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Heat Treatment of a Casting Element of a Through Clamp to Suspension of Electric Cables on Line Post Insulators

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Abstract

Heat treatment of a casting elements poured from silumins belongs to technological processes aimed mainly at change of their mechanical properties in solid state, inducing predetermined structural changes, which are based on precipitation processes (structural strengthening of the material), being a derivative of temperature and duration of solutioning and ageing operations. The subject-matter of this paper is the issue concerning implementation of a heat treatment process, basing on selection of dispersion hardening parameters to assure improvement of technological quality in terms of mechanical properties of a clamping element of energy network suspension, poured from hypoeutectic silumin of the LM25 brand; performed on the basis of experimental research program with use of the ATD method, serving to determination of temperature range of solutioning and ageing treatments. The heat treatment performed in laboratory conditions on a component of energy network suspension has enabled increase of the tensile strength R_m and the hardness HB with about 60-70% comparing to the casting without the heat treatment, when the casting was solutioned at temperature 520 °C for 1 hour and aged at temperature 165 °C during 3 hours.

Keywords: Heat treatment, Aluminum alloys, ATD, Tensile strength, Hardness HB

1. Introduction

Obtained structure of castings has a direct effect on technological quality of machinery components in range of their mechanical properties.

Heat treatment of aluminum alloys, aimed mainly at increase of their strength, consists in dispersion hardening (precipitation one), which can be obtained in result of successively performed operations of solutioning and ageing of solid solution. Reduction of solubility limit of alloying components in solid state as the temperature decreases is the main condition on which the precipitation hardening is based. Contemporary heat treatment

processes, due to market demands posed by the customers, comprising expectations on quality and reliability, low manufacturing costs and energy consumption, as well as environmental concerns, result in necessity of searching after a technical solutions enabling obtainment of satisfactory results in form of maximal improvement of the mechanical properties of poured machinery components with simultaneous reduction of time and temperature of the solutioning and ageing treatments.

To obtain homogenous supersaturated structure, the solutioning treatment is performed mainly at temperatures close to eutectic temperature of the alloy, during sufficiently long period of time. In practice, the solutioning temperature should be lower with 20-30°C than the eutectic temperature, because too high

heating temperature could lead to partial melting of the eutectic mixture and generation of surface defects. Inner partial melting of the metal is especially detrimental, because it results in brittleness and cracks after the solutioning, even at very minimal loads. In turn, too low temperature will not assure proper structure of the solutioned alloy.

Hardened alloying elements, such as Cu and Mg in heat treated aluminum alloys, exhibit sufficient solubility in solid state; however the solubility decreases considerably with decrease of the temperature. Dissolution of the Mg_2Si phase in result of high solutioning temperature and solubility of the Mg in Al elements is facilitated – as informs Rometsch [1] – and for the alloy of the 356.0 brand was completed after 2-4 minutes at temperature 540 °C, while for the alloy of the 357.0 brand during 50 minutes, what was caused by its coarse-grained structure and higher concentration of the Mg. However, Zang in the study [2] informs that the solutioning treatment for 30 minutes at 540 or 550 °C is sufficient to achieve more than 90% of the maximum yield strength and more than 95% of the maximum UTS, and the maximum average elongation to fracture. Similar results had been achieved in the studies [3-5].

With the solutioning treatment is also connected process of spheroidizing of the Si precipitations, i.e. change of its morphology, having effect on the mechanical properties. Spheroidizing process of the Si can be divided into stage of fragmentation and dissolution of the eutectic silicon arms, and spheroidization of its precipitations [6].

Rapid cooling, which occurs after the solutioning should result in arresting within the solution of maximal quantity of hardening elements and vacancies [7-8]. The most often it can be attained by insertion of cooled element into water directly after the solutioning; the water belongs to dominant medium used in heat treatment of aluminum alloys.

The ageing is the second operation of the precipitation hardening, and is performed after the solutioning; the ageing is aimed at obtainment of structures characterized by uniform distribution of small precipitations, allowing obtainment of high strength of the alloy.

