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EXPERIMENTAL RESEARCH ON INCREASING THE DURABILITY OF CAST ATCSi 5 Cu 1 ALLOYS FOR SEA SHIPS THROUGH HEAT TREATMENT

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ABSTRACT

This paper presents an experimental research study on the utilization of complex heat treating on aluminum alloys in order to increase their durability. The practical usage of the studied aluminum alloys (more specifically, silumin type alloys) is envisaged to be in marine industry, where fatigue is very important, especially in corrosive medium. The applied complex heat treating is of tremendous importance and the results can be very good.

Durability means a combination of different characteristics that determine the time period in which a cast part can be used in safe conditions. For a seagoing ship condition, the durability of ATCSi 5 Cu 1 cast parts depends especially on mechanical resistance and corrosive resistance in marine water.

The present work investigates the possibilities offered by different heat-treating techniques in order to increase the overall durability of the seagoing ship parts by increasing the mechanical resistance and reducing the corrosion in sea water.

Thus, we conceived an original methodology of experimental research comprising of an optimum combination of adequate heat treating, static and dynamic tests as well as corrosion tests under pressure in conditions similar to sea water.

KEYWORDS: aluminum alloys, heat treating, durability, intercrystalline corrosion

1. Introduction

Applying thermal treatments to cast aluminum alloys is carried out in order to increase the mechanical strength characteristics or to increase certain physicochemical properties, ideally together. These types of thermal treatments are "quenching solutions" followed by artificial aging. Solution quenching leads to solubilization, dissolution of precipitated phases from the structure to a rigorously determined temperature followed by fast cooling in order to retain the dissolved atoms in the solution and to maintain a certain number of vacant sites in the network in order to increase possibilities of diffusion at low temperatures, thereby obtaining a solid supersaturated solution at room temperature, which is the optimal condition for hardening by precipitation. At the same time, corrosion resistance can be improved by slowing down using a rigorously controlled cooling jacket. For these reasons, it results that the choice of temperature-time cycles for the thermal treatment of artificial aging should be done very carefully depending on the desired purpose 1).

The basic requirements for an aluminum alloy to be thermally treated by solution hardening and artificial aging [1, 2, 4] are those that must allow for solid phase transformations in the equilibrium diagram. These alloys can withstand an order-disordered-hardening reaction.

2. Materials and methods

The ATCSi 5 Cu 1 alloy is a complex siluminous alloy from which pots used in the naval industry can be poured, an alloy that allows the structural hardening phenomenon by suitable heat treatments because magnesium forms intermetallic phases with silicon or aluminum, phases having variable solubility in the solid state of the Al_2Cu type.

The research methodology essentially presents the following steps:

- determination of chemical composition (Table 1);
- making Amsler study specimens (Fig. 1);
- experimentation of various cycles of complex thermal treatments, cycles covering STAS 201 / 2-80 indications.

***Table 1.** Determination of chemical composition*

Type of alloy		**Chemical composition**					**Impurity**	**%**	
	Cu	Si	Mg	Mn	Al	Fe	Zn	Pb	Ni
ATC Si 5 Cu 1									
STAS 201/2- 80	1-1.5	5- 6	0.3-0.6	0.2-0.5	rest	0.8	0.5	0.2	0.3
charge exp.	1.15	5.4	0.32	0.25	rest	0.55	0.2	-	-

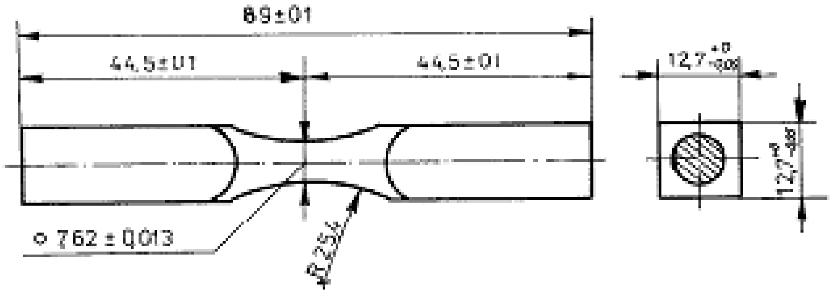

***Fig. 1.** Amsler specimens*

***Fig. 2.** Oval furnace of thermal treatments*

The ATC Si 10 Mg alloy is widely used in the naval industry. The alloy has the potential for structural hardening through the appropriate heat treatments, since magnesium forms intermetallic phases with silicon or aluminum, phases having a solid state variable solubility type Al2Cu.

