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Influence of Natural Ageing on Impact Strength of the EN AC-AlSi9Cu3(Fe) Alloy

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Abstract

Growing market demand, more and more efficient and cleaner vehicles create a challenge for automotive industry. Properties of aluminum, such as: high strength stiffness to weight ratio, high fluidity and castability, easy machinability and weldability and good corrosion resistance make them ideal candidate to replacement of a heavier materials used in vehicles, and the same, have direct effect on fuel consumption. Comparing to steel, titanium or carbon fibers, aluminum alloys are characterized by low impact strength, which can be improved by a heat treatment. In this study one investigated the effect of the heat treatment (natural ageing) on the EN AC-AlSi9Cu3(Fe) alloy modified with strontium. Solution heat treatment temperature's ranges were selected on the base of heating (melting) curves recorded with use of the thermal derivative analysis (ATD) method. Temperatures of the solution heat treatment were 495 °C, 510 °C, and 525 °C ± 5°C, while the solutioning time ranged from 15 to 105 minutes (15; 60 and 105 min.). Time of the ageing amounted to 1, 3 and 7 days. To determine impact strength of the alloy after performed heat treatment one implemented simplified Charpy test. Maximal values of the impact strength (9,6 J/cm^2) were obtained for solutioning temperature 510 °C and solutioning time 15 minutes, after seven days of ageing. Obtained results enabled determination of solutioning parameters, which allow obtainment of increased impact strength of the investigation alloy for the T4 heat treatment.

Keywords: Aluminum alloy, Natural ageing, Impact strength

1. Introduction

Aluminum alloys are used everywhere low mass and corrosion resistance are required. Due to this, aluminum alloys are especially preferred to replace heavier materials (steel or copper) in a car to respond to weight reduction demand within the automotive industry [1-3]. For example, weight reduction enables the manufacturer to develop the same vehicle performance with a smaller engine, and such smaller engine enables use of a smaller transmission and a smaller fuel tank [4]. A total of about 110 kg of aluminum in vehicle from 1996 is predicted to rise to 250 or 340 kg, with or without taking body panel or structure applications into account, by 2015 [5]. Typical applications of such alloys are poured components like: pistons, cylinder heads, manifolds and transmission, wheels and brackets, brake components, suspension, steering components, among others, etc. [6-9]. Comparing to steel, titanium or carbon fibers, aluminum alloys are characterized by low impact strength, and their usage to components working under dynamic loads require improvement of this property, resulting also from safety aspect in vehicle operation. To a methods allowing considerable improvement of the impact strength belongs a heat treatment [10-12].

The heat treatment of aluminum alloys consists in heating the alloy to relatively high temperature to dissolve Cu- and Mg- rich particles formed during solidification, to achieve a high and homogeneous concentration of the alloying elements in solid solution, cooling down to room temperature, to obtain a supersaturated solid solution of solute atoms and vacancies, and ageing to cause precipitation from the supersaturated solid solution, either at room temperature (natural ageing) or at an elevated temperature (artificial ageing). Various heat treatment cycles, e.g. different combinations of temperatures and times, are used depending on the casting process, the alloy composition and desired mechanical properties [13-15].

The change of time-temperature parameters for precipitation treatment should receive careful consideration, because such parameters have the main effect on obtained mechanical properties. Unfortunately, the cycle required to improve one mechanical property only, such as e.g. tensile strength, is usually different from that required to growth of other properties, such as e.g. elongation. Consequently, the cycles used act as compromises that give the best combination of the properties, i.e. in this case suitable impact strength without e.g. drop of hardness of the alloy.

The present paper focuses on an effect of temperature and duration of solutioning, and time of natural ageing of modified AlSi9Cu3(Fe) foundry alloy on change of its impact strength.

2. Methodology of the research

Hypo-eutectic EN AC-AlSi9Cu3(Fe) alloy, having chemical composition as shown in Table 1, was used to the investigations.

Table 1.
Chemical composition of the investigated alloy

Chemical composition / % mass							
Si	Cu	Zn	Fe	Mg	Mn	Ni	Al
8,5	3,8	0,6	0,65	0,3	0,15	0,3	rest.

Analysis of the chemical composition was performed using an optical emission spectrometry method, with inductively coupled plasma on the PerkinElmer optical emission spectrometer, Optima 4300 Dv model, in the Bosmal R&D Institute in Bielsko-Biala.

Investigated alloy was poured into metal mould destined to production of moulded test pieces to the impact test. The test pieces for the impact strength tests were prepared according to Figure 1.

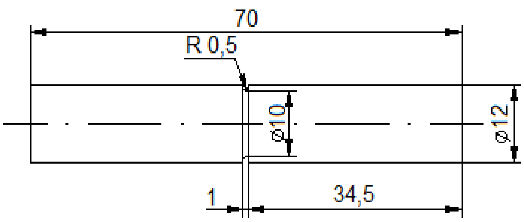

Fig. 1. Test piece to the impact strength test

Impact strength tests were performed on the Charpy pendulum tester.