Sequence of the ageing process for the Al-Si-Mg alloys is based on formation of the phase (Mg_2Si) and looks like [9-12]:

Supersaturated solid solution $\alpha_{SSS} \rightarrow GP \rightarrow \beta'' \rightarrow \beta' \rightarrow \beta (Mg_2Si)$

Sequence of the ageing of the Al-Si-Mg alloys commences from formation of spherical GP zones, connected with local segregation of the Mg and Si atoms. Next, the GP zones elongate and develop into coherent phase β'' with acicular shape. The precipitations of the phase β'' elongate with time, taking form of partially coherent bars (phase β') and finally non-coherent bars, with the matrix in form of lamella or bars (stable phase $\beta-Mg_2Si$). Maximal strength of the alloy (peak of the ageing) can be achieved directly before precipitation of non-coherent lamella of the $\beta-Mg_2Si$.

Processes of the precipitation during artificial ageing comprise release of hardening phases from the supersaturated alloy, at increased temperature (150-260 °C). At such temperatures the hardening precipitations are usually bigger than the GP zones.

As the main problem emerges determination of temperature and time intervals of individual operations, enabling obtainment of considerably higher mechanical properties of the alloy.

In the present paper is depicted the heat treatment process of a energy network fittings element, performed on the basis of determined parameters of this process, having as the objective considerable improvement of the mechanical properties of poured material, with consideration of economical aspect of performed process (reduction of temperature and time of the solutioning and ageing treatments).

2. Methodology of the research

In the firsts stage of the research it has been performed investigation concerning selection of the solutioning and ageing heat treatment parameters of a test pieces made from the same alloy as used to production of poured component (yoke) of the energy network fittings, consisting in heating of the alloy to temperature of the solutioning (close to solidus line), keeping at this temperature for suitably long time, and next cooling down in cold water (20 °C), and next artificial ageing according to assumed plan of the research. Next, basing on determined parameters of the process it has been performed heat treatment of the casting of the energy network fittings component.

The component of the energy network fittings, which underwent operation of the heat treatment, was made in form of a chill casting from the LM25 alloy (the symbol according to the BS 1490:1998 [13]). This alloy is used as a British equivalent of the 356.0 alloy (AlSi7Mg) with reduced contents of Cu.

The casting of the yoke constitutes integral part of the self-aligning through clamp used to suspension of cables on the line post insulators of medium and high voltage lines. The clamp, depending on its design, consists of the yoke and the cover plate, made from aluminum alloy, and of links and fasteners, while in case of the cable support, it incorporates a mounts made from steel or hot galvanized cast iron.

Chemical composition of the investigated alloy is presented in the Table 1.

Table 1.

Chemical composition of the LM25 (EN AC-AlSi7Mg) alloy

Chemical composition / mass %				
Si	Cu	Zn	Fe	Mg
6,6	0,08	0,08	0,37	0,54
Ni	Mn	Pb	Sn	Al
0,01	0,3	0,01	0,01	rest

To produce the test pieces which were used in course of the investigations, the alloy was melted in the electric resistance furnace at temperature of 720 ÷ 750°C. In the next stage it has been performed refining treatment with use of refining preparation (Rafal 1), in quantity 0,4% mass of the charge. Refined alloy, after removal of oxides and slag from the metal level, was modified with the AlSr10 master alloy, in quantity of 0,5-0,6% mass of the charge. Temperature of the liquid alloy was maintained at the level of 720-740 °C. Experimental castings (test pieces to the investigations of the mechanical properties) were

poured in a metal mould produced according to the PN-88/H-88002 standard, clad with Kokilokryt layer and heated to temperature 220-250 °C.

Ranges of temperature of the solutioning and ageing treatments were selected basing on analysis of recorded curves from the ATD method (Fig. 1). Such method has been used to recording of crystallization processes of metals and alloys for many years, both in research projects and in quality control of alloys within industrial environment [4,14-18]. Process of the solidification and melting of the alloy was recorded with use of fully automated Crystaldimat analyzer.

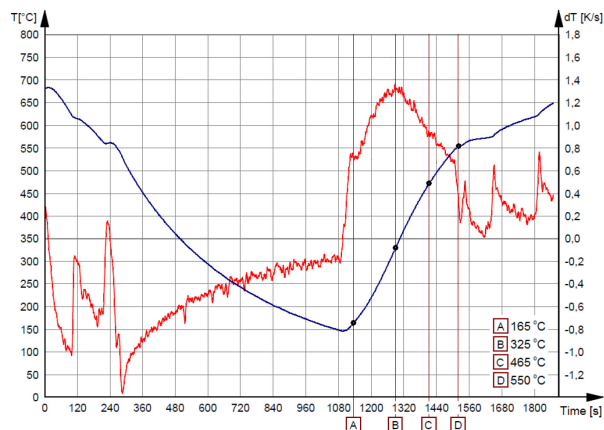


Fig. 1. ATD diagram of the investigated alloy

On the curves from the ATD method were marked temperature ranges of the solutioning (C-D) and ageing treatment (A-B), which were used in the assumed plan of the research. In the Table 2 are presented parameters of the solutioning and ageing operations for the performed heat treatment of the investigated alloy.

