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# Effect of Soft Annealing Treatment on Impact Strength and Hardness of the EN AC- $\text{AlSi11}$ Alloy

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## Abstract

The paper presents research on the effects of soft annealing parameters on a change of the impact strength KC and Brinell hardness (HB) of the EN AC- $\text{AlSi11}$  alloy. The research has been performed according to the trivalent testing plan for two input parameters – temperature in the range between 280°C and 370°C and time in the range between 2 and 8 hours. The application of such heat treatment improves the plasticity of the investigated alloy. The improvement of the impact strength KC by 71% and the decrease of the hardness HB by 20% was achieved for the soft annealing treatment conducted at a temperature 370°C for 8 hours, compared to the alloy without the heat treatment. A change of the form of eutectic silicon precipitations which underwent refinement, coagulation and partial rounding, had a direct effect on the hardness HB and impact strength KC. The results obtained were used to prepare space plots enabling the temperature and time for soft annealing treatment to be selected with reference to the obtained impact strength KC and hardness HB of the alloy with the heat treatment.

**Keywords:** Heat treatment, Aluminium alloys, Alpac alloy, Silumins, Soft annealing

## 1. Introduction

The largest group of castings made from non-ferrous metal alloys comprises aluminium alloy castings, including widely used Al-Si alloys (Alpac or Silumins) [1,2]. Aluminium forms an eutectic system with silicon (with 12.6% silicon concentration), with two boundary solid solutions with the solubility of their components decreasing along a temperature drop, based on which the Al-Si alloys are categorized as hypo-eutectic, near-eutectic and hyper-eutectic [3]. The Al-Si alloys, especially of the near-eutectic category, are characterized by very good casting properties, such as good castability, low casting shrinkage [4]. Furthermore, they do not show any susceptibility to hot cracking, which enables producing thin-walled castings with intricate

shapes [5]. That is why they are widely used in the automotive industry, mainly for pistons, transmission housings [6] and clutch housings, cylinder heads in combustion engines [7] and in the shipbuilding industry for engine component castings and shipbuilding fittings [8].

The disadvantage of near-eutectic Al-Si alloys is an irregular acicular or lamellar form of eutectic silicon precipitations [9] which conduce to the propagation of cracks due to external stresses, this has an adverse effect on the mechanical properties, and above all on the plasticity and impact strength of alloy [10].

The morphology of eutectic silicon precipitations can be changed by modifying the EN AC- $\text{AlSi11}$  alloy by e.g., means of  $\text{AlSr10}$  preliminary alloy used for that purpose [11]. Lamellar precipitations of eutectic silicon with the addition of 0.2%  $\text{AlSr10}$

assume a favourable fibrous form, which has a positive effect on the alloy plasticity and impact strength which reaches approximately 22 J/cm<sup>2</sup> [12].

Another popularly used method to improve the mechanical properties of the material is a heat treatment [13] in a broad sense. Soft annealing causes refinement, coagulation and partial rounding of eutectic silicon precipitation edges, which improves the plasticity of near-eutectic Al-Si alloys [14].

The purpose of the investigations performed was to determine the effects of soft annealing parameters on the impact strength KC and hardness HB of the EN AC-ALSi11 alloy.

## 2. Methodology of the investigations

The investigations were performed for the near-eutectic EN AC-ALSi11 alloy with chemical composition given in Table 1.

Table 1.

Chemical composition of the EN AC-ALSi11 alloy

Chemical composition / mass %				
Si	Cu	Zn	Fe	Mg
10.9	0.45	0.19	0.82	0.22
Ni	Mn	Pb	Ti	Al
0.01	0.06	0.05	0.09	rest

Test pieces used to determine the mechanical properties (impact strength KC and hardness HB) were cast in permanent moulds heated to 300°C prior to pouring. Alloy temperature during the pouring was 730°C. In the next step, based on the assumptions adopted, the trivalent fractional testing plan was selected for two input parameters – temperature (T) and time (τ) of the soft annealing treatment – in the Statistica software, DOE (Design of Experiments) module. Based on the adopted testing plan (Table 2), nine variants of heat treatment were performed with test piece air cooling.

Table 2.

Parameters of soft annealing treatment of the EN AC-ALSi11 alloy

Plan variant no.	Parameters of soft annealing treatment	
	Temperature (T), °C	Time (τ), h
1	280	2
2		5
3		8
4	325	2
5		5
6		8
7	370	2
8		5
9		8

The temperature in the furnace chamber was continuously monitored during the heat treatment and maintained within the range of ±5°C from the preset value.

The mechanical properties of the EN AC-ALSi11 alloy were measured after the heat treatment. The impact strength KC was

determined based on the simplified method [15], on the VEB 50J Charpy pendulum machine, using cylindrical test pieces with notch (Fig. 1).

