HEAT TREATMENT OF Al-7Si-0.3Mg ALLOY PREVIOUSLY INOCULATED WITH A NEW TYPE OF QUATERNARY MASTER ALLOY

P. MOLDOVAN[1], Gabriela POPESCU[2], M. BUȚU[3]

În lucrare se prezintă rezultatele obținute la tratamentul termic (T6) al aliajului Al-7Si-0,3Mg, tratat în stare lichidă cu un nou tip de prealiaj finisor-modificator AlSrTiB. Aplicarea tratamentului termic T6 (punere în soluție la 540^{o}C/6h şi răcire în apă, urmat de îmbătrânire artificială la 165^{o}C/6-12h) conduce la îmbunătățirea caracteristicilor structurale (sferoidizarea siliciului şi finisarea grăunților) şi a proprietăților mecanice (creşterea alungirii relative, a rezistenței la curgere precum şi creşterea indicelui de calitate, Q, al aliajului). De remarcat că rezultatele tratamentului termic al aliajului Al-7Si-0,3Mg, finisat şi modificat cu AlTiBSr, sunt similare cu cele obținute la modificarea cu stronțiu sub formă de prealiaj AlSr10.

The paper presents the results obtained in T6 heat treatment of Al-7Si-0.3Mg alloy, treated in liquid state with a new type of master alloy (AlTiBSr) for simultaneous grain refining and modification. The heat treatment (solution treatment at 540^{o}C/6h, water quenching, and artificial ageing) leads to improvement of structural characteristics (silicon spheroidization and grain refining) and mechanical properties (increasing of elongation, of yield strength and of the Q quality index). We remark that the results of heat treatment of Al-7Si-0.3Mg alloy refined and modified with AlTiBSr are similar to those obtained for strontium modification with AlSr10 master alloy.

Keywords: heat treatment, solution treatment, artificial ageing, grain refining, modification, quality index

1. Introduction

It is commonly known that the most used heat treatment for Al-Si-Mg alloy is T6 which consists in solution heat treatment and natural or artificial ageing. The solution treatment between 400-560^{0}C has as result the dissolution of the hardening phase (Mg_2Si) in the aluminum matrix, the homogenization of the

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cast alloy and the spheroidization of the brittle silicon. The quantity dissolved in solution as well as the dissolution rate increases with increasing the solution treatment temperature, but the temperature is limited by the eutectic phase melting temperature.

The alloy is then aged at low temperature (150…200^{0}C) for precipitation of the hardening compounds which improves mechanical properties of the aluminum matrix.

Different international organizations recommend a T6 heat treatment quite enough varied for Al-7Si-0.3Mg alloy [1]. So, ASTM standard recommends for the die cast alloy a solution heat treatment at 540^{0}C for 4-12 hours, followed by artificial ageing at 155^{0}C for 2-5 hours. AFS recommends a heating for 12 hours at 538^{0}C and artificial ageing for 3-5 hours at 227^{0}C.

Apelian a.o. [2] has reviewed the heat treatment of Al-7Si-0.3Mg alloy, showing that it is possible to reduce the cost of this operation and the energy consumption through strontium modification. Strontium favors the eutectic silicon spheroidization in few hours. E.Ogris a.o. [3] have presented fundamental aspects of the spheroidization process of eutectic silicon in Al-Si cast alloys. It is theoretically as well as experimentally found that the disintegration and spheroidization of well modified eutectic silicon is finished within minutes of exposure to temperatures above 500^{0}C. D.L.Zang a.o.[4] has studied short heat treatment effect over the mechanical properties of Al-7Si-0.3Mg alloy modified with strontium. They showed that at 540^{0}C or 550^{0}C the short solution heat treatment (30 min) is enough for obtaining 90% from the tensile strength which is obtained after 6 hours of heat treatment.

Eivind Bondhus a.o. [5] have presented a new master alloy (Strobloy) for use in grain refining and modification of hypoeutectic aluminum silicon foundry alloys. Also, P.Moldovan a.o. [6] have been carried out investigations to produce a new master alloy (AlTiBSr) in order to simplify today's addition practice of grain refiner and modifier by reducing the number of additions from two to one.

This study was conducted to investigate the improving of structure and mechanical properties of Al-7Si-0.3Mg alloy by T6 heat treatment. The alloy was previously treated in liquid state for grain refining and modification with a new type of master alloy (AlSrTiB).