Table 2.

Heat treatment parameters of the alloy

solutioning temperature t_{p} , °C	solutioning time τ_p , h	ageing temperature t_{s1} , °C	ageing time τ_s , h
t_{p1} - 465	0,5	t_{s1} - 165	2
t_{p2} - 520	1,5	t_{s1} - 235	5
t_{p3} - 550	3	t_{s1} - 325	8

Taking into considerations quantity of input variables (temperature and time of the solutioning and ageing operations), it has been assumed trivalent plan of the research with four variables, enabling limitation of quantity of performed measurements [19] and validated, among others, in course of the investigations performed on the AlSi13Cu2Fe and AlSi7Cu3Mg [20-21].

The heat treatment consisted in the solutioning operation followed by rapid cooling in water at temperature 20 °C (poured test pieces and castings), and next, operation of artificial ageing with cooling in the air.

The electric resistance furnace, as the main component of the test bed, was used in operations of the solutioning and ageing (for

the temperatures above 300 °C) of the castings and the alloys. Measurement of the temperatures was performed with use of a Ni-NiCr thermo-elements, type K, with accuracy $\pm 5^\circ\text{C}$, directly in chamber of the furnace, both temperature of the test piece and the castings. Recording of the temperature inside chamber of the furnace and temperature of the test piece was performed continuously.

After performed heat treatment, the test pieces destined to measurement of the mechanical properties (R_m) were produced according to the PN-EN ISO 6892-1:2010P standard [22] (the test piece with measuring length of 50 mm and diameter of 10 mm). The test pieces to determination of the energy network fittings (R_m) of material of the castings of the energy network fittings were cut from the area shown in the Fig. 2. These test pieces were produced according to the PN-EN ISO 6892-1:2010P standard (the test piece with measuring length of 30 mm and diameter of 6 mm). The castings are depicted in form of drawings produced on the basis of 3D scanning with use of the eviXscan Pro+ scanner, with accuracy 0.01-0.025 mm, and in form of editable models from the Geomagic Design X software.

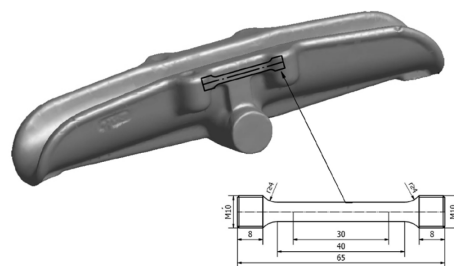


Fig. 2. Area where the test pieces were cut from casting

Static tensile tests were performed according to the PN-EN ISO 6892-1:2010P standard, on the strength tester of the ZD-20 type (poured test pieces) and on the Instron 33R4467 tester, with measuring head 30 kN, class 1 (the test pieces cut from the castings, with use of the extensometer 25 mm (0-2,5 mm, resolution 1 μm , class 1) and the Instron Bluehill 3 software.

Measurements of the Brinell hardness were performed according to the PN-EN ISO 6506-1:2008P standard [23], using the Brinell hardness tester of the PRL 82 type, with steel ball 10 mm diameter, under load of 9800 N, sustained for 30 seconds. The hardness of the poured test pieces was measured on grip sections of milled test pieces, while in case of the castings – area where the hardness was measured is shown in the Fig. 3

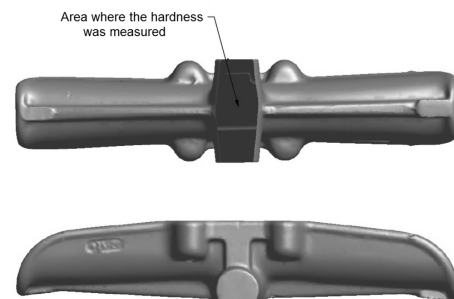


Fig. 3. Area of the casting where the hardness was measured

Heat treatment of the casting of the yoke, produced from the LM25 alloy consisted in heating of the casting to solutioning temperature $t_p = 520$ °C, keeping in such temperature for 1 hour, and next, cooling down in cold water (20 °C), and ageing at temperature $t_s = 165$ °C for 3 and for 5 hours. Additionally for the castings, it has been performed the T4 heat treatment (with natural ageing).