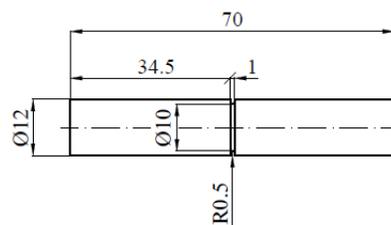


Fig. 1. The test piece used to determine the impact strength KC by means of the simplified method

The hardness HB was measured using the Brinell method on the PRL 82 hardness tester (steel ball with diameter φ10 mm, under the load of 4903 N applied for 30 seconds).

The photos of investigated alloy microstructures were taken using the Neophot-32 optical microscope.

## 3. Description of obtained results

The impact strength KC values obtained for successive testing plan variants (Table 2) in comparison with the alloy without the heat treatment (W) are presented in Figure 2.

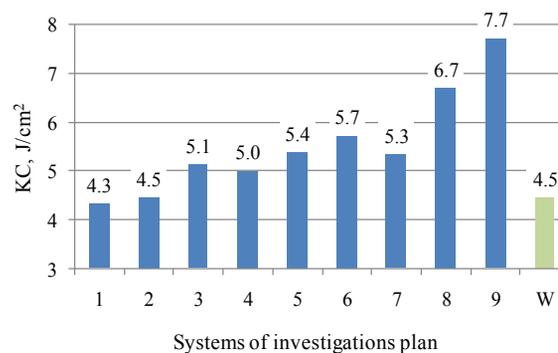


Fig. 2. Impact strength KC after the soft annealing treatment of the EN AC-ALSi11 alloy

Based on the impact strength results obtained, a space plot was prepared in Statistica showing the effects of temperature (T) and time (τ) on a change of the impact strength KC of the investigated alloy (Fig. 3).

The effects of soft annealing parameters on the impact strength KC of the investigated alloy, based on the statistical analysis performed, can be described by a mathematical relation in the form of a quadratic polynomial (1), for which the coefficient of determination is: R<sup>2</sup>=0.97 (for α=0.05).

$$KC = 14.57121 - 0.07005 \cdot T + 0.00012 \cdot T^2 - 0.75962 \cdot \tau + 0.00314 \cdot \tau^2 + 0.00291 \cdot T \cdot \tau, \text{ J/cm}^2 \quad (1)$$

For example  $KC = 5,5 \text{ J/cm}^2$  (for  $T = 325^\circ\text{C}$ ,  $\tau = 5\text{h}$ )

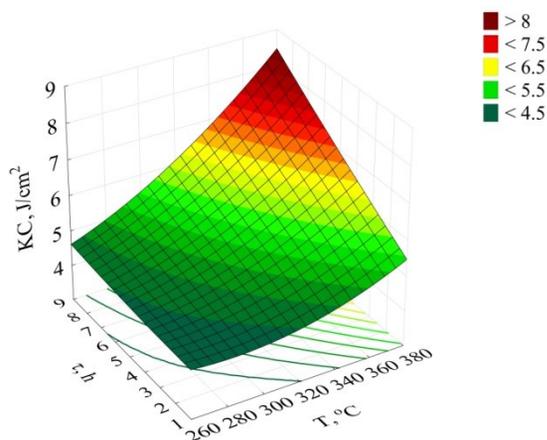


Fig. 3. The effect of soft annealing treatment temperature and time on the impact strength KC of the EN AC-ALSi11 alloy

Soft annealing also resulted in the changed hardness HB of the investigated alloy. The results obtained for the individual testing plan variants (Table 2) with regard to the alloy without the heat treatment (W) are presented in Figure 4.

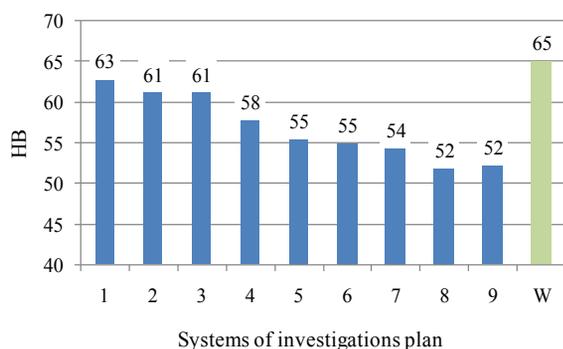


Fig. 4. Hardness HB after the soft annealing treatment of the EN AC-ALSi11 alloy

As in case of the impact strength KC, a plot (Fig. 5) was prepared to illustrate the effect of soft annealing temperature (T) and time ( $\tau$ ) on the hardness HB value of the investigated alloy.

