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CRYSTALLIZATION AND STRUCTURE OF CAST A390.0 ALLOY WITH MELT OVERHEATING TEMPERATURE

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Preliminary Note – Prethodno pripćenje

The paper presents the research on the influence of melt overheating temperature on crystallization parameters and primary structure of cast AlSi17Cu5Mg (A390.0) alloy overheated to temperature: 820 °C, 880 °C, 940 °C and 1 000 °C. It was found that the degree of overheating influences the change of microstructure significantly and morphologies of primary silicon of the castings from Al-Si alloys. Research has shown that the overheating of the liquid metal bath is one of the methods of finding more applications of hypereutectic Al-Si system alloys without the addition of modifiers.

Key words: cast Al-Si Alloy, crystallizatio, structure, melt overheating temperature,

Kristalizacija i struktura lijevane A 390.0 legure iz taline zagrijane na povišenim temperaturama. Članak daje istraživanje utjecaja taline na parametre kristalizacije i primarne strukture lijevane legure AlSi17Cu5Mg (A 390.0) zagrijane na povišenim temperaturama: 820 °C, 880 °C, 940 °C i 1 000 °C. Utvrđeno je da stupanj utjecaja pregrijavanja mjenja značajnije mikrostrukturu silikata lijevanih Al-Si legura. Istraživanje ukazuje da pregrijavanje tekućeg metala je jedna od metoda pronalaženja veće primjene hipereutektičkih Al-Si legura bez dodataka modifikatora.

Ključne riječi: lijevane Al-Si legure, kristalizacija, struktura, pregrijana talina

INTRODUCTION

In normal casting conditions the crystals of primary silicon in hypereutectic of Al-Si alloys show many morphological features such as: polygons, star-shaped and thick plates, "big arms", etc. Such coarse-grained structure has a negative influence on mechanical properties (HB, Rm), tribological properties and the possibility of machining of the aluminium castings. The key aspect for the increase in the number of applications of Al-Si alloys is then the size decrease and the uniform arrangement of the primary crystals of silicon. It can be achieved by modification, refining, the use of ultrasound [1-3] and with the use of melt overheating of liquid alloy before casting [4-6]. Such action causes the melting of the heterogeneities and impurities, the increase of density and/or the appearance of new pads for heterogeneous nucleation of primary Si crystals.

The increase of melt overheating temperature causes the change of the morphological shape of the structural casting ingredients of the Al-Si alloys which is characteristic for disintegrated structure without the application of modifying additives.

The results of these studies [7-9] have proved that in the case of hypoeutectic silumins, an increase in the melt overheating degree results in a partially reversible change of their structure, while in the case of hypereutectic alloys this change is practically irreversible.

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TEST MATERIALS AND METHODS

The base alloy used in this study was hypereutectic A390.0 alloy that the results of chemical composition are compared in Table 1. The cast AlSi17Cu5Mg (A390.0) alloy was melted in a SiC crucible of Balzers VSG induction furnace, using as a charge material pure aluminium (99,99 wt.% purity) and Si (99,95 wt.% purity) remelted to obtain a homogeneous chemical composition. Before casting, the alloy was refined with "Rafglin-3", added in an amount of 0,3 wt.% respective of the alloy weight.

Table 1 **Chemical analysis of the examined silumin, /wt.%**

Alloy	Si	Cu	Fe	Mn	Mg	Ni	Al
A390.0	16,61	4,85	0,23	0,03	0,95	0,03	rest

The tested alloy is characterised by the low coefficient of thermal expansion, very good resistance to corrosion, high hardness and resistance to material consumption. That is why it is widely applied to cast internal combustion engines, blocks and bodies of cylinder compressors and to cast pumps and braking systems.

The cast A390.0 alloy overheated to four temperatures: 820 °C, 880 °C, 940 °C and 1 000 °C, and casted to 780 °C temperature. The effect of alloy overheating on the solidification parameters was examined by ATD on a Crystaldigraph NT3-8K apparatus equipped with Mlab2 programme. The studies of solidification process were completed with light microscopy and scanning electron microscopy, using a Hitachi microscope with EDXS Norah attachment based on the Voyager programme. Preserving the same parameters of melting and casting, the examined silumin was poured into a standard QC 4080 Heraeus Electro-Nite probe, plotting the temperature curve (TA) and its derivative in function of time dT/dt (ATD).

AIM AND SCOPE OF STUDIES

The aim of the studies was to determine what effect the degree of melt overheating on the solidification process and microstructure evolution of A390.0 alloy. The scope of the studies included:

– melt overheating to: 820 °C, 880 °C, 940 °C and 1 000 °C,
– holding the melt for 40 minutes in an electric chamber furnace,
– cooling the alloy "in air" at a rate of about 277/Ks^{-1} to a temperature of 780 °C with subsequent pouring into an QC 4080 standard ceramic sampler,
– thermal analysis, plotting of solidification curves and determination of solidification temperatures: $T_{liq,}$ $T_{Emin.}$, $T_{Emax.}$, $T_{EMg,}$ T_{ECu} and $T_{sol.}$,
– microstructure examinations.