3. Description of obtained results

3.1. Tensile strength R_m

Tensile strength of the raw alloy (from pig sows) amounted to 190 MPa. After the refining it was observed a slight change (199 MPa), whereas performed treatment of the modification has enabled obtaining of the R_m within limits of 200-205 MPa. After performed heat treatment of the alloy, obtained tensile strength R_m amounted from 154 to 335 MPa.

Making comparison of obtained values of the tensile strength R_m for the alloy after the heat treatment and the alloy without the heat treatment (Fig. 4), it has been confirmed the highest increase of the tensile strength R_m in case of the following systems: 13 ($t_p = 520$ °C; $\tau_p = 1,5$ hour; $t_s = 165$ °C; $\tau_s = 5$ hours), 19 ($t_p = 550$ °C; $\tau_p = 0,5$ hour; $t_s = 165$ °C; $\tau_s = 5$ hours) and the system 25 ($t_p = 550$ °C; $\tau_p = 3$ hours; $t_s = 165$ °C; $\tau_s = 8$ hours). A slightly lower tensile strength, having value within limits of 300 MPa, was obtained for the systems 4, 16 and 22, which were characterized by, like in case of the systems 13, 19 and 25, low ageing temperature ($t_s = 165$ °C) during time 2 to 8 hours.

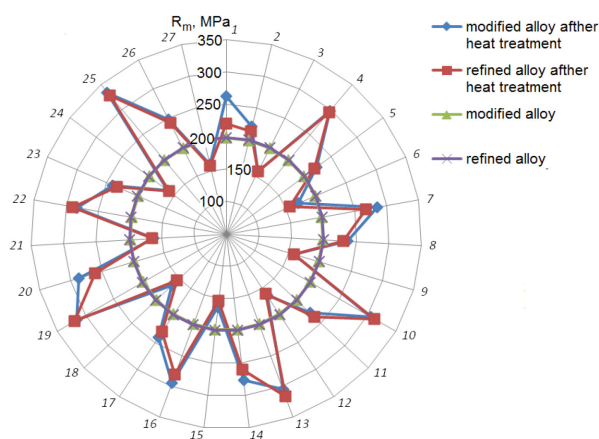


Fig. 4. Tensile strength R_m of the investigated alloy

The lowest tensile strength R_m was obtained for the systems 3, 9 and 27, which were characterized by a high ageing temperature ($t_s = 325$ °C), in complete range of the ageing times. Obtained value of the R_m for these systems amounted to 158 - 163 MPa, what denoted its considerable decrease in relation to the alloy without the heat treatment. Effect of the temperatures and durations of the solutioning and ageing of performed heat treatment operations on change of the tensile strength R_m , is

presented in graphical form in the spatial diagrams (Fig. 5). For the solutioning operation it has been assumed constant values of the ageing parameters: temperature $t_s = 165$ °C and time $\tau_s = 5$ hours, while for the ageing operation it has been assumed the following constant parameters of the solutioning temperature $t_p = 520$ °C and time $\tau_s = 1$ hour.

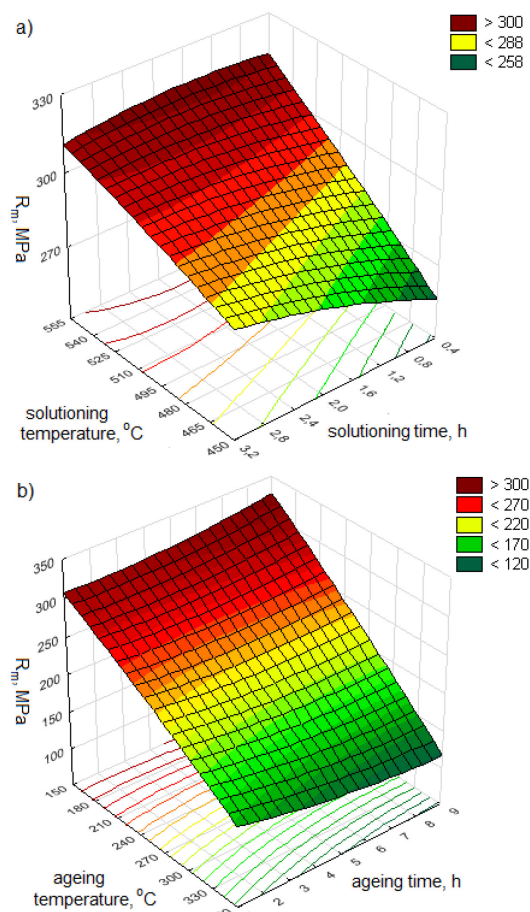
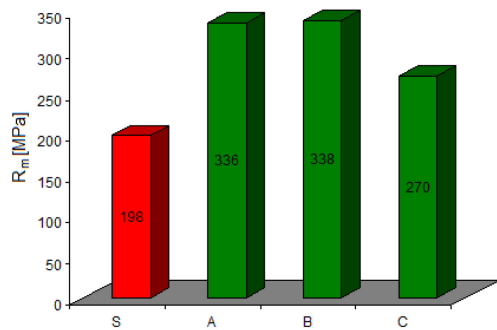