An equation (2) characterizing a change of the hardness HB in relation to the heat treatment parameters adopted was also determined. Coefficient of determination:  $R^2=0.99$  (for  $\alpha=0.05$ ).

$$HB = 151,28452 - 0,46672 \cdot T + 0,00057 \cdot T^2 - 1,23843 \cdot \tau + 0,11481 \cdot \tau^2 - 0,00083 \cdot T \cdot \tau \quad (2)$$

For example  $HB = 55$  (for  $T = 325^\circ\text{C}$ ,  $\tau = 5\text{h}$ )

The heat treatment applied resulted in the change of the investigated alloy microstructure. Figure 6 shows the microstructures of the alloy without the heat treatment and the alloy after soft annealing performed according to the variant 9 ( $T = 370^\circ\text{C}$ ,  $\tau = 8\text{h}$ ).

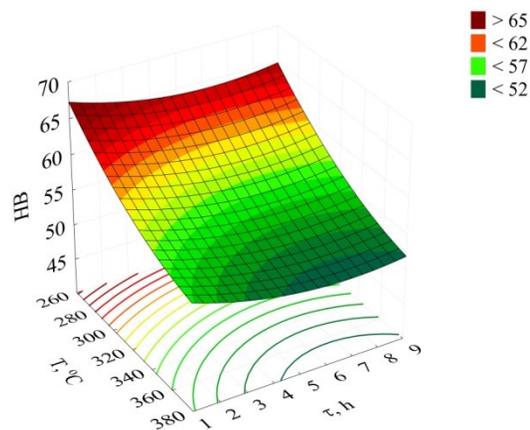


Fig. 5. The effect of soft annealing treatment temperature and time on the hardness HB of the EN AC-ALSi11 alloy

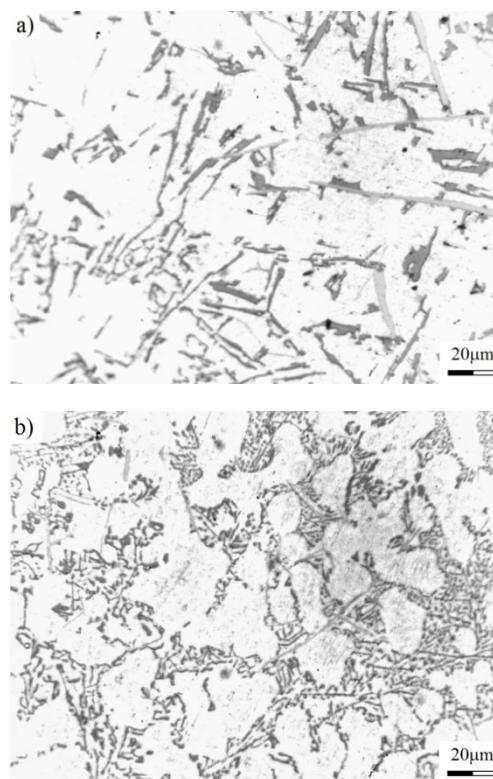


Fig. 6. EN AC-ALSi11 alloy microstructures: a) initial alloy, b) alloy after soft annealing treatment performed according to the variant 9

For the initial alloy (Fig. 6a), large eutectic silicon precipitations in the form of irregular lamellas with sharp edges and sparse precipitations of primary silicon are visible against the  $\alpha$  phase background.

Next Figure (Fig. 6b) shows the microstructure of the investigated alloy after soft annealing performed under conditions of temperature  $T = 370^\circ\text{C}$  and time  $\tau = 8\text{h}$ , which resulted in the maximum increase of impact strength KC. In comparison with the

alloy without the heat treatment, the form of eutectic silicon precipitations underwent a considerable change consisting in its refinement, coagulation and partial rounding of edges.

Increase of the impact strength KC for the investigated alloy after performed soft annealing treatment is caused by the changes in the form of eutectic silicon. Silicon precipitations in lamellar form (Fig. 6a) conduce to propagation of cracks due to external stresses (micro-notch effect) while refinement and partial rounding of the form (Fig. 6b) eliminates this disadvantage.

## 4. Conclusions

Obtained results of the investigations of the EN AC- $\text{AlSi11}$  alloy subjected to the soft annealing treatment confirmed considerable improvement of the impact strength KC and the decrease of its hardness HB in comparison with the alloy without the heat treatment.

The maximum increase in the impact strength KC by 71% and decrease in the hardness HB by 20% versus the initial alloy were obtained after the soft annealing performed at 370°C for 8 hours.

The change of the form of eutectic silicon precipitations had the main effect on the properties obtained after the annealing.

The coefficients of determination obtained for the equations (1) and (2) are close to 1, thereby confirming that mathematical relations sufficiently describe the effect of soft annealing parameters on the change of the impact strength KC and hardness HB.

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