃, although the melt is also of more homogeneous, Na burns rapidly; thus Na content becomes less, and as a result, the modification effect fades and eutectic Si becomes coarser and has less branches. From 950 to 1 000 ℃, Na might burn completely, and the Si atoms in the melt distribute homogeneously. This leads Si to nucleate directly from the melt during solidification process; thus some granular Si appears.

3.4 Effect on mechanical properties

Fig. 4 shows the effect of melt superheating on the mechanical properties of A357 alloy in as cast and T_6 state. For the properties of as cast alloy (Fig. 4(a)), when superheated from 750 to 800 ℃, ultimate strength (σ_u), yielding

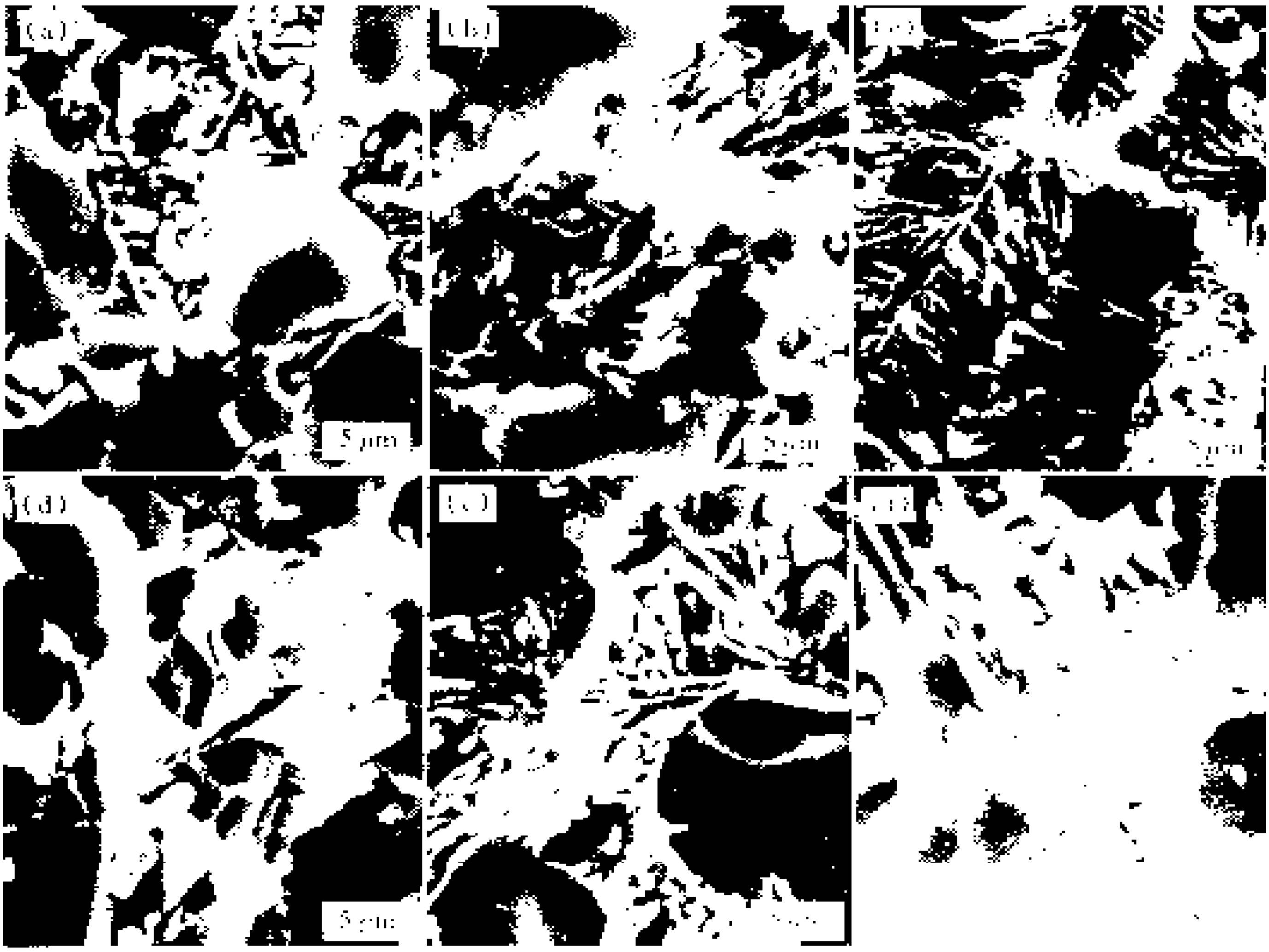

Fig. 3 Effect of melt-superheating on the morphology of eutectic silicon of A357 alloy
(a) —750 ℃; (b) —800 ℃; (c) —850 ℃; (d) —900 ℃; (e) —950 ℃; (f) —1 000 ℃