Fig. 5. Effect of the solutioning and ageing parameters on the tensile strength R_m : a) t_p and τ_p , b) t_s and τ_s

Maximal increase of the tensile strength R_m of the alloy is possible to be obtained after its solutioning at temperature $t_p = 520$ - 550 °C during 1 to 3 hours, and next cooling in cold water and ageing for 5 to 8 hours at temperature $t_s = 165$ °C.

In the Fig. 6 are presented, in form of bar diagrams, obtained values of the tensile strength of the raw alloy and the alloy after the heat treatment of the casting of the yoke of energy network fittings. The symbol „S” denotes the casting without the heat treatment, symbol A denotes the casting solutioned at 520 for 1 hour and aged for 3 hours at 165, symbol B denotes the casting solutioned at temperature 520 for 1 hour and aged for 5 hours at 165, whereas the symbol C concerns the casting solutioned at temperature 520 for 1 hour and naturally aged for 7 days.

Fig. 6. Tensile strength R_m of material of the casting

3.2. Hardness HB

Hardness of the alloy after the refining amounted to 60 HB10/1000/30. The modification resulted in a slight decrease of the hardness of the alloy (56 HB10/1000/30). After performed heat treatment of the alloy its obtained hardness HB10/1000/30 was included within range of 41 to 101.

Comparing obtained values of the hardness for the alloy after the heat treatment and the alloy without the heat treatment (Fig. 7), it has been ascertained that the highest increase of the hardness HB occurred for the system 10 (solutioning temperature - $t_p = 520$ °C; solutioning time - $\tau_p = 0,5$ hour; ageing temperature - $t_s = 165$ °C; ageing time - $\tau_s = 8$ hours) and the system 25 ($t_p = 550$ °C; $\tau_p = 0,5$ hour; $t_s = 165$ °C; $\tau_s = 8$ hours) - 101 HB10/1000/30. A slightly lower hardness having value of 91 - 92 HB10/1000/30 was observed for the test pieces from the system 13 ($t_p = 520$ °C; $\tau_p = 1,5$ hour; $t_s = 165$ °C; $\tau_s = 8$ hours) and the system 19 ($t_p = 550$ °C; $\tau_p = 0,5$ hour; $t_s = 165$ °C; $\tau_s = 5$ hours).

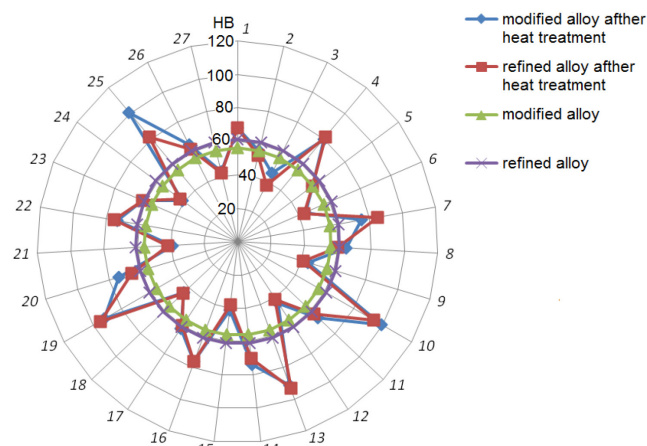
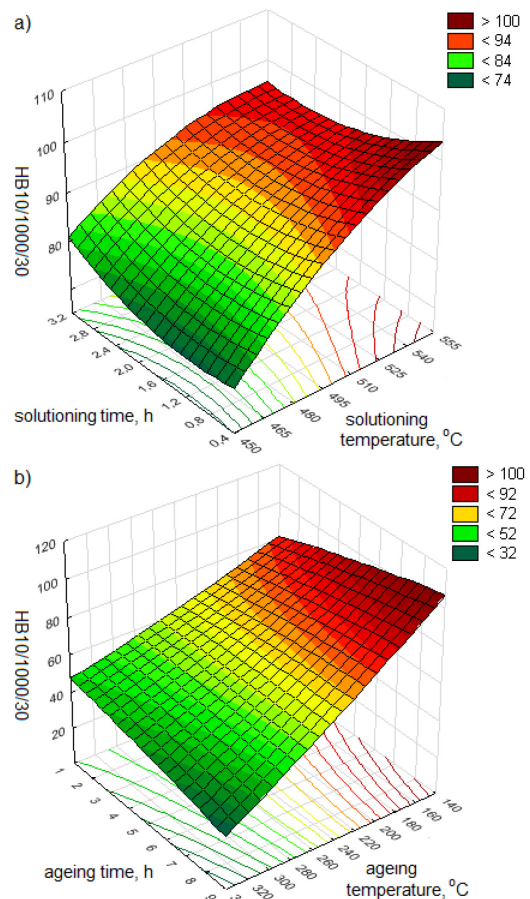