The heat treatment was performed for the modified alloy (modification treatment with strontium was performed, using AlSr10 master alloy in quantity of 0,4 % of the mass charge). Temperature ranges of solutioning treatment were selected on the base of melting curves from the ATD method (Fig.2).

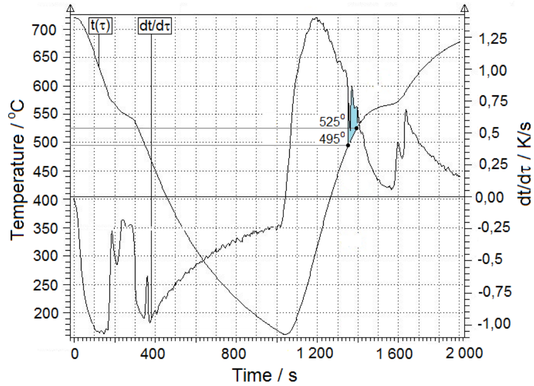

Fig. 2. Curves from the ATD method for melting and crystallization of the investigated alloy

Heat treatment of the investigated alloy was performed on the base of the following parameters:

- solutioning temperature 495, 510 and 525 ^{o}C,
- solutioning time 15, 60 and 105 minutes,
- cooling in water with temperature 20 ^{o}C.
- ageing time 1, 3 and 7 days.

After performed heat treatment, properly prepared test pieces (Fig. 1) underwent simplified impact tests. The test, comparing to normalized impact test, is characterized by more simple and more economic production of the test piece due to its cylindrical shape [16]. In such case, the impact strength is determined as a ratio of the work needed to break the test piece to cross section in area of the notch.

3. Description of the results

Impact strength of initial alloy (refined and modified) amounted from 2,1 to 3,9 J/cm^2. After performed heat treatment of the alloy, obtained impact strength was included within range from 2,1 to 9,6 J/cm^2.

In the Fig. 3-5 are presented obtained values of the impact strength of the investigated alloy after natural ageing during 1, 3 and 7 days.

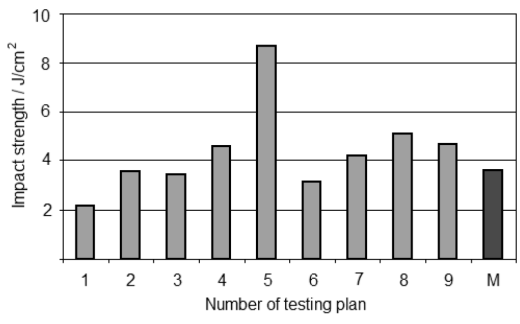

Fig. 3. Impact strength of the investigated alloy after 24 hours of ageing (M - initial alloy prior the heat treatment)

Parameters of solutioning operation for the system of testing plan as presented in the Fig.3-5 are specified in the Table 2.

Table 2.
Parameters of solutioning operation

Number of testing plan	Solutioning temperature, ^oC	Solutioning time, min.
1	495	
2	510	15
3	525	
4	495	
5	510	60
6	525	
7	495	
8	510	105
9	525	

In case of the alloy aged during 24 hours, the highest impact strength (8,4 J/cm^2) was obtained for the system no. 5 (Fig. 3) characterized by solutioning temperature of 510 ^oC and solutioning time of 60 minutes. On the other hand, the lowest impact strength (2,1 J/cm^2) was obtained for the system no. 1 (Fig. 3) characterized by solutioning temperature of 495 ^oC and solutioning time of 15 minutes.

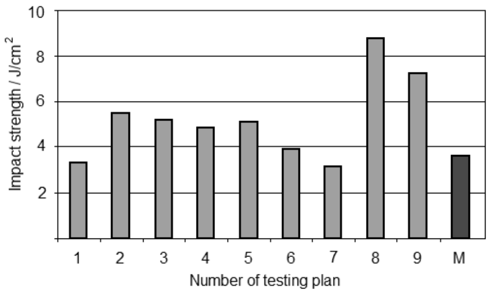

Fig. 4. Impact strength of the investigated alloy after 3 days of ageing (M - initial alloy prior the heat treatment)

After three days of ageing of the investigated alloy, the highest impact strength (8,7 J/cm^2) was obtained for the system no. 8 (Fig 4), which is characterized by solutioning temperature of 510 ^oC and solutioning time of 105 minutes. The lowest impact resistance (3,3 J/cm^2) was obtained for the system no. 7 (Fig. 4), which is characterized by solutioning temperature of 495 ^oC and solutioning time of 15 minutes.