The research methodology presents the following steps:

- determination of chemical composition (Table 1);
- realization of Amsler study specimens (Fig. 1);
- experimentation of various treatment cycles thermal complexes, indicating cycles data by STAS 201/2 -80 (SREN 1706/2000), (Table 2);
- determination and analysis of the main static and dynamic mechanical properties;
- determination of fatigue strength reduction due to stress corrosion effects (durability to breakage at constant effort).

The research methodology approached made possible the experimental determination of the correctness of the theoretical hypothesis of correlation between mechanical characteristics and susceptibility to stress corrosion developed by Thomas and Nutting, respectively Speidel and Engell [1-4].

Thermal treatments were carried out in oval furnaces of heat treatment (Fig. 2) according to STAS 201/2 -80 (SREN 1706/2000), (Table 2).

The research methodology approached made possible the experimental determination of the rightness of the theoretical assumptions of correlation between mechanical characteristics and susceptibility to stress corrosion developed by Thomas and Nutting [1, 3, 4] respectively Speidel and Engell.

Table 2. *Thermal treatments in oval furnaces*

Type of alloy		**Heat experienced treatments**				
		Burning			Aging	
	Heating temp. ºC	Maintaining time	Cooling med.	Heating temp. ºC	Maintaining time	Cooling med.
ATC Si 5 Cu 1	520 ºC	6 h	water at 90ºC	140, 160, 180	4-12	air

Thermal treatments have been carried out in heat-treated oval heat treatment furnaces (Fig. 2), which provide excellent sealing of the working space as well as different heating speeds due to the highly efficient controller from Euroline Inc.

Tensile strength tests were performed on the Amsler 40ZD 1094-1973 traction test machine.

Tests for fatigue resistance and stress corrosion resistance were performed on a Amsler NPL 434 type machine, a load-carrying machine with a centrifugal care mechanism providing 1500 cycles per minute.

For the stress corrosion study, the Amsler NPL 434 construction bolts were modified to overlap the mechanical stress of the corrosive coating agent (3.5% aqueous NaCl) on similar seawater.

For the mechanical and stress test for stress corrosion or for each thermal treatment cycle, 5 specimens (in the diagrams presented in the paper we use the average obtained values)

3. Experimental results

The tensile strength (R) obtained from the experimental thermal treatment cycles for the ATC Si 5 Cu 1 alloy shows a maximum increase over the casting state of the alloy of 24.80-daN / mm^2 for the thermal treatment cycle containing an artificial aging at 160 ºC for 7 hours (Fig. 3). The average tensile strength obtained from the heat treatment cycles applied (Fig. 3) is superior to the minimum mean value of STAS 20l / 2-80 (R = 22 daN / mm), for thermal treatment cycles that only contain an artificial aging at 160 °C with a residence time of 4-10 hours.

Following the study of the value tables and the graphs of the average variation curves of the static mechanical characteristics, it is found that a complex thermal treatment consisting of hardening and artificial aging at 160 °C with a holding time of 7-8 hours leads to the optimal mechanical properties obtained after treatment for the ATCSi 5 Cu 1 alloy.

Corrosion-resistance durability curves (in 3.5% NaCl solution overlapping a mechanical stress of 14 daN / mm^2) until the experimentally determined test specimens are broken down as:

lg N = f (t), in which:

N - stress cycles up to breakage;

t - the holding time at the constant temperature of artificial aging, hours.

Aluminum alloys that are suitable for plastic deformation are much more researched in terms of physical-mechanical and structural properties due to their predominant use in car body construction.

Casting alloys, of which complex copper, or magnesium alloys, are increasingly being used to cast parts that are required at varying loads, which leads to the need to study their fatigue behavior.

The approach of the experimental researches carried out to determine the fatigue behavior of the alloy studied was also determined in order to study the stress corrosion behavior of the ATC Si Cu Cu alloy in casting or thermally treated after different thermal treatment cycles in the research.

The experimental research methodology of the variation of fatigue strength and stress corrosion, depending on the thermal treatments applied [1], adopted in the frame of the paper consists of:

1. Achievement of Amsler-type specimens (Fig. 1) needed to study the fatigue resistance of stress corrosion and durability to stress corrosion at the mechanical stress of cyclic bending constant;

2. Determination of fatigue resistance Wõhler curves of the studied alloys as well as tempered and artificially aged at 160 °C for 7 hours to study the influence of thermal treatments on the resistance to fatigue.