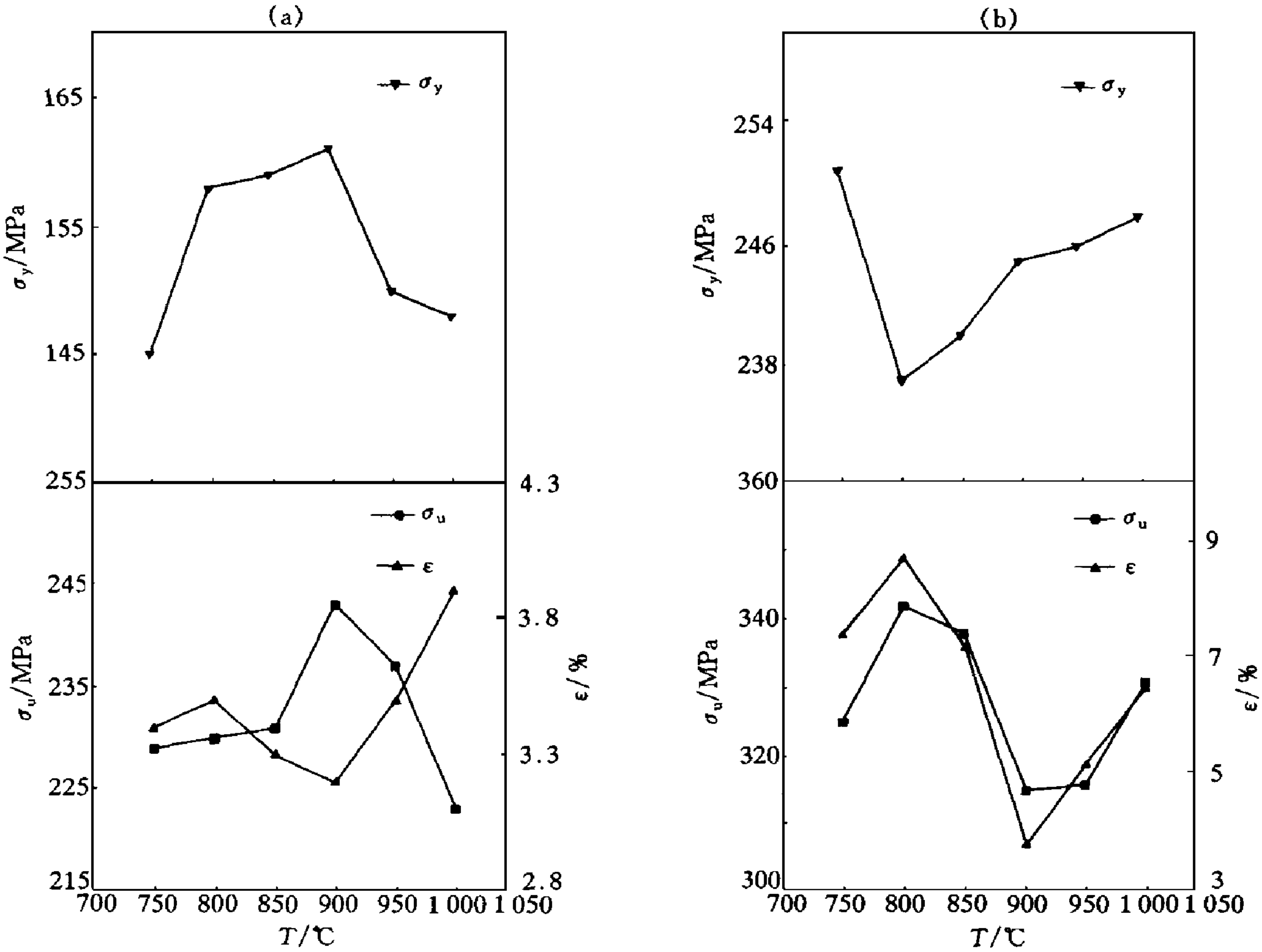

Fig. 4 Effect of melt superheating on the mechanical properties of A357 alloy
(a) —As cast; (b) —T_6 state

strength (σ_y) and elongation(ε) increase slightly; from 800 to 900 ℃, σ_u and σ_y increase, but ε decreases; from 900 to 1 000 ℃, σ_u and σ_y decrease sharply, only ε increases remarkably. For the properties of T_6 state (Fig. 4(b)), the changes of σ_u and ε are similar: they increase first and are up to the peak values at 800 ℃; then decrease remarkably; at 900 ℃, they are the lowest; from 900 to 1 000 ℃, they increase again. Apparently, when superheated from 750 to 800 ℃, most of the mechanical properties of A357 alloy are remarkably improved.

