ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 10
Issue 4/2010

173 – 176

33/4

# Effect of overheating degree of molten alloy on material reliability and performance stability of AlSi17CuNiMg silumin castings

**J. Piątkowski*, J. Szymszal**
Chair of Materials Technology, Silesian University of Technology,
ul. Krasińskiego 8, 40-019 Katowice, Poland
*Corresponding author. E-mail address: jaroslaw.piatkowski@polsl.pl

Received 01.07.2010; accepted in revised form 09.07.2010

## Abstract

The article discusses the effect of overheating degree (above the casting temperature) on material reliability of AlSi17 silumin. The examined alloys was poured at temperatures, 760; 870 and 980$^o$C, holding the melt for 40 minutes and casting from the temperature of 760$^o$C. The assessment of the impact of the degree of overheating was to analysis the tensile strength. From the results of the static tensile test, the main estimators of the descriptive statistics, and coefficients of variation. Having determined the boundary value $\sigma_O$ for Weibull distribution, the value of „m" modulus was computed along with other coefficients of material reliability, proposed formerly by the authors. Basing on the obtained results, a model of Weibull distribution function was developed for the tensile strength with respective graphic interpretation. The time-temperature parameters of the melting and casting technology have been chosen to determine the scatter of resultant parameter (Rm) in function of overheating degree. The time-temperature treatment of hypereutectic AlSi17CuNiMg silumin, through its effect on the cluster structure of molten alloy, is shaping the material reliability and performance stability of castings.

**Keywords:** Structure of molten alloy, Hypereutectic silumins, Statistics, Weibull distribution

## 1. Introduction

Coarse-grain structure has very adverse effect on the mechanical properties and machinability of castings. Therefore, a key role in the use of Al-Si alloys in industry has the refining treatment and uniform distribution of primary silicon crystals. This goal can be achieved through modification, refining, application of ultrasounds [1] and overheating of molten alloy during casting [2], owing to the formation of a large number of substrates for the heterogeneous nucleation of silicon crystals. In world literature [3, 4] one can find but only scarce information on studies carried out on the structure of molten AlSi alloys and its effect on alloy constitution in the solid state. The results of the investigations indicate that in the case of hypoeutectic silumins the increasing degree of alloy overheating results in a partly reversible change of their structure, while in the case of hypereutectic silumins this change is practically irreversible [5]. Studies on the structure of liquid metals and alloys do not allow yet a definitive and unambiguous assessment of processes going on in these materials, but our knowledge of these phenomena can have a significant effect on the determination of molten alloy predisposition to the occurrence of certain type of crystalline structures after solidification and consequently to improvement of casting properties.

Known from literature [6], the cluster theory used in the theoretical description of liquid metal as well as other hypotheses (statistical, condensation, network, geometric, thermodynamic) [7] do not fully explain numerous phenomena that take place in liquid metal. Therefore, it seems advisable to undertake research on the effect of time and temperature of heat treatment on the tensile strength ($R_m$) of alloy. The results of these studies will make basis for further determination of alloy performance reliability measured by Weibull modulus „m".

## 2. Scope and aim of investigations

The main aim of the investigations was determination of Weibull modulus for AlSi17CuNiMg silumin. The results of static tensile test were basis for the determination of a boundary value of $\sigma_O$ used in Weibull distribution and of the value of modulus „m" generally considered a measure of the performance reliability of the investigated alloy.
The scope of investigations included:

- determination of tensile strength (20 samples were cast for each temperature value),
- determination of the main estimators and variability indeces,
- calculation of Weibull modulus,
- development of graphical relationships for the survival probability „p" in function of the tensile stress „σ", considered a measure of the performance reliability of the examined silumin.

The selection of overheating times and temperatures applied during holding of the hypereutectic silumin melt was to a great extent based on information given in reference literature, on the results of the research done previously and described in [8], and on a new concept of the relationship that is supposed to exist between the cluster structure, mechanical properties, and performance reliability of material determined by „m" modulus.

## 3. Test materials and methods

Tests were carried out on, adapted for this purpose, standard hypereutectic silumin of the chemical composition shown in Table 1.

Table 1.
Chemical composition of AlSi17 silumin (wt/%)

| | The percentage of elements (wt.%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Si | Cu | Fe | Mn | Mg | Ni | Al |
| Alloy | 16,21 | 0,87 | 0,44 | 0,03 | 0,64 | 0,63 | reszta |

This silumin resembles alloys from the A3XX.X series, grade A390.0, cast in sand and metal moulds, used mainly for pistons operating in I.C. engines, and for blocks and bodies of cylinder compressors, pumps and brakes [7, 9].
The stand for melting and casting of tensile specimens to examine the silumin properties is shown in Figure 1.