THE RESULTS OF STUDIES

As an example, Figures 1 and 2 shows the thermal analysis graph plotted for cast A390.0 alloy no overheated and overheated to 940 °C.

The characteristic solidification temperatures read out for the examined alloy from the thermal analysis curves A390.0 alloy overheated to 940 ˚C shown in Table 2.

Figures 3 and 4 compares the values of solidification temperatures ($T_{liq,}$ $T_{Emin,}$ $T_{Emax,}$ $T_{sol.}$) and crystallisation temperatures of the complex eutectics: T_{EMg}, T_{ECu} with melt overheating temperature read out for the examined alloy from the ATD curves.

A complementary research to the overheating temperature on solidification process was study of microstructure. Samples were taken from the areas of temperature measurement.

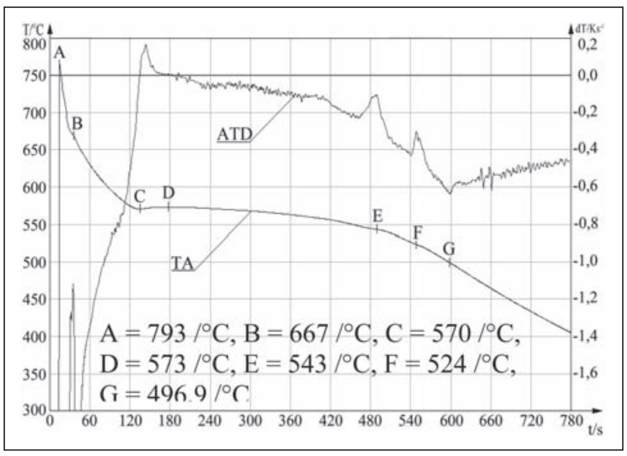

Figure 1 Thermal analysis graph plotted or cast A390.0 alloy no overheated with characteristic temperatures

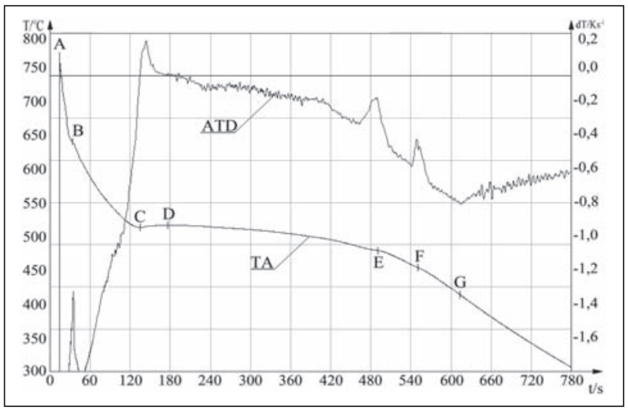

Figure 2 Thermal analysis graph plotted for cast A390.0 alloy overheated to 940 °C

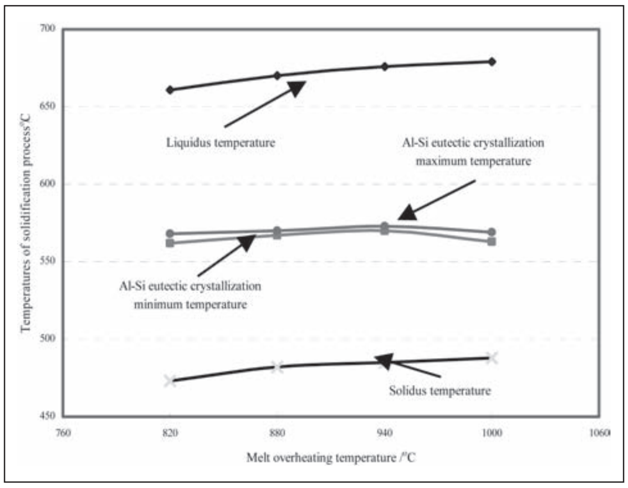

Figure 3 Effect of melt overheating degree on solidification temperatures: T_{liq}, $T_{Emin.}$ $T_{Emax.}$ and T_{sol}