This phenomenon is correspondent to the changes of the chemical composition and microstructures of the alloy, especially the change of the Mg content and the morphology of eutectic Si. When superheated from 750 to 800 ℃, although the Mg content decreases from 0.55% to 0.42%, eutectic Si becomes finer fibre, so δ_e of both as cast and T_6 state increase, whereas the as cast decrease. The changes of σ_u and σ_y of T_6 state could be attributed to the decreasing of Na and the homogeneities of Na and Mg in the melt. Because Na can hinder the formation of GP zones by decreasing vacancies in the alloy during quenching, the GP zones in the alloy superheated at 750 ℃ will be less than those superheated at 800 ℃. As a result, the σ_u and σ_y of T_6 state are improved. When superheated from 800 to 900 ℃, eutectic Si coarsens due to the burning of Na. This also results in coarse Si particles with high aspect ratio in as cast and T_6 state. Coarse Si is the source of crack, so, elongations of as cast and T_6 state decrease. Apart from this, because of the decreasing of the Mg content in the melt, the σ_y of as cast, σ_u and σ_y of the T_6 state decrease. When superheated from 900 to 1000 ℃, the Mg content decreases slightly, and because the Si in the melt becomes more homogeneous, the eutectic Si begins to granulate. The former change results in the decreasing of σ_u and σ_y of the as cast, the later change is contributed to improving the elongations of as cast and T_6 state. As for the decrease of σ_u and σ_y of as cast, it may result from the coarsening of grains. These indicate that the ε is very sensitive to the morphology of eutectic Si, and the σ_u and σ_y are mainly determined by the amounts of GP zones or precipitates, which are related to the Mg and Na contents in the melt.

According to Fig. 1~ 4, during the superheating process, there exist three characteristic temperature ranges: (a) from 750 to 800 ℃, (b) from 800 to 900 ℃ and (c) from 900 to 1 000 ℃. During (a), Na and Mg in the melt become homogeneous, and decrease gradually; During (b), Na and Mg contents decrease sharply; During (c), the Si in the melt becomes homogeneous. These indicate that there happen two processes during superheating: melt homogeneizing and burning of the elements of Na, Mg, Ti, Si, etc. Melt homogeneizing, which includes Na, Mg, Si, etc., is contributed to improving the elongations of both as cast and T_6 state. Optimum Mg content is necessary for obtaining high strength. In order to keep the chemical composition within the range of A357 alloy and improve its mechanical properties, melt superheating during (a) (from 750 to 800 ℃) is advisable in practical applications.

4 CONCLUSIONS

(1) During melt superheating of A357 alloy, there appear three characteristic temperature ranges correspondent to the changes of chemical composition, microstructure and mechanical properties, they are: from 750 to 800 ℃, from 800 to 900 ℃ and from 900 to 1 000 ℃.

(2) During the melt superheating, there happen two processes: the burning of elements of Na, Mg, Ti, Si, etc, and the melt homogeneizing. Optimum Mg content is necessary to obtain high strength, and the melt homogeneizing is contributed to improving elongation.

(3) When melt superheated from 750 to 800 ℃, most of mechanical properties of A357 alloy are remarkably improved.

REFERENCES

1 ASM International Handbook Committee. Metals Handbook, Tenth Edition, Vol. 2. Ohio: ASM International, 1990: 166– 167.
2 Smith W F. Structure and Properties of Engineering Alloys. New York: McGraw Hill inc, 1993: 26.
3 Li P J. Ph D thesis, (in Chinese). Harbin Institute of Technology, 1995: 115.
4 Awano Y, Shimizu Y. AFS Transactions, 1990, 98: 889.
5 Gui M C, Jia J, Li Q C. Special Casting and Nonferrous Alloys, (in Chinese), 1995, (1): 15.
6 Li P Y, Jia J, Guo J J *et al*. Journal of Harbin Institute of Technology, 1995, E-2(4): 67.

(Edited by Huang Jinsong)