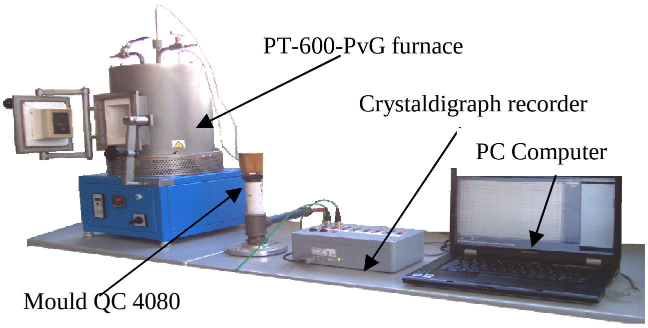


Fig. 1. Test stand for melting and casting of silumins

Schematic representation of the concept of melting, overheating, cooling and casting of tensile specimens is depicted in Fig. 2.

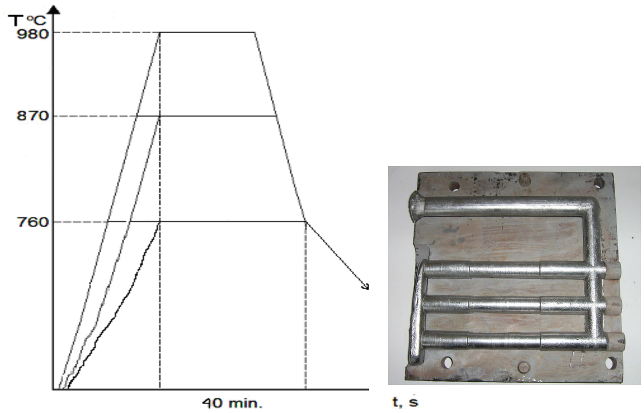


Fig. 2. Schematic representation of time-temperature treatment

Specimens prepared according to PN-EN 1706 are shown in Fig. 3.

a) b)

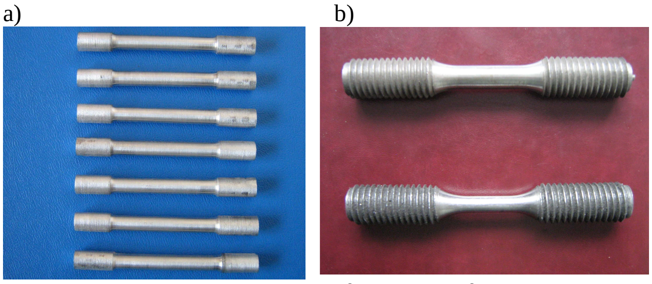

Fig. 3. Tensile specimens: a) before b) and after machining

The tensile test was carried out on an Instron 4469 machine at a rate of 20 mm/min.

## 4. Results and discussion

Since studies described in this paper are of a preliminary character only, the AlSi17 silumin was cast without modification and refining.

At the first stage of investigations, the main parameters of the descriptive statistics of the AlSi17 silumin overheated to a preset temperature and cooled at a constant rate of about 2,5 $^{o}$C/s were determined. The results are presented in Table 2.

Next, the tensile strength Rm was determined, along with the respective mean values, intervals of confidence, stability ranges and the scatter of results measured with standard deviation (SD). The results are graphically depicted in Fig. 4.

Table 2.
Parameters of descriptive statistics

| Statistical parameter | Overheating temperature, $^{o}$C | | |
|---|---|---|---|
| | **760** | **870** | **980** |
| Number of observations | 20 | 20 | 20 |
| Mean | 129,2 | 116,2 | 92,8 |
| Confidence - 95% | 115,3 | 105,8 | 87,3 |
| Confidence + 95% | 143,0 | 126,5 | 98,4 |
| Median | 129 | 116 | 94 |
| Min. | 95 | 91 | 78 |
| Max. | 174 | 146 | 104 |
| Lower quartile (25%) | 114,8 | 104 | 85,7 |
| Upper quartile (75%) | 142,6 | 128,3 | 99,6 |
| Range | 78,8 | 55 | 25,8 |
| Variance | 473,6 | 265,2 | 77,1 |
| Standard deviation | 21,7 | 16,3 | 8,9 |
| Standard error | 6,2 | 4,7 | 2,5 |
| Skewness | 0,45 | 0,18 | -0,4 |
| Curtosis | 0,24 | -0,59 | -1,24 |
| Coefficient of variation | 0,168 | 0,14 | 0,095 |
| Percentile 63 (Sigma 0) | 136,3 | 121,8 | 98,5 |