Fig. 7. Hardness HB of the investigated alloy

The lowest hardness (within limits of 41 - 44 HB10/1000/30) was obtained in case of the systems 6, 9, 12 - (Fig. 7), which were characteristic of high ageing temperature $t_s = 325$ °C in complete range of ageing times, what resulted in a distinct decrease of the obtained hardness comparing to refined and modified alloy. To

maintain value of the hardness at least at the level of the alloy without heat treatment, it requires ageing temperature $t_s = 200 - 240$ °C, during 2-8 hours. In turn, reduction of the ageing temperature to the level of 165 °C results in increase of hardness of the alloy practically without any impact of solutioning parameters.

In the Fig. 8 are presented spatial diagrams of the effect of temperature and time of the solutioning and ageing operations on the hardness HB10/1000/30 of the investigated alloy at constant parameters of the ageing treatment ($t_s = 165$ °C and $\tau_s = 5$ hours) for the solutioning operation; and constant parameters of the solutioning ($t_p = 520$ °C and $\tau_p = 1$ hour) for the ageing operation.

Fig. 8. Effect of solutioning and ageing operation parameters on the hardness HB: a) t_p and τ_p , b) t_s and τ_s

The highest hardness HB was obtained for the test pieces solutioned at temperature $t_p = 520-535$ °C, for 30 minutes to 1 hour, cooled in water and aged at temperature $t_s = 165$ °C, during 5 to 8 hours, similarly like in case of the tensile strength R_m .

Temperatures of the ageing treatment above 270 °C have a detrimental effect on change of the hardness HB of the 356.0 alloy, resulting in its decrease comparing to the alloy without the heat treatment. In the Fig. 9 are presented, in form of bar diagrams, obtained values of the hardness for the raw alloy and

the alloy after the heat treatment, of the casting of the yoke of energy network fittings.

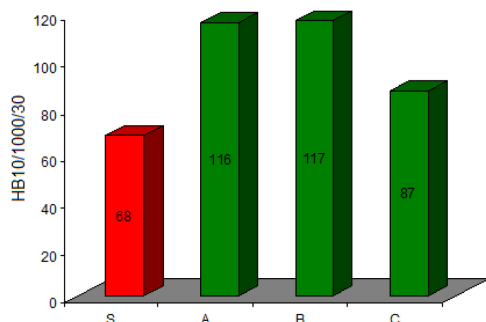


Fig. 9. Hardness HB of material of the casing

Performed heat treatment of the alloy resulted in a significant growth of its tensile strength R_m and hardness HB, while ageing treatment in time of 3 hours enables obtainment of a comparable mechanical properties of the alloy like in case of five hours of the ageing operation.

4. Conclusions

Developed methodology of the research, concerning heat treatment of the casting produced from the LM25 (AlSi7Mg) alloy has enabled determination (selection) of parameters of the solutioning and ageing operation, assuring significant increase of the tensile strength R_m and the hardness HB with simultaneous reduction of time of individual treatments.

Introduction of shortened heat treatment technology will enable substantial reduction of total manufacturing costs (which in connection with standard processes of the heat treatment undergo a significant increase), what in turn should encourage manufacturers of poured machinery parts to take full advantage of potential opportunities offered by the material in range of its mechanical properties.

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