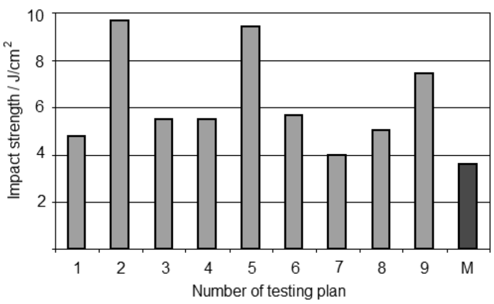

Fig. 5. Impact strength of the investigated alloy after 7 days of ageing (M - initial alloy prior the heat treatment)

The highest impact resistance (9,6 J/cm^2) after seven days of ageing of the investigated alloy was obtained for the system no. 2 (Fig. 5), which is characterized by solutioning temperature of 510 ^oC and solutioning time of 15 minutes. The system no. 5 is characterized by a little bit lower impact strength, for which temperature of solutioning amounted to 510 ^oC while solutioning time amounted to 60 minutes. On the other hand, the lowest impact resistance (3,9 J/cm^2) was obtained for the system no. 7 (Fig. 5) for which temperature of ageing amounted to 495 ^oC with ageing time of 105 minutes.

Comparing obtained impact resistances of the investigated alloy in aspect of time of its ageing, it has been confirmed that 7 days period of time gives the highest growth of the impact resistance.

In the Fig. 6 are presented spatial diagrams of influence of temperature and time of solutioning on the impact strength of the investigated alloy.

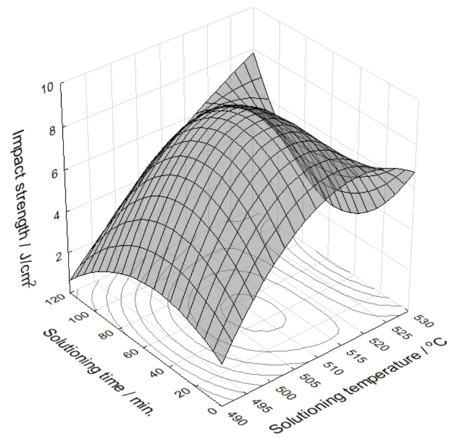

Fig. 6. Influence of temperature and time of the solutioning on the impact strength of the AlSi9Cu3(Fe) alloy

However, there exist such parameters of solutioning treatment, which allow obtainment of a considerable growth of the impact strength of the alloy as early as after 24 hours of ageing (system no. 5 - Fig. 3), where continued ageing results in a slight change of its impact strength (system no. 2 - Fig. 5) amounting to about 1 J/cm^2.

In the Fig 7 are presented structures of refined and modified alloy.

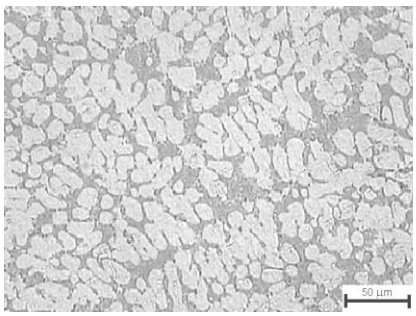

Fig. 7. Microstructure of the EN AC-AlSi9Cu3(Fe) alloy after modification

Performed modification resulted in substantial refinement of dendrites of phase α, and change of morphology of precipitations of silicone (Fig. 7) consisting in transformation of the lamellar eutectics into eutectics of fibrous type.

In the Fig. 8 is presented microstructure of the alloy after 24 hours of ageing in case of the system characterized by the highest impact resistance (Fig. 3 – system no. 5).

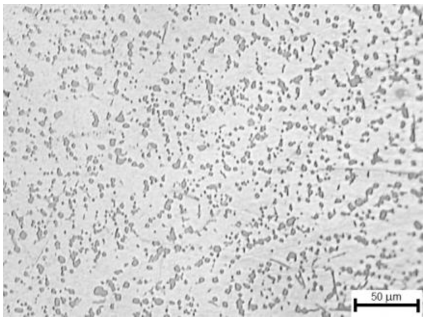

Fig. 8. Microstructure of the investigated alloy after the 24 hours of ageing

Structure of the alloy after performed heat treatment (Fig. 8) is typical of changed morphology of silicone crystals precipitations (their coalescence), which take a form close to a spherical one, what results in more advantageous distribution of stresses in the material, and damping of influence of brittle phase β(Si) acting as internal notches.

4. Conclusions

Performed T4 heat treatment of the AlSi9Cu3(Fe) alloy resulted in a distinct improvement of its impact resistance when suitable parameters of solutioning treatment are used.

Too low temperature of the solutioning (495 ^{o}C) have only a slight effect on improvement of the impact strength of the alloy, which in case of such temperature amounted to from 2,1 to 5,4 J/cm^2.

The highest values of the impact strength were obtained after solutioning in temperature 510 ^{o}C during 15 minutes and ageing during 7 days (9,6 J/cm^2), and after solutioning in temperature 510 ^{o}C during 60 minutes and ageing during 1 day (8,6 J/cm^2), what denotes its triple increase with respect to the initial alloy (before the heat treatment).

On the base of obtained test results one ascertains that solutioning of the alloy in temperature 505-515 ^{o}C during period of 15-60 minutes and seven days ageing enables obtainment of the highest growth of the impact strength.

The impact resistance of the alloy is directly connected with mechanical properties of the alloy, such as tensile strength, yield strength, elongation and hardness among others, and therefore, further studies can concern a relationship between these parameters and the impact strength, what would allow to obtain complete information about the material, basing on performed simplified impact test.

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