In the experimental research studies on the variation curves were plotted:

$$\lg 1 = f (1g N)$$

where: lg 1 is the bending fatigue resistance for the symmetrical alternating cycle, daN / mm^2.

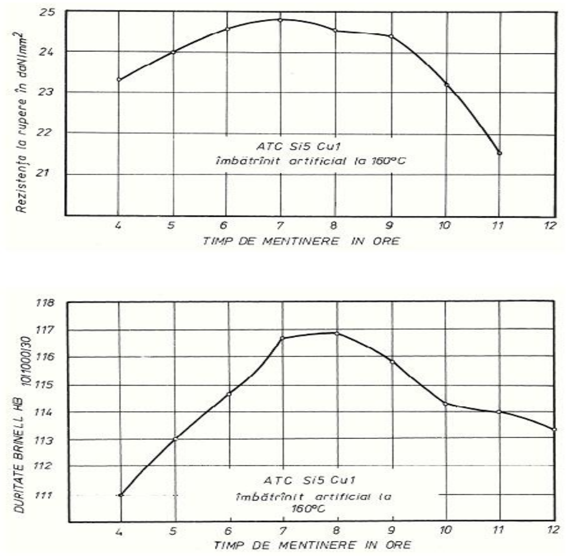

Fig. 3. *Static mechanical tests*

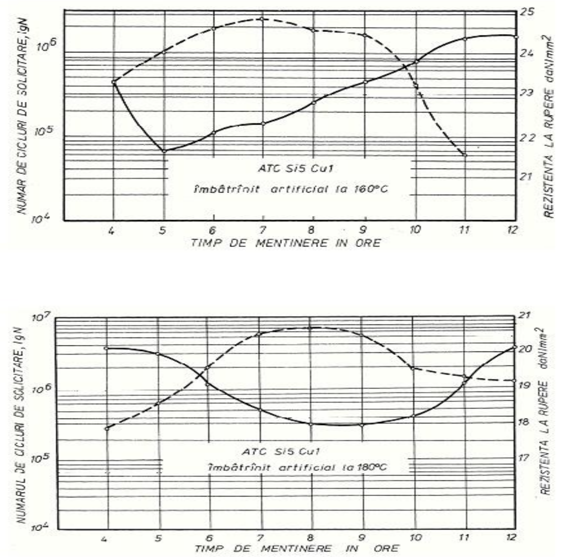

Fig. 4. *Dynamic mechanical tests*

For the determination of Wöhler fatigue curves for cyclic variable and alternating symmetrical bending variables, the classical working methodology was used, taking a number of 14-16 samples for each trace curve.

For the studied alloys, for the determination of fatigue resistance, the number of cycles of stress at 10^8 cycles was limited. Similarly, we also proceeded to determine the resistance to stress corrosion.

In the experiments, we have drawn Wöhler type charts, in semilogarithmic coordinates, for the cast alloy and aged at 160 °C (Fig. 4). At the same time, with the same methodology, we traced the Wöhler stress corrosion resistance curves for the cast alloy and artificially aged at 160 °C and 180 °C (Fig. 4).

These parallel experimental tests were necessary to highlight the influence of corrosive agent overlapping (seawater, 3.5% NaCl solution) the symmetrical bending cycle on the fatigue strength of the alloy, studied in the mold and artificially aged at 160 °C, after pre-setting at 520 °C for 6 hours.

From the study of Wöhler fatigue curves, it can be noticed that in the case of stress corrosion, the fatigue strength limit decreases from 4 daN / mm² to 3.2 daN / mm². For the ATCSi 5 Cast 1 alloy it is noted that by applying complex heat treatment cycles containing aging at 160 °C, cycles that lead to optimal mechanical properties, the fatigue strength increases from 4 daN / mm to 10 daN / mm. Applying stress corrosion to heat-treated alloys reduces fatigue strength, which is still superior to 2 daN / mm² for the studied alloy. It should be noted that the experiments carried out on the live corrosion confirmed the non-asymptomatic aspect of the aliasing of the variation curves at 10^8 load cycles.

For tracing the durability curves to stress corrosion at constant mechanical stress, depending on the time, the heat treatment is maintained for artificial aging, or using sets of 18 specimens, two for each holding time. The specimens used were checked for roughness and ovality.

From the study of the mean points of durability diagram for the ATC Si 5 Cu 1 alloy, it can be observed that the minimum lifetime of corrosion resistance is at a maintenance time of about 6 hours. For this value of the holding time, the maximum durability is represented by the artificially aged specimens (3.3 x ≦ 10〗 ^ 8 stress cycles) at 160 °C (Figure 4).