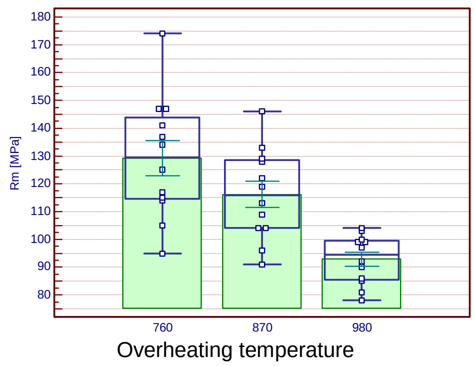


Fig. 4. Plotted relationship for the examined silumin tensile strength in function of overheating temperature

At the next stage of investigations, the value of the tensile stress „$\sigma$” was determined and, based on relationship (1), the value of the survival probability ($P_S$), called model parameter, was calculated.

$$P_s(V_0) = \exp\left\{-\left(\frac{\sigma}{\sigma_0}\right)^m\right\} \qquad (1)$$

were:
$P_S(V_0)$ – survival probability,
$\sigma$ – tensile stress, MPa,
$\sigma_0$ – tensile stress, for which 37% of samples exceed this value in terms of test features, Mpa,
m – Weibull modulus

Based on these data, the boundary value of $\sigma_O$ was calculated for Weibull distribution along with the value of modulus „m” considered a measure of the examined alloy performance reliability when overheated from three temperatures. The results are shown in Table 3.

Table 3.
Parameters of reliability

| Overheating temperature, $^{o}$C | Reliability parameter | |
|---|---|---|
| | $\sigma_0$, MPa | Modulus „m” |
| 760 | **136,3** | **7,12** |
| 870 | **121,8** | **8,56** |
| 980 | **98,5** | **12,69** |

Based on these values, graphical relationships for the tensile stress „$\sigma$” in function of the survival probability (P) were determined, as shown in Figure 5.

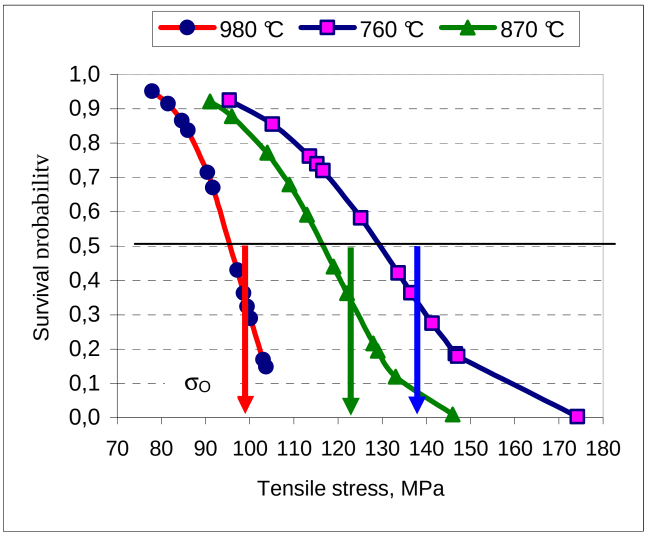


Fig. 5. Survival probability in function of tensile stress

Structure examinations were carried out as a tool complementary to statistical calculations. Examples of AlSi17 silumin microstructures in as-cast condition and after overheating to the above stated temperatures are shown in Figures 6 and 7.

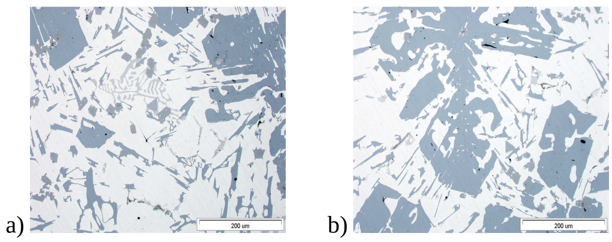


Fig. 6. Microstructure of AlSi17 silumin in as-cast condition (without overheating)

a)

b)

c)