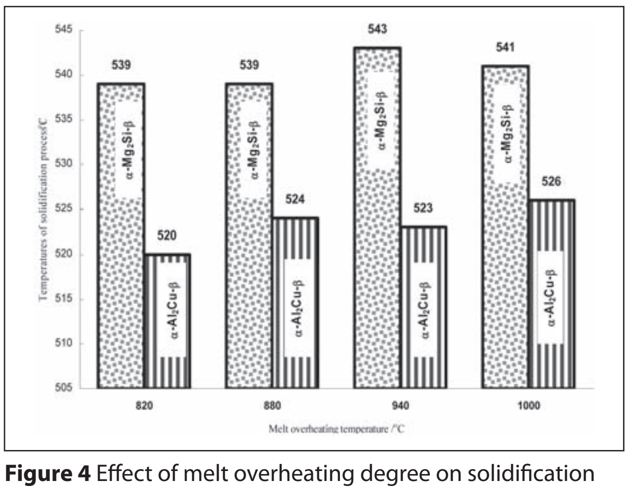

Figure 4 Effect of melt overheating degree on solidification temperatures complex eutectic: T_{EMg} α-Mg_2Si-β (1) and T_{ECu} α-Al_2Cu-β (2)

Table 2 **The characteristic solidification temperatures cast A390.0 alloy overheated to 940 °C**

Point on TA	Time /s	Temperature /°C	Temperature description
A	15,5	780	pouring temp. – $T_{por.}$
B	35,0	678	liquidus temp. – $T_{liq.}$
C	134,5	570	Al(α)-Si(β) eutectic crystallization minimum temperature – $T_{E\ min.}$
D	180,5	573	Al(α)-Si(β) eutectic crystallization maximum temperature – $T_{E\ max.}$
E	490,5	543	α -Mg_2Si- β eutectic crystallization temperature – $T_{E\ Mg}$
F	549,0	523	α -Al_2Cu- β eutectic crystallization temperature – $T_{E\ Cu}$
G	623,5	485	solidus temperature – $T_{sol.}$

DISCUSSION OF RESULTS

Proper selection of melting and casting parameters is very important as it determines the processes of nucleation, crystal growth and shaping of the primary microstructure. Better knowledge of these phenomena can have a significant impact on further determination of the liquid alloy ability to develop certain types of crystal microstructure after the solidification process (cluster structure), which can improve the casting mechanical properties and performance. To investigate the effect of melt overheating temperature on the solidification parameters and microstructure, an cast A390.0 alloy was selected that overheated to 820 °C, 880 °C, 940 °C and 1 000 °C temperatures.

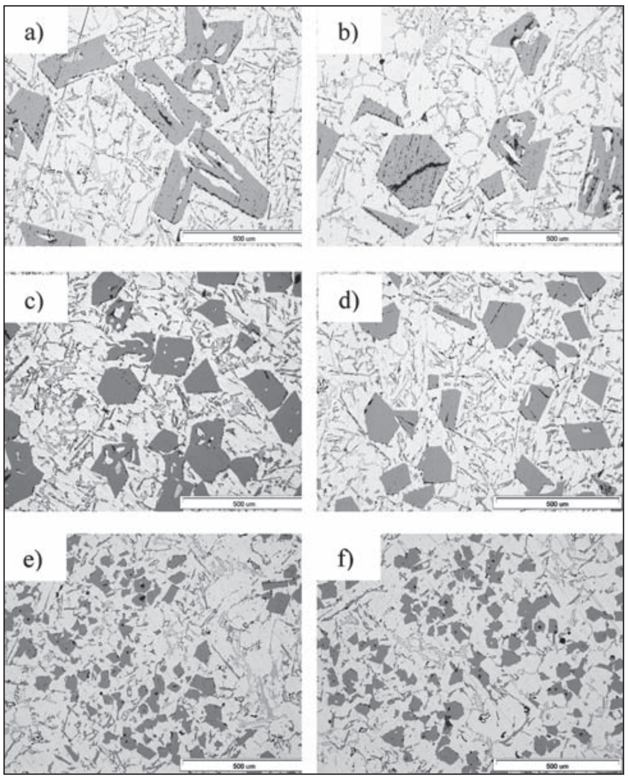

Figure 5 Microstructure of cast A390.0 alloy a, b) without overheated and overheated to: c) 820 °C; d) 880 °C; e) 940 °C; f) 1 000 °C

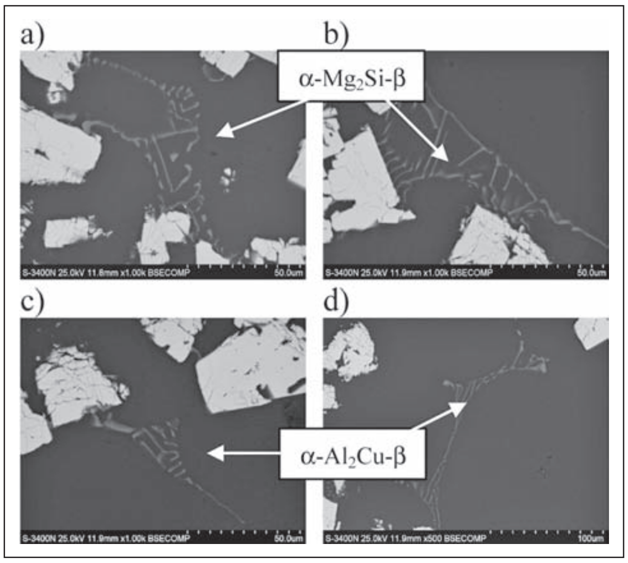

Figure 6 Microstructure of A390.0 alloy overheated to 940 °C with com-plex eutectics: a, b) α-Mg_2Si-β and c, d) α-Al_2Cu-β