The variation curves of the corrosion resistance of the alloy studied will be used in the work in correlation with experimentally determined physico-mechanical characteristics.

In conclusion, the experimental determinations have highlighted the fact that the application of complex thermal treatment cycles of structural hardening totally leads to the increase of the fatigue resistance and of the resistance to the corrosion under tension of the studied alloy.

Thermal treatments for structural hardening are therefore a very effective method of reducing the effects of stress corrosion on foundry aluminum alloys while increasing the static and dynamic characteristics of resistance.

From the diagrams of the average values obtained for the ATC Si Cu 1 alloy (Fig. 4) diagram drawn for distinct temperatures of thermal treatment of artificial aging, the following main aspects are important:

In the case of the ATC Si 5 Cu 1 alloy (Fig. 4), the Speidel and Engell hypothesis is verified, the maximum mechanical characteristics being different from the minimum resistance to corrosion under voltage [3, 4]. Only for the artificially aged ATC Sil5 Cu 1 alloy 180 °C, we can consider valid (for experimental mean values) Thomas' hypothesis, too.

From the point of view of the temperature of thermal treatment of artificial aging, it is noted that a thermal treatment of artificial aging at 160 °C (Fig. 3, Fig. 4) leads to the highest values, both in terms of the resistance to traction and resistance to corrosion under voltage.

In conclusion, a complex heat treatment solution, followed by artificial aging (Fig. 4) at 160 °C for 10 hours, simultaneously leads to the maximum tensile strength correlated with a high resistance to corrosion under tension.

4. Conclusions

Based on the research work carried out, the following aspects can be highlighted:

1. The research carried out completes the knowledge of the possibilities of applying thermal treatment cycles to complex cast aluminum alloys;

2. In the field of theoretical and experimental foundation of the influence of the duration of maintenance on the thermal treatment of artificial aging on susceptibility to the corrosion under voltage, the following important conclusions are reached:

- the application of thermal treatments of structural hardening leads to the increase of the mechanical characteristics and the resistance to the corrosion under voltage;

- the theoretical hypothesis elaborated by Speidel and Engell is confirmed in the case of "Corrosion Fatigue" stress corrosion, too;

- resistance to corrosion under stress is minimal when the alloys exhibit a non-homogeneous supersaturated solid structure and begins to increase with the occurrence of separation processes of the precipitation equilibrium;

3. A contribution is the accomplishment, by constructive modifications, of the Amsler NPL-434 type fatigue test machine, to a corrosion-fatigue corrosion test machine;

4. The experimental results obtained confirm the validity of the methods for determining the maintenance time for artificial aging, which gives high resistance to corrosion under voltage;

5. Experimental temperature and maintenance time were determined for heat treatment of artificial aging to provide the physical and mechanical properties or the corrosion resistance desired;

6. The method of research used in the research on the effects of thermal treatments applied to cast aluminum alloys is an original contribution, as it also allows to study the intensity of the main physico-mechanical and structural characteristics;

7. Research on the possibilities of decreasing the effects of stress corrosion by application of thermal treatment cycles has highlighted that this method of reducing corrosion under tension is particularly advantageous since at the same time it is possible to obtain optimal physico-mechanical properties.

The prospects for further research are evident, as similar research can be done on other types of non-ferrous alloys.

References

[1]. Dima Margareta Iulia, *Researchers regarding the improvement of physical and mechanical properties of cast aluminum alloys using heat treatment*, University of Brasov, Ph.D Thesis, 2010.

[2]. Dima Adrian, Dima Margareta Iulia, Minea Alina, *Studies Concerning the Enhancing of the Mechanical Characteristics of the Aluminium Cast Alloys by Heat Treatments*, Buletinul IP Iași, tomul LII (LVI), Fasc.1 Secția SIM, Iași, p. 117-120, 2006.

[3]. Dima Adrian, Minea Alina, Dima Margareta Iulia, *Researches for the Determination of the ATC Si 10Mg Alloy Fatigue Life, Function of Different Applied Thermal Treatment Cycles*, The Annals of “Dunarea de Jos” University of Galati Fascicle IX Metallurgy and Materials Science, p 16-19, nr. 1, 2005.

[4]. Engell H. V., Speidel M. O., *Werkstoffe und Korrosion*, Bd. 81, nr. 45, p. 79-95, Bd. 81, nr. 5, p. 77-83, 118, 120, 122, 1962.