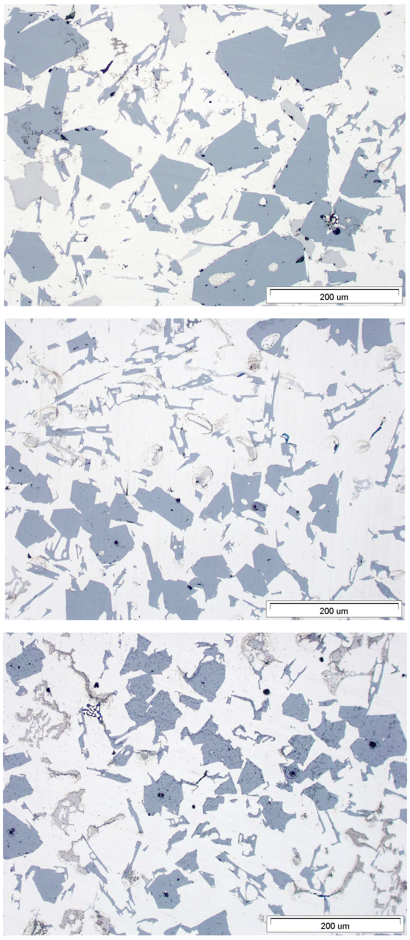


Fig. 7. Microstructure of AlSi17 silumin overheated to:
a) 760°C, b) 870°C, c) 980°C and held for 40 min

## 4. Summary

As proved by the investigations, melting, overheating and cooling to the pouring temperature change in a significant way the value of the tensile stress ($\sigma$), consequently affecting also the value of Weibull modulus. As shown in Figure 4, an increase in the overheating temperature of molten silumin makes the mean value of $R_m$ drop by 13 to 23 MPa. This drop, however, is accompanied by a reduced scatter of results obtained for the examined property (from 5,4 to 7,4 MPa), measured by standard deviation (SD) (Table 2).

Hence a conclusion follows that the degree of molten alloy overheating reduces the tensile strength of alloy, reducing also the scatter of the obtained results. Making the stability range of the resultant feature more narrow, and hence increasing the alloy technological and operational stability reduces the coefficient of variability and the boundary value of $\sigma_O$ for Weibull distribution, increasing at the same time the value of parameter „m". It has been assumed that this coefficient, responsible for the survival probability (p), determines the material reliability which for an engineer-designer may constitute an important advantage over other materials. The reduced scatter of the tensile stress values ($\sigma$) was confirmed by the reduced slenderness in Figure 5.

The statistical calculations were completed with structure examinations. The AlSi17 silumin poured from the temperature of 760°C (without holding at this temperature and without modification) shows „star-like" hypereutectic crystals of silicon characterised by a non-uniform distribution in matrix (Fig. 6). This is the structure typical of unmodified hypereutectic silumins. Holding of alloy for 40 minutes at the temperature of 760°C (Fig. 7a) results in slight refining of the alloy structure. The crystals of silicon are finer and their distribution in matrix is much more uniform. With increasing temperature of overheating, the alloy structure seems to be even more refined and homogeneous. The crystals of silicon are more compact and very fine (Fig. 7b). Further overheating of alloy to 980°C refines the structure even more, which can suggest that overheating of alloy is the factor strongly affecting the AlSi17 silumin structure modification.

## Acknowledgements


The financial support from the Polish Ministry of Science and Higher Education under contract N N507351235 is gratefully acknowledged.


## References


[1] J. Szajnar, T. Wróbel, Inoculation of pure aluminium with an elektromagnetic field. Journal of Manufacturing Processes, vol. 10, No. 2, 2008, p. 74. (in English).

[2] Peijie Li, V. I. Nikitin, E. G. Kandalova and K. V. Nikitin: Effect of melt overheating, cooling and solidification rates on Al–16wt.%Si alloy structure. Materials Science and Engineering A vol. 332, Issues 1-2, July 2002, p. 371-374.

[3] Jun Wang, Shuxian He, Baode Sun, Qixin Guo and Mitsuhiro Nishio: Grain refinement of Al–Si alloy (A356) by melt thermal treatment. Journal of Materials Processing Technology, vol. 141, Issue 1, 1 October 2003, p. 29-34.

[4] Li Wang, Xiufang Bian and Jiantong Liu: Discontinuous structural phase transition of liquid metal and alloys. Physics Letters A vol. 326, Issues 5-6, 2004, p. 429-435.

[5] Weimin Wang, Xiufang Bian, Jingyu Qin, S.I. Syliusarenko: The Atomic-Structure Changes in Al-16 Pct Si Alloy above the Liquidus. Metallurgical And Materials Transactions A vol. 31A, September 2000 - 2163.

[6] Z. Górny, J. Sobczak, Non-ferrous metals based novel materiale in foundry practice. ZA-PIS Cracow, 2005 (in Polish).

[7] G.K. Gavrilin, Plavlenie i kristallizatsiya metallov i splavov, Metallurgiya, Moskva, 1996, (in Russian).

[8] J. Piątkowski, Effect of overheating degree on the solidification parameters of AlSi17CuNiMg silumin. Archives of Foundry, vol. 10, issue 2, 2010, p. 103-107.

[9] S. Pietrowski, Silumines. Silesian University of Technology. Łódź, 2001 (in Polish).