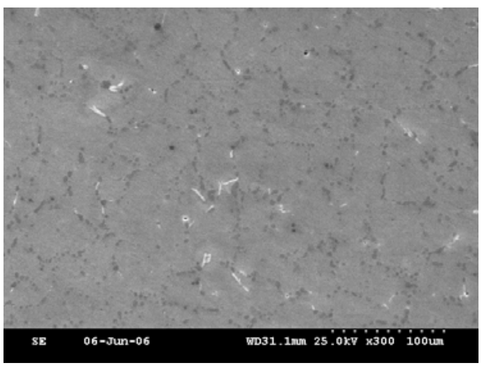
2. Experimental

Solution treatment was carried out at 540^{0}C for 6 hours, followed by a quench of ~ 1 minute in water at 80^{0}C. There was a 15 minute changeover time from the solution treatment furnace to the ageing furnace. The samples were aged at 165^{0}C for 12 hours and then quenched in room temperature water.

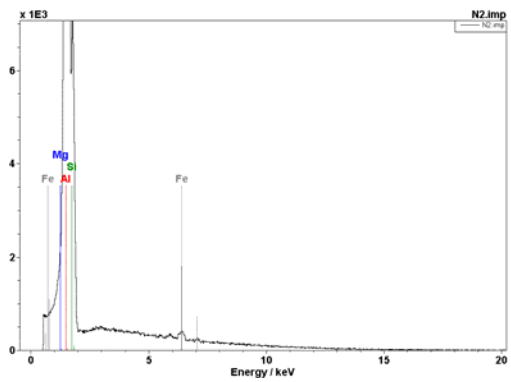
Microstructural characterization

Heat treated samples have been analysed using Olympus BX60M optical microscope, XL ESEM electron microscope equipped with X ray energy dispersive spectrometer (EDS), HITACHI S-2600N electron microscope equipped with X ray spectrometer (EDS), and DRON 3 X ray diffractometer.

Fig.1 presents the microstructure (SEM) of Al-7Si-0.3Mg alloy after solution treatment and the X ray characteristic spectrum for the alloying elements (Mg, Si) and impurities (Fe). The alloy was not previously treated with AlTiBSr master alloy.



(a)



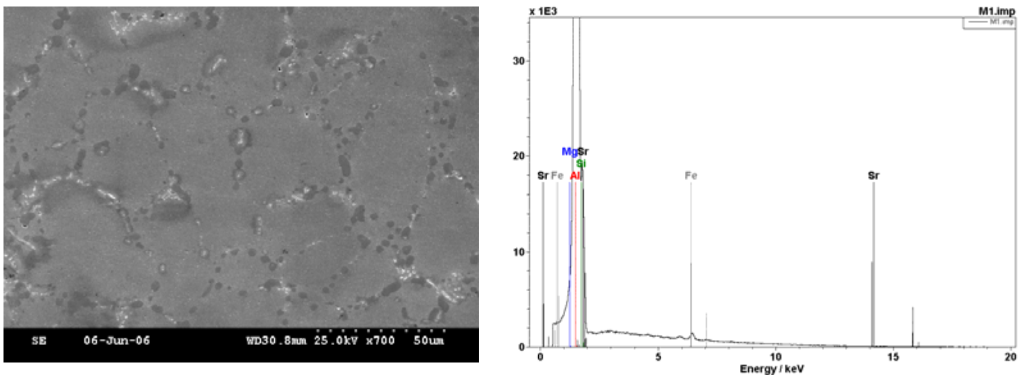
(b)

Fig.1. SEM image of Al-7Si-0.3Mg alloy untreated with AlTiBSr, after solution treatment (a), and X ray characteristic spectrum for alloying elements and impurities (b).

We can remark a globular eutectic silicon at the grains boundary and insoluble compounds like AlFeSi type.

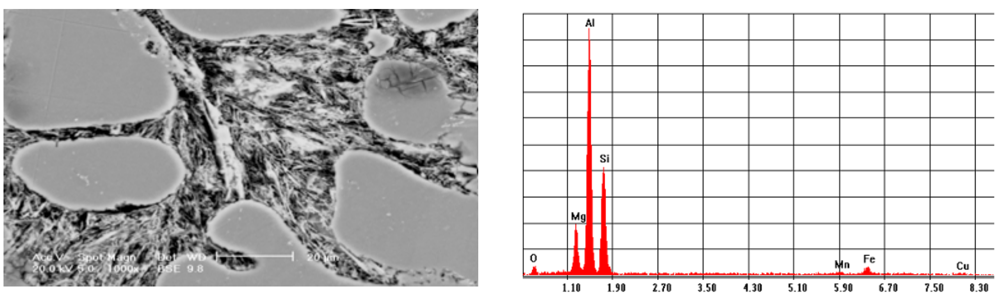
The microstructure of grain refined and modified Al-7Si-0.3Mg alloy, with AlSrTiB, is given in Fig.2. The presence of globular silicon in eutectic phase as well as of particles which contain Al, Fe and Si were observed (Fig.2a). In Fig.2b, the alloying elements (Si, Mg), modifier (Sr = 250ppm) and impurities (Fe) characteristic spectrum is presented. Titanium and boron characteristic lines doesn’t appear because of the very small contents of Ti and B.

