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Heat treatment of the EN AC-AlSi9Cu3(Fe) alloy

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Abstract

Silumins are widely used in automotive, aviation and shipbuilding industries; as having specific gravity nearly three times lower than specific gravity of cast iron the silumins can be characterized by high mechanical properties. Additionally, they feature good casting properties, good machinability and good thermal conductivity. i.e. properties as required for machinery components operating in high temperatures and at considerable loads. Mechanical properties of the silumins can be upgraded, implementing suitably selected heat treatment. In the paper is presented an effect of modification and heat treatment processes on mechanical properties of the EN AC-AlSi9Cu3(Fe) alloy. Investigated alloy has undergone typical processes of modification and refining, and next heat treatment. Temperature range of the heat treatment operations was determined on base of curves from the ATD method. Obtained results concern registered melting and solidification curves from the ATD method and strength tests. On base of the performed tests one has determined range of the heat treatment parameters which would assure obtainment of the best possible mechanical properties of the EN AC-AlSi9Cu3(Fe) alloy.

Keywords: Modification, Heat Treatment, ATD, Mechanical Properties

1. Introduction

Growth of requirements demanded from structural materials is connected mainly with objective of mass reduction. Fulfilment of these requirements is connected with simultaneous increasing of strength and plasticity of the materials. The same concerns also the casting materials from group of aluminum-silicon alloys (silumins). Mechanical properties of silumins depend on chemical constitution, refining, modification and heat treatment operations. [1÷6]. Presently performed investigations aimed at growth of mechanical properties of the silumins, and in consequence, possibility of application in machinery components castings with high durability and reliability, are boiled to the following directions of search [2, 5, 7÷15]:

- improvement of selection methods of main and supporting alloy additions with use of contemporary attainments from area of synthesis of alloys,
- rationalization of selection of complex compounds which modify structure,
- reduction of hydrogen and gaseous porosity quantities,
- reduction of non-metallic impurities,
- crystallization under pressure,
- development and implementation of modern heat treatment technology.

A method how the heat treatment is performed and its effects depend on morphology of primary structure of the alloys [16]. Obtainment of high mechanical properties is possible in suitable conditions of macro- and microstructure of the alloys, what is determined by shape and distribution of hardening phases, segregation of alloy-forming elements, as well as distribution of porosity, etc. [16].

In case of modified alloys from Al-Si group, due to soaking of the alloy is explicitly seen not only a growth of concentration in solid solution α of chemical elements (e.g. Cu and/or Mg), which constitute potential source of precipitation processes, but also is seen advantageous change of morphology of eutectic silicon crystals - their coalescence and spheroidizing. Owing to it, the material as a whole does not show any worsening of plastic properties in spite of strengthening of the solid solution α, due to ageing of the castings which occurs later [4].

More advantageous stresses distribution and damping of interaction of fragile phase Si, as internal notches in material under load, correspond to changed morphology of eutectic Si crystals, which take form similar to spherical one [4].

Another very important issue connected with heat treatment of the silumins is selection of temperatures and durations of solutioning and ageing treatments. It is connected with necessity of obtaining of optimal results, i.e. improvement of mechanical properties of processed alloy, as well as with economical aspect of heat treatment operations.

Having in mind the effect of quality of the alloy destined to heat treatment it is reasonable to make use of quick methods of its valuation, such as the ATD and ATND are [17, 18].

Implementation of these methods enables comparatively accurate valuation of modification extent and selection of temperatures range of solutioning and ageing treatments.

2. Methodology of the research

The EN AC-AlSi9Cu3(Fe) (EN AC-46000) alloy is characterized by very good casting and technological properties. Due to very good mechanical properties, this alloy is used for heavy duty components of machinery, like cylinder heads and pistons of engines.

The first stage of the investigations consisted in testing of the crystallization course for the alloy from pig sows.

Next, one performed treatment of refining with use of Rafal 1 preparation in quantity of 0,4% mass of metallic charge. After completion of the refining one removed oxides and slag from metal-level and performed operation of modification of the alloy with strontium, making use of AlSr10 master alloy in quantity of 0,5% mass of metallic charge (0,05% Sr).

Test pieces to strength tests were prepared according to PN-88/H-88002 standard, whereas static strength tests were performed on ZD-20 tester.

Process of solidification and melting of the alloy was recorded with use fully automated Crystaldimat analyzer.

Chemical constitution of the investigated alloy is presented in the Table 1. Analysis of chemical constitution was performed with use of spectrometric method (GDS 850A type emission spectrometer with glow-type excitation).

