E. TILLOVÁ, M. PANUŠKOVÁ

ISSN 0543-5846
METABK 47(3) 207-210 (2008)
UDC – UDK 669.14-418:539.37:620.17=111

EFFECT OF SOLUTION TREATMENT ON INTERMETALLIC PHASES MORPHOLOGY IN AlSi9Cu3 CAST ALLOY

Received – Prispjelo: 2007-03-07
Accepted – Prihvaćeno: 2008-01-31
Preliminary Note – Prethodno priopćenje

In the present work was investigated the influence of solution treatment by 505°C, 515°C and 525°C ± 2°C with different holding times 2, 4, 8, 16 and 32 hours on microstructural elements of commercial AlSi9Cu3 cast alloy. During this heat treatment was observed the spheroidization of eutectic Si, gradual disintegration of iron rich intermetallic phases on base Al(FeMnMg)Si, shortening and thinning of Al_5FeSi iron needles and the dissolving of Al-Al_2Cu-Si intermetallic phase by temperature 525°C.

Key words: Al-Si cast alloys, eutectic Si, solution treatment, intermetallic phases

Učinak postupka topline obrade na morfologiju intermetalne faze ljevačke legure AlSi9Cu3. U članku je dano istraživanje utjecaja toplinskog otapanja na 505°C, 515°C i 525°C ± 2°C sa različitim vremenima držanja 2, 4, 8, 16 i 32 sata na mikrostrukturu komercijalne ljevačke legure AlSi9Cu3. Tijekom toplinske odredbe došlo je do sferoidizacije eutektičkog Si, postepenog raspada željeznih intermetalnih faza sa osnovom Al(FeMnMg)Si, skraćivanje i stanjivanje iglica faze Al_5FeSi i otapanje intermetalne faze Al-Al_2Cu-Si na temperaturi 525°C.

INTRODUCTION

Aluminium alloys represent an important category of materials due to their high technological value and wide range of applications, especially in aerospace, automotive and household industries. The alloys of the Al-Si-Cu system have become increasingly important in recent years, mainly in the automotive industry that uses secondary aluminium (recycled) in the form of various motor mounts, pistons, cylinder heads, heat exchangers, air conditioners, transmissions housings, wheels, fenders, loads floor and suspension components due to their high strength at room and high temperature [1]. However, these Al-Si-Cu systems usually contain a certain amount of Fe, Mn and Mg that are present either undeliberately, or they are added deliberately to provide special material properties. Fe is a common impurity in aluminium alloys that leads to the formation of complex intermetallic phases during solidification, and how these phases can adversely affect mechanical properties, especially ductility, and also lead to the formation of excessive shrinkage porosity defects in castings. The presence of some Mg improves the hardenability of the material and some Mn is usually added to reduce the detrimental effects of impurities like iron and silicon. Depending on the purity of the base material, the impurities and alloying elements partially go to into α- matrix and partly form intermetallic phases. During the solidification process enormous variety of intermetallic phases are formed, at the grain boundaries and between the dendritic arms.

The present study is a part of larger research project, which was conducted to investigate and to provide a better understanding morphology in Al-Si-Cu casting alloys during solution treatment.

EXPERIMENTAL WORK

As an experimental material was analyzed hypoeutectic AlSi9Cu3 alloy, with chemical composition given in the table 1. Experimental cast samples were heat treated. The castings were subjected solution treatment at three temperature (505, 515 and 525°C) for times ranging from 2 to 32 hours, then quenched in warm water at 40 – 60°C and natural aged at room temperature for 24 hours. The samples for microscopic analysis were prepared by standards metallographic procedures (wet ground, DP polished with diamond pastes and etched by Dix-Keller, HNO_3 or MA [2]). AlSiCu alloys usually contain Cu (2 - 4 %) and sometimes Mg as the main alloying elements, together with various impurities such as Fe, Mn or Cr (table 1).

During the industrial processing of the alloys, these elements go into solid solution but they also form different intermetallic phases. The formation of these phases should correspond to successive reaction during solidi-

E. Tillová, M. Panušková, University of Žilina, Faculty of Mechanical Engineering, Žilina, Slovakia

Table 1. **Chemical composition of the alloys / wt. %**

Si	Cu	Mn	Fe	Mg	Ni	Sn	Zn	Ti	Al
10,7	2,4	0,22	0,9	0,27	0,08	0,03	1,1	0,03	rest

fication – table 2 [3]. To determine the chemical composition of the intermetallic phases was employed scanning electronic microscopy equipped with EDX.