The heat treated alloy microstructure was also put in evidence after artificial ageing. In order to observe 3-dimensional silicon particle morphology and also the presence of intermetallics in the alloy a deep attack was applied using a solution of HCl acid. This deep attack was carried out with a solution of 36% HCl for 9 minutes. Fig.3 put in evidence the lamellar silicon particles (Fig.3a) and intermetallic phases like Mg_2Si (Fig.3b).

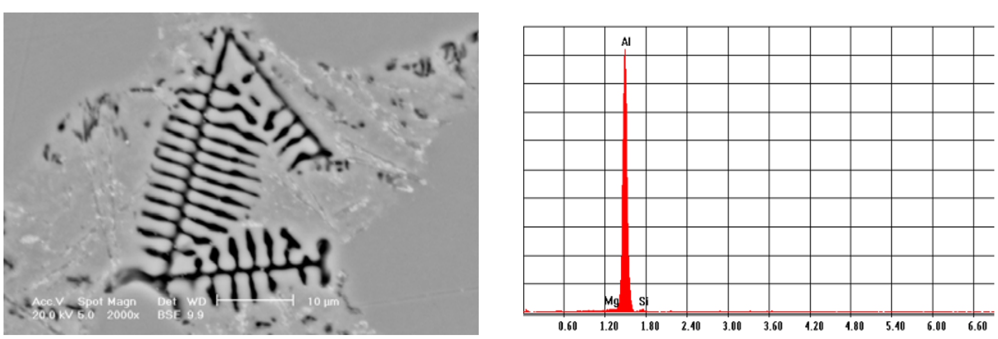


(a) (b)

Fig.2. SEM image for Al-7Si-0.3Mg alloy grain refined and modified with AlSrTiB master alloy (250 ppm Sr, 52 ppm Ti, 35 ppm B) (a) and X ray characteristic spectrum of characteristic elements (b) after solution treatment.



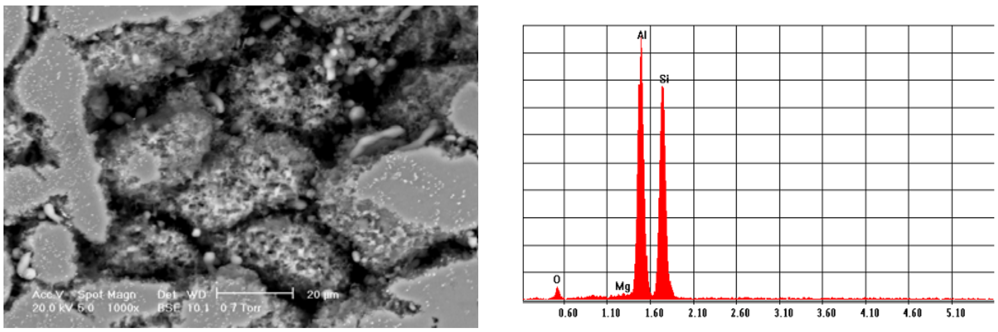
(a)



(b)

Fig.3. SEM microstructure and EDS analysis of cast Al-7Si-0.3Mg, untreated with AlTiBSr, after T6 heat treatment: (a) lamellar silicon, and (b) Mg_2Si intermetallic phase.

The modified and grain refined samples with AlSrTiB master alloy (250 ppm Sr, 52 ppm Ti and 35 ppm B) put in evidence the tridimensional morphology of spheroidized silicon particles (Fig.4). We can remark the dendrites porous surface, which was put in evidence by deep attack with 36% HCl solution.