Table. 1.
Chemical constitution of investigated alloy

EN AC-46000	Si	Fe	Cu	Zn	Ti	Mn	Ni	Sr	Pb	Cr	Mg	Al
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
from pig sows	7,88	0,6	4,5	0,658	0,12	0,138	0,33	-	0,06	0,04	0,4	rest
refined	8	0,75	3,8	0,65	0,17	0,206	0,5	-	0,05	0,08	0,327	rest
modified	8,5	0,65	4	0,6	0,18	0,15	0,32	0,035	0,05	0,07	0,3	rest

In the Fig. 1 are shown recorded curves of heating (melting) and crystallization of refined and modified alloy, recorded with use of the ATD method.

On the thermal curve were marked temperatures of solutioning and ageing treatments of the investigated alloy.

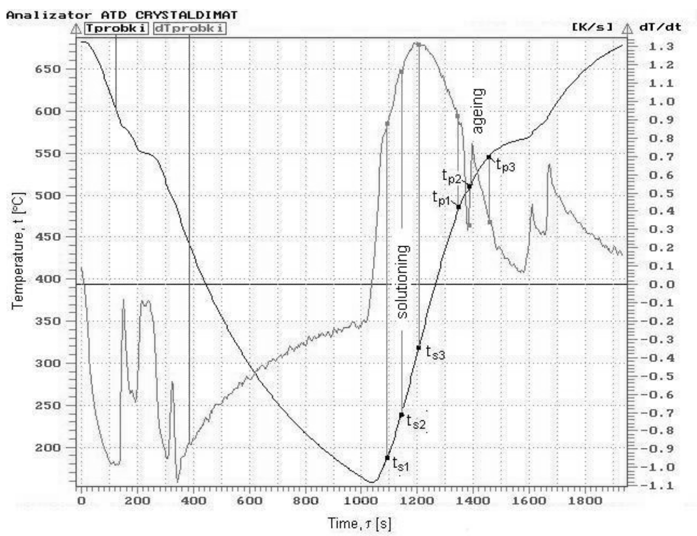

Fig. 1. Curves of the ATD method for refined and modified EN AC-AlSi9Cu3(Fe) alloy

In the Table 2 are presented parameters of the heat treatment operations for tristage plan of testing with four variables. For the assumed plan of the investigations, number of configurations amounts to 27.

Table. 2.
Heat treatment parameters of the alloy

ageing temperature t_s [°C]	ageing duration τ_s [h]	solutioning temperature t_p [°C]	solutioning duration τ_p [h]
t_{s1} - 525	0,5	t_{p1} - 180	0,5
t_{s1} - 540	1,5	t_{p2} - 250	1,5
t_{s1} - 555	3	t_{p3} - 330	3

Temperatures of solutioning and ageing treatment were selected on base of recorded points values from the ATD melting curves (Fig. 1).

3. Description of obtained results

3.1. R_m tensile strength

Tensile strength obtained for the raw alloy (from pig sows) amounted from 213 to 243 MPa. After refining there occurred a slight change of the R_m tensile strength (246÷249 MPa). Performed operation of modification of the alloy enabled obtainment of the R_m tensile strength within range of 248÷272 MPa.

To the heat treatment one used refined and modified alloy.
In the Fig. 2 are shown average values of the R_m tensile strength for the EN AC-AlSi9Cu3(Fe) alloy after the heat treatment.

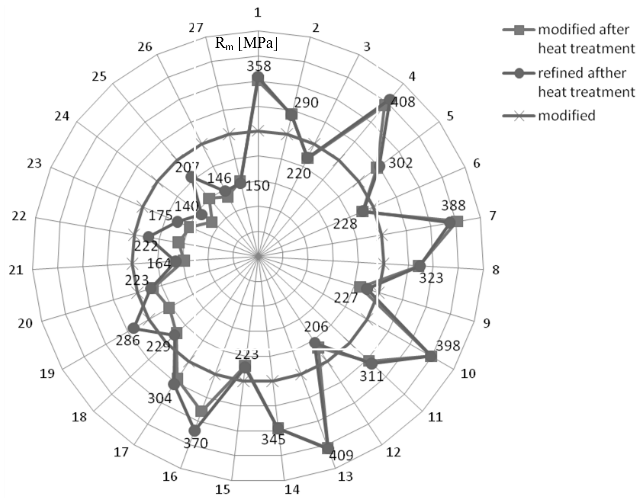

Fig. 2. Change of R_m tesile strength of the investigated alloy for individual configurations of the testing plan

Modification treatment of the alloy did not effect in any significant changes in R_m tensile strength of the investigated alloy after the heat treatment, with respect to refined alloy which underwent the same treatment (Fig. 2).

Making comparison of the obtained average values of parameters from the test of the alloy after heat treatment and the alloy without heat treatment, one confirmed growth of the R_m tensile strength with 65%.

For the specified parameters (4, 7, 10, 13 – Fig. 2) of the heat treatment there were obtained the best (maximal) R_m tensile strength of the alloy. The highest R_m tensile strength, amounted to 409 MPa, was obtained for the following parameters of the heat treatment operations:

- solutioning temperature - 510°C,
- solutioning duration - 1,5 hour,
- ageing temperature - 240°C,
- ageing duration - 2 hours.