Table 2. **Reactions occurring during solidification of AlSiCu alloys**

Martínez & Bäckerud [3]	Temperature °C
α - dendritic network	609
Liq. → α - phase + $Al_{15}Mn_3Si_2$ + Al_5FeSi	590
Liq. → α - phase + Si + Al_5FeSi	575
Liq. → α - phase + Si + Mg_2Si + $Al_8Mg_3FeSi_2$	554
Liq. → α - phase + Al_2Cu + Al_5FeSi + Si	525
Liq. → α - phase + Al_2Cu + Si + $Al_5Mg_8Si_6Cu_2$	507

The effect of solution heat treatment has demonstrated by the changes in the size and shape of the eutectic Si particles and intermetallic phases for solution treatment of 4 hours. The as-cast structure of AlSi9Cu3 alloy is shown in Figure1a. The light grey is α-matrix. The dark grey platelets are silicon phases. Figure 1b-d demonstrates the Si morphology changes as a function of solution treatment. By temperature 505°C were noted that the relatively large eutectic Si platelets were fragmentized into smaller spherical ones (Figure 1b). The spheroidization process dominated for 515°C and 525°C. The smaller Si particles were spheroidized to attain a more fine rounded shape (Figure 1c, d). As the solution holdtime continued, the spheroidized particles gradually grew larger (coarsening). This growth took place after 16th hour of the holding stage.

Fe and Si alone do not have any contribution to porosity; however, they form intermetallics whose morphology affects feeding. Fe and Si form Al_5FeSi phase with monoclinic crystal structure [1,3-5]. Al_5FeSi phases precipitates in the interdendritic and intergranular regions as platelets (in microscope needle like - Figure 2A-a). The length of Al_5FeSi needles in the absence of Mn, increase with increasing Fe content [6] and decreasing cooling rate. But in the presence of Mn the effect is opposite. Al_5FeSi compound heavily blocks the interdendritic path and hinders liquid flow.

The platelets appeared to be the main nucleation sites for the eutectic Si, eutectic Al_2Cu and Cu-rich phase (Figure 3). Nucleation of Si and Al_2Cu may occur on large Al_5FeSi platelets [7]. Long Al_5FeSi platelets (more than 500 μm) can adversely affect mechanical properties, especially ductility, and also lead to the formation of excessive shrinkage porosity defects in castings. The evolution of the Al_5FeSi phase during solution treatment is described in Figure 2A. Solution treatment at 505°C

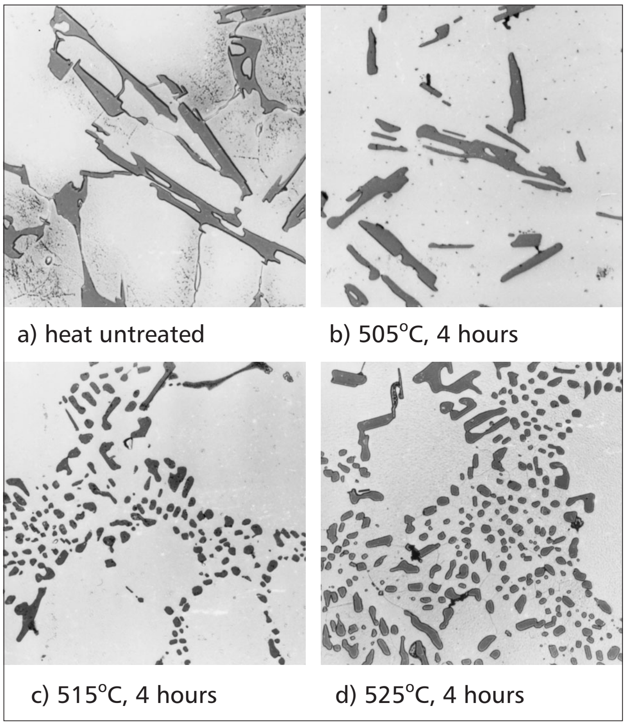

Figure 1. Effect of solution treatment on morphology of eutectic Si, etch. Dix-Keller, 1000 x

tends to shortening and narrowing big needle-like Al_5FeSi phase (Figure 2A-b). At 515°C shows thin needles (Figure 2A-c) and by 525°C is observed, that Al_5FeSi phase is dissolved into small needles (segmentation – Figure 2A-d). Fe and Si along with Mn form common iron intermetallic $Al_{15}(MnFe)_3Si$ phase with cubic crystal structure. This phase has a compact morphology "Chinese script" (skeleton-like phase - Figure 2b), which does not initiate cracks in the cast material to the same extent as the Al_5FeSi [3,5,6].