The key issue in an assessment of the time/temperature parameters of the liquid alloy overheating was maintaining the conditions of melting and casting at a similar level. This eliminated the effect of other factors, and enabled correct determination of a relationship that is believed to exist between the overheating degree and solidification parameters of the examined cast A390.0 alloy.

For this purpose, the ATD thermal analysis was applied, plotting next the solidification curve of the examined alloy, overheated to selected temperatures.

Studies have proved that overheating of A390.0 alloy to 820 °C, 880 °C, 940 °C and 1 000 °C raises quite considerably the crystal-lisation temperature of the primary silicon crystals - T_{liq} ($T_{liq.}$ = 678 °C), compared to the silumin cast from 780 °C, i.e. without overheating - difference is 11 °C. The effect of copper and magnesium added to the cast A390.0 alloy is not so prominent as regards the value of the temperature T_{liq}. From the theory of crystallization it follows that magnesium added to silumins has no beneficial effect on the modification process. It is added mainly to facilitate the heat treatment. Examining a relationship that is said to exist between the crystallisation temperature of α+β eutectic (T_E) and overheating temperature of the examined alloy, one can observe that the melt overheating degree has no significant effect on changes in the value of the temperatures: T_{Emin}. and T_{Emax}. Examining the melt overheating degree on the crystallisation temperature of the ternary α-Mg_2Si-β and α-Al_2Cu-β eutectics, from Figures 4 and 6 no distinct tendency or relationship could be derived as overheating temperature and crystallisation temperature of the ternary eutectics T_{EMg} and T_{ECu}. Examining a relationship between the solidus temperature (T_{sol}) and overheating temperature cast A390.0 alloy one can conclude that in melt overheating degree on the temperature of the end of crystallisation is not so prominent.

The next important issue in the explanation of the effect of overheating temperature on the solidification parameters of hypereutectic A390.0 alloy is the examination of microstructure of alloy overheating from different temperatures. Holding the alloy for 40 minutes at 780 °C (Figure 5a and 5b) did not cause any more significant changes in its microstructure. The crystals of silicon assumed a large, star-like shape, typical of unmodified alloy. However, with increasing temperature of overheating (Figure 5 c-f), high degree of structure refinement was observed. Silicon crystals reduced their size, became more compact and more evenly distributed in the matrix of α(Al)-β(Si) eutectic. Further overheating of alloy melt to a temperature of 1 000 °C did not bring any more significant changes in the morphology of silicon crystals. This can suggest that overheating of alloy is greatly responsible for the modification of AlSi-17Cu5Mg (A390.0) alloy structure.

It is also worth noting that microstructure of the silumin cast from the 780 °C temperature (without overheated) includes a coarse-grained α(Al)-β(Si) eutectic, surrounded by silicon crystals and oblong precipitates of the AlFeSi phase [10-11]. Overheating the alloy reduces the size of the complex eutectics: T_{EMg}α-Mg_2Si-β) and T_{ECu} (α-Al_2Cu-β) - Figure 6. Hence it can be concluded that raising the temperature of the A390.0 alloy overheating not only refines the micro-structure of primary Si crystals but also dissolves the Al-Fe-Si phase-containing eutectic in α solution.

CONCLUSIONS

Based on the conducted studies the following conclusions have been drawn:

1. Overheating of cast A390.0 alloy to 820 °C, 880 °C, 940 °C and 1 000 °C tem-peratures raises the liquidus temperature T_{liq} compared to the cast alloy at 780 °C without overheated.
2. Other values of solidification temperatures: $T_{Emin.}$ $T_{Emax.}$ and T_{sol} remain basically unchanged.
3. An increase in the liquid alloy overheating temperature is accompanied by refinement and more uniform distribution of the primary silicon crystals in α(Al)-β(Si) eutectic, which is typical of the alloy structure after modification.
4. Overheating of cast A390.0 alloy to a temperature above of 820 °C refines the AlFeSi precipitates, while further overheating makes them dissolve in a solution of α (Al).
5. Overheating of cast A390.0 alloy to a temperature of 940 °C will change the form of the complex eutectics: T_{EMg}, T_{ECu} (because of the addition of Mg and Cu).

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