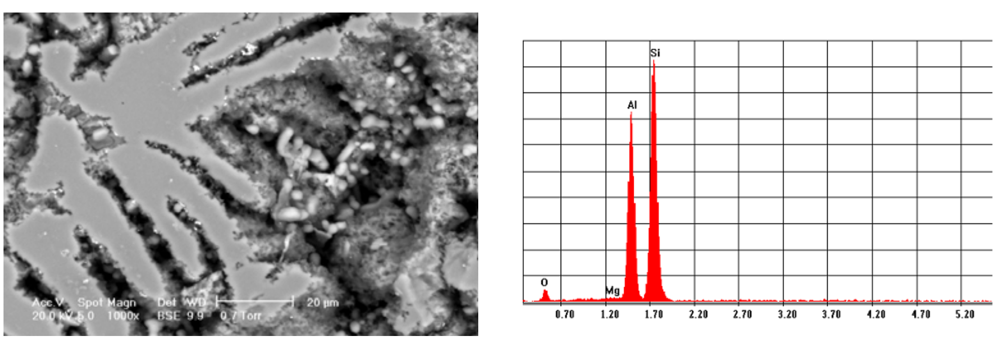


(a) **(b)**

Fig.4. Microstructure of Al-7Si-0.3Mg treated in liquid state with AlTiBSr (250 ppm Sr, 52 ppm Ti, 35 ppm B), after T6 heat treatment (a) and EDS analysis (b).

EDS analysis of the non-etched dendrites indicates the presence of dissolved elements in α solid solution (Si, Mg), as well as their oxidation.

The modified and grain refined samples with a higher content of AlSrTiB master alloy (350 ppm Sr, 72 ppm Ti and 48 ppm B) put in evidence the tridimensional morphology of spheroidized silicon particles (Fig.5). Also, we can remark that the increase of strontium content to 350 ppm promote the growth of primary Al dendrites which is deleterious to the mechanical properties of alloys. This phenomenon has been reported by H.Liao a.o. [7, 8].



(a) **(b)**

Fig.5. Microstructure of Al-7Si-0.3Mg treated in liquid state with AlTiBSr (350 ppm Sr, 72 ppm Ti, 48 ppm B), after T6 heat treatment (a) and EDS analysis of dendrites (b).

EDS analysis of α solid solution dendrites indicate the presence of interdendritic particle which contain silicon, intermetallic phase Mg_2Si and oxygen.

Mechanical properties

The evolution of the main mechanical characteristics of Al-7Si-0.3Mg alloy treated in liquid state with Sr, Ti and B as AlSrTiB master alloy (250 ppm Sr, 52 ppm Ti and 35 ppm B) is presented in Fig.6.

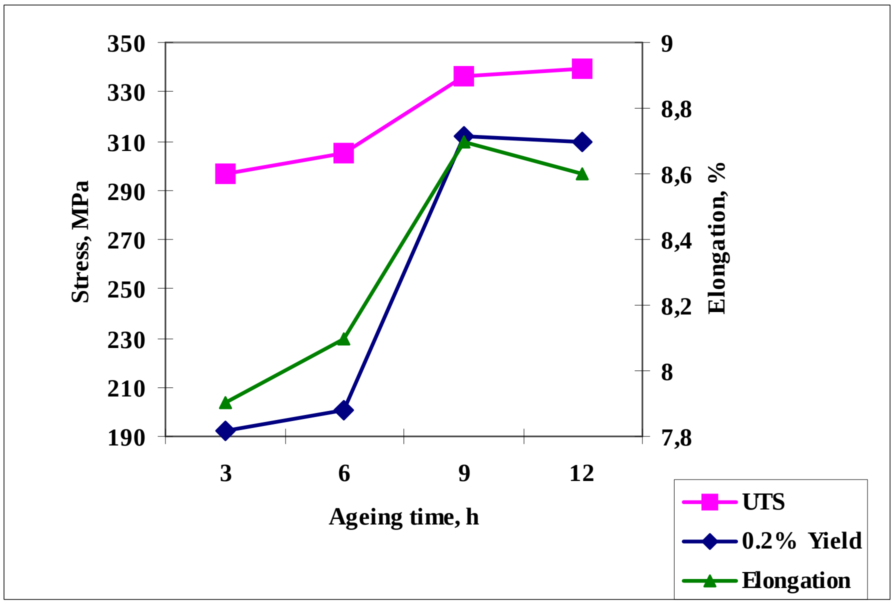


Fig.6. Variation in ultimate tensile strength, 0.2% yield strength and elongation to fracture of Al-7Si-0.3Mg treated in liquid state with AlSrTiB (250 ppm Sr, 52 ppm Ti and 35 ppm B) as a function of ageing time at 165^0C.