In alloy AlSi9Cu3 which contains % Fe nearly twice as much Mn, Mn in $Al_{15}(FeMn)_3Si_2$ substitutes the half of Fe. Fe and Si with Mg and Cu form $Al_5Mg_8Cu_2Si_6$ which along with Al_2Cu phase form clusters. Al_2Cu also forms on the Al_5FeSi needles (Figure 2C-c). It is observed too that Fe-rich phases are completely brittle since its particles break during polishing in slurry of alumina [4]. The effect of solution treatment on the $Al_{15}(FeMn)_3Si_2$ phase for solution time 4 hours is described in Figure 2B – b-d. It is observed, that solution treatment of this skeleton-like phase by 505°C tends to fragmentation (Figure 2B-b) and by 515 or 525°C to spheroidization and segmentation (Figure 2B-c,d). Solution treatment reduces its area rather than change the morphology.

The effect of copper appears primarily as an increased amount of dispersed microporosity [8]. Half or

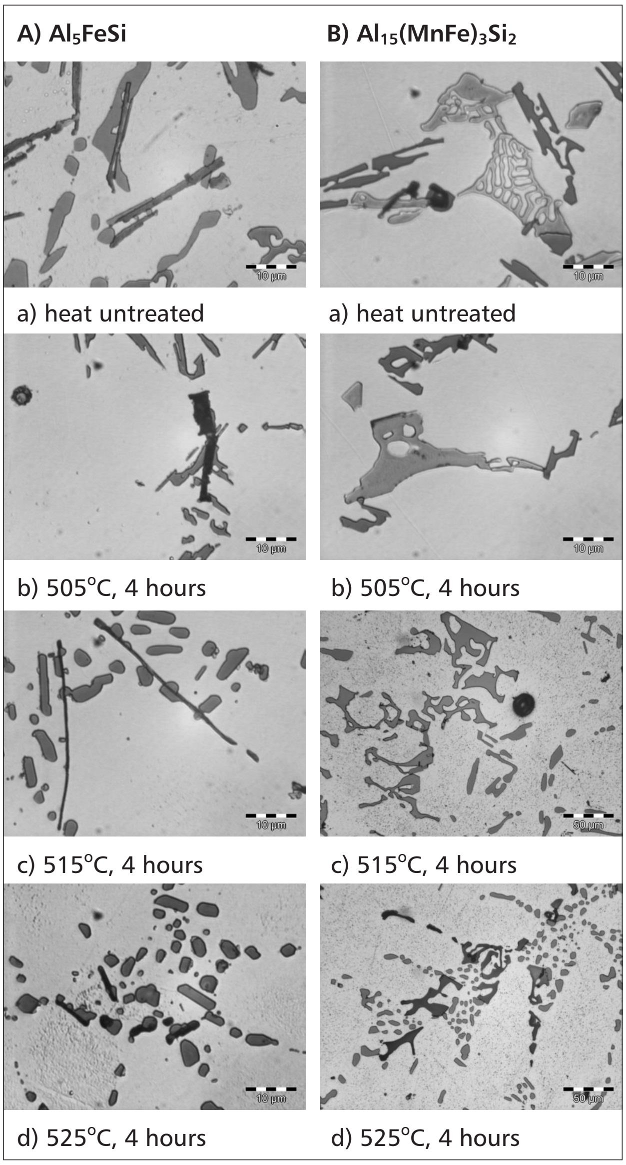

Figure 2. Evolution of Fe-rich intermetallic phases during solution treatment, etch. Dix-Keller

more of the copper is found as a component of intermetallic compounds, especially Al_2Cu phase. Al_2Cu with tetragonal crystal structure precipitates in two distinct morphologies: in the form of blocky phase with high copper concentration ~38 - 40 % Cu and first of all as fine spheroidal Al-Al_2Cu-Si ternary eutectic - Figure 3a. Because it is the last phase to solidify (table 2), it nucleates at the interfaces of other microstructural constituents, namely Si and Al_5FeSi. The effect of solution heat treatment has demonstrated in Figure 3b-d. It is observed, that solution treatment by 505°C tends to fragmentation ternary eutectic Al-Al_2Cu-Si from compact spherical phase to fine isolated particles Al_2Cu (Figure 3b). Prolonged annealing at temperature 515°C resulted complete coarsening and spheroidization isolated particles Al_2Cu (Figure 3c). 525°C is temperature, when being melting of this Cu-rich phase. Solidification of the melted Al_2Cu phase is documented in Figure 3d.