3.2. A_5 elongation

The A_5 elongation for raw alloy amounted from 1,4 to 1,8%. After refinement one obtained elongation in range of 2 to 2,4%. Modification treatment affected in growth of the elongation, which amounted from 2,4 to 3%. In case of the elongation, similarly like in case of the R_m tensile strength, modification treatment of the alloy did not effect significantly on change of elongation of the alloy after heat treatment, with respect to refined alloy which underwent the same treatment in the same conditions (Fig. 3).

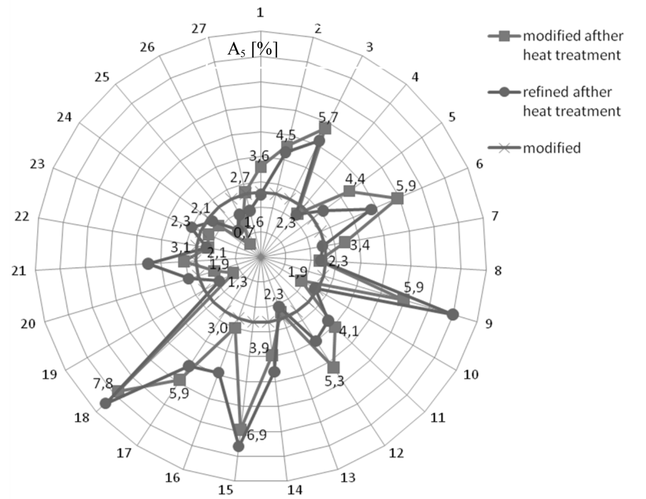

Fig. 3. Change of A_5 elongation of the investigated alloy for individual configurations of the testing plan

In result of the performed heat treatment one obtained growth of the elongation up to 300%. Maximal values of the elongation were obtained for the predermined parameters (18, 15 – Fig. 3) of heat treatment process.

Elongation amounted to 7,8 % was obtained for the following patrameters:

- solutioning temperature – 510°C,
- solutioning duration – 8 hours,
- ageing temperature – 320°C,
- ageing duration – 8 hours.

3.3. HB hardness

The hardness of raw alloy (from pig sows) amounted to 94 HB. Refining of the alloy effected in drop of the hardness to value of 91 HB. Performed modification of refined alloy enabled obtainment of the hardness having value of 87 HB. Values of the hardness specified here constitute average values obtained from the testing.

Hardness values of the alloy after heat treatment process for the alloy which underwent modification treatment do not differ significantly from the hardness of refined alloy after heat treatment in the same conditions.

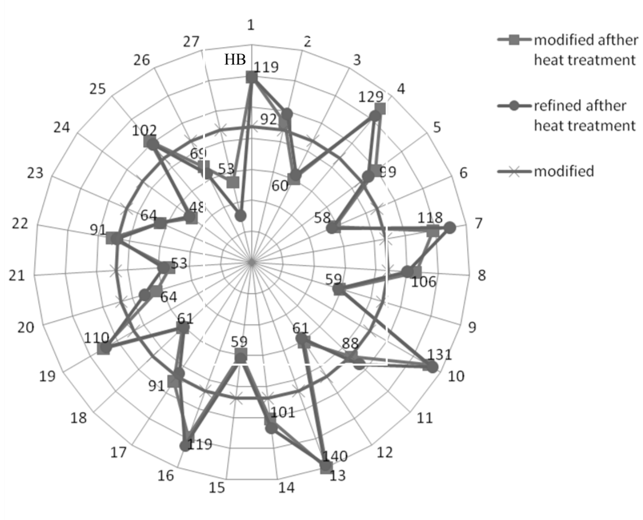

Fig. 4. Change of HB hardness of the investigated alloy for individual configurations of the testing plan

Performed heat treatment resulted in growth of the hardness of the alloy up to 62% with respect to hardness of the alloy after refining and modification.

The highest values of the HB hardness of the investigated alloy were obtained for predetermined parameters (13, 10, 4 – Fig. 4) of the heat treatment process. Hardness amounted to 140 HB was obtained for the following parameters:

- solutioning temperature – 510°C,
- solutioning duration – 1,5 hour,
- ageing temperature – 240°C,
- ageing duration – 2 hours.

4. Conclusions

Necessary condition to be fulfilled in order to obtain improved mechanical properties of the EN AC-AlSi9Cu3(Fe) alloy is selection of a suitable parameters of heat treatment process (temperature and duration of solutioning and ageing treatments). The ATD method has enabled determination of temperature ranges of solutioning and ageing treatments of the investigated alloy, used in assumed plan of the testing.

Lack of any significant difference between mechanical properties obtained after the heat treatment for the refined alloy, and refined and modified alloy results probably from a partial structure modification of the alloy in pig sows.

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