It is observed that the heat treatment T6 of Al-7Si-0.3Mg alloy (grain refined and modified with AlSrTiB) leads to increasing in ductility and yield tensile strength due to silicon spheroidization.

We can remark that the increasing of ageing time over 9h is not leading to a substantial improvement of mechanical properties.

In table 1 the quality index (Q) has been tabulated using the formula established by Drouzy a.o. [9]:

$$Q = UTS + 150 \log E \qquad (1)$$

where Q and UTS are in MPa, and E is the elongation to fracture (%) in a tensile test.

Table 1

The quality index (Q) values computed for Al-7Si-0.3Mg alloy in different states

Sample's number	The alloy state	Q, MPa
1	Cast, untreated (C1 state)	271
2	Cast, treated with AlSrTiB master alloy (250 ppm Sr, 52 ppm Ti, 35 ppm B) (C2 state)	401
3	Cast, treated with AlSrTiB master alloy (350 ppm Sr, 72 ppm Ti, 48 ppm B) (C3 state)	386
4	T6/1, solution treating at 540^0C/6h and artificial ageing at 165^0C/3h	432
5	T6/1, solution treating at 540^0C/6h and artificial ageing at 165^0C/6h	441
6	T6/1, solution treating at 540^0C/6h and artificial ageing at 165^0C/9h	477
7	T6/1, solution treating at 540^0C/6h and artificial ageing at 165^0C/12h	479

It is observed that the adding of AlSrTiB (250 ppm Sr) master alloy into the melt before solidification leads to a significant increase of the quality index, Q. The quality index decreases for an over-modification (350 ppm Sr) with about 5%. The value of Q still increases after the T6 heat treatment, increasing with the increase of ageing time until 12h. Still, the increase from 9h to 12h can be neglected.

The obtained results are similar to those from the literature, for strontium modification of Al-7Si-0.3Mg alloy with AlSr10 master alloy.

The quality index allows the estimation of Al-7Si-0.3Mg alloy cast parts quality, but also the estimation of the elongation limit. Practically, it can be considered that the ageing time at 165^0C can be of 9h, because over this value the increase of quality index is not significant.

3. Conclusions

• T6 solution treatment of Al-7Si-0.3Mg alloy, treated in liquid state with Ti, B and Sr as AlTiBSr master alloy, leads to increasing in ductility and yield tensile strength due to silicon spheroidization.

• The adding of 250 ppm Sr, 52 ppm Ti and 35 ppm B in liquid Al-7Si-0.3Mg alloy leads to a significant increase of the quality index (*Q*), but the quality index decreases for an over-modification (350 ppm Sr). The value of *Q* still increases after T6 heat treatment.

• The results obtained by authors are similar to those from literature, for strontium modification of Al-7Si-0.3Mg alloy with AlSr10 master alloy.

• The treatment in liquid state of Al-7Si-0.3Mg alloy, before heat treatment, simplifies today's addition practice of grain refiner (AlTiB) and modifier (AlSr) by reducing the number of additions, and cost and time saving, without any adverse effect on the microstructure and mechanical properties of the alloy.

R E F E R E N C E S

[1]. *D.Emadi, et al.,* Optimal Heat Treatment of A356.2 Alloy, Light Metals, Ed. by Paul N.Crepeau, TMS (The Minerals, Metals & Materials Society), 2003, pp.983-989.

[2]. *D.Apelian., S.Shivkumar and G.Sigworth,* AFS Trans., **97**, 1989, pp.727-742.

[3]. *E.Ogris, A.Wahlen, H.Lüchinger and P.J.Uggowitzer,* Journal of Light Metals, Vol.2, Issue 4, November 2002, pp.263-269.

[4]. *D.L.Zhang, L.H.Zheng and D.H.StJohn,* Journal of Light Metals, Vol.2, Issue 1, February 2002, pp.27-36.

[5]. *Eivind Bondhus, Trond Sagstad,* Light Metals, Ed. by R.D.Peterson, The Minerals, Metals & Materials Society, 2000, pp.845-849.

[6]. *P.Moldovan, G.Popescu, M.Cuhutencu,* Mat.Sci. Forum, Vol.526, 2006, pp.223-228.

[7]. *H.Liao, G.Sun,* Scr.Mater.48, 2003, pp.1035-1039.

[8]. *H.Liao, Y.Sun, G.Sun,* J.Mater.Sci., **37**, 2002, pp.3489-3495.

[9]. *M.Drouzy, S.Jacob, M.Richard,* AFS International Cast Metals Journal, Vol.5, 1980, pp.43-50.