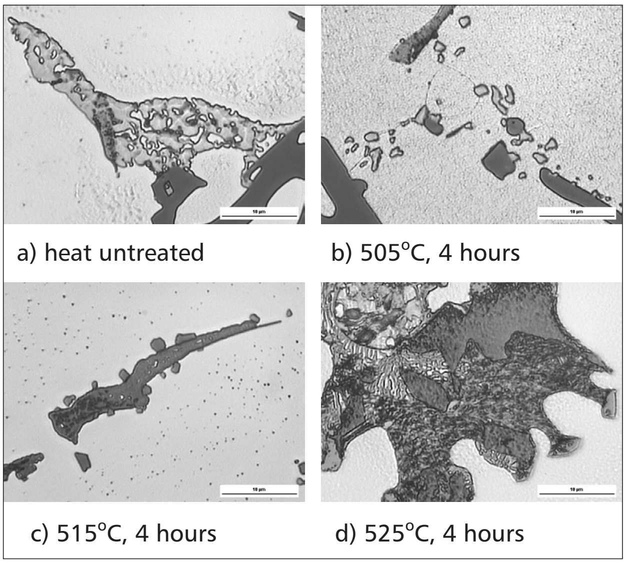

Figure 3. Evolution of Al-Al_2Cu-Si phase during solution solution treatment, etch. Dix-Keller

Cu-rich phase get to its gradual dissolving with the increasing of heat treatment temperatures and this fact confirm the results of hardness too (Figure 4).

With increase of solution temperature, the hardness increase's to a maximum value at 515°C and then decreases. The hardness is a reflection of solution strengthening and silicon particle distribution in matrix.

Temperature 515°C is a suitable temperature for this alloy. Below this temperature, solution process is insufficient; above it, overcoarsening of Si particles and melting Al_2Cu occurs. These two unsatisfied aspects are result in a reduction in hardness and strength.

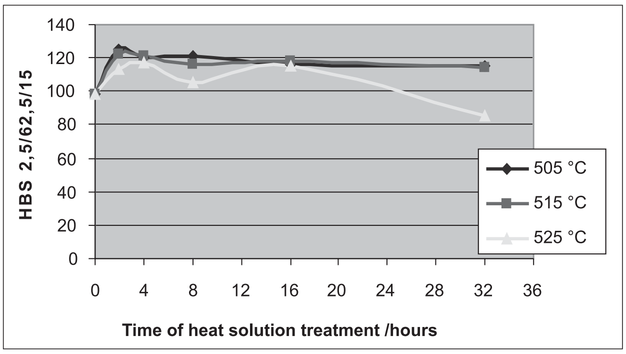

Figure 4. Changes of hardness of AlSi9Cu3 alloy during the heat treatment

CONCLUSIONS

The study was focused to investigate the effect of solution heat treatment on the microstructure. The temperatures of solution heat treatment were 505°C, 515°C, 525°C ± 5°C and the solution time ranged from 0 to 32 hours (0, 2, 4, 8, 16 and 32 hours). Alloy AlSi9Cu3 contained of α-matrix, eutectic silicon and other Fe and Cu rich phases in formation. Solution treatment is often specified as the first step in a precipitation hardening thermal cycle and performs tree roles: homogenization of as-cast structure, dissolution, fragmentation, coarsening or spheroidization of certain intermetallic phases (Al-Al_2Cu-Si dissolves and melted by temperature 525°C), changes the morphology of eutectic Si phase by fragmentation, spheroidization and coarsening, thereby improving mechanical properties, particularly ductility.

REFERENCES

[1] C. T. Rios, R. Caram: Acta Mikroskopica, 12(2003)1, 77-81.

[2] J. Belan, S. Pospíšilová: Materiálové inžinierstvo, 13 (2006)2, 35-38.

[3] J. E. Martinez, A. M. Cisneros, S. Valtierra, J. Lacaze: Scripta Materialia 52(2005), 439-443.

[4] E. Tillová, M. Panušková, M. Chalupová: Berichte und Informationen, 2(2006), 49-55.

[5] E. Tillová, M. Panušková, M. Chalupová: Druckguss-praxis 4/5(2007)3, 108-112.

[6] R. Kovatcheva: Praktische Metallographie 30(1993), 68-81.

[7] B. Suárez-Peňa, J. Asensio-Lozano: Scripta Materialia 54(2006), 1543-1548.

[8] C. Cáceres, H. M. B. Djurdjevic, T. J. Stockwell, J. H. Sokolowski: Scripta Materialia 40(1999)5, 631-637.

Acknowledgement: This work has been supported by Scientific Grant Agency of Ministry of Education of Slovak republic and Slovak Academy of Sciences, N° 1/0208/08 and N° 1/3153/06.

Note: The responsible translator for English language is Panušková Marta, Žilina, Slovakia.