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Heuristic Model of the Mechanical Properties of a Hypoeutectic EN AC-42100 (EN AC-AlSi7Mg0.3) Silumin Alloy Subjected to Heat Treatment

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Abstract

The object of the experimental studies was to determine the mechanical properties of a hypoeutectic EN AC - 42100 (EN AC-AlSi7Mg0,3) silumin alloy, where the said properties are changing as a result of subjecting the samples of different types to solution treatment. An important aspect of the studies was the use type of device for the heat treatment. As a basic parameter representing the mechanical properties, the tensile strength of the metal (Rm) was adopted.

Keywords: Application of information technology to the foundry industry, Mechanical properties silumin alloy, Heat treatment, Fuzzy logic, Artificial intelligence

1. Introduction

For many years, forced cooling processes have been applied as a means to promote heat treatment conducted during the manufacture of cast parts. The solution treatment alone (hardening) and possibly the additional aging enable shaping in a wide range of values the required performance characteristics of castings.

Apart from a few cases - such as a tendency of cast iron to the formation of hard spots or warping of parts with varying wall thickness - accelerated cooling during casting solidification has usually a beneficial effect on the quality obtained [1]. This is due to the increased degree of supersaturation of the solid solution present in an alloy, the refinement of microstructural constituents (so-called undercooling modification), and reduced level of gas porosity.

Immersion cooling is said to belong to the group of the fundamental heat treatment processes of aluminium alloys associated with conditions T4 (solution treatment) and T6 (solution treatment + aging). However, today, other methods of cooling also find application, e.g. those related with the use of a jet technique (in micro- or macroscale, including ablation [2]) , the liquid spray (including water mist) [3], etc.

According to PN-76/H-01200 (Heat treatment of metals. Terms and definitions), the following types of cooling in solution treatment (hardening) are distinguished:

- immersion cooling - cooling by immersion of the product in a liquid medium;

- spray cooling - cooling by spraying coolant onto the surface of the product.

Generally, the microjet modules can operate with the cooling media in both liquid and gaseous form.

The investigation of the available reference patents and publications indicates that neither in Poland nor in the foreign countries, the microjet technology has been or is used in foundries. Various methods of jet (macroscale) and forced air cooling of the heated surface of metals in the solid state are applicable.

2. The microjet device

In cooperation with the Swiss NOVALTEC SARL company, a cooling module was designed (Figure 1). It uses a highly advanced microjet technique, whose main advantage - compared to traditional cooling methods – is a marked increase (up to 10 fold) in the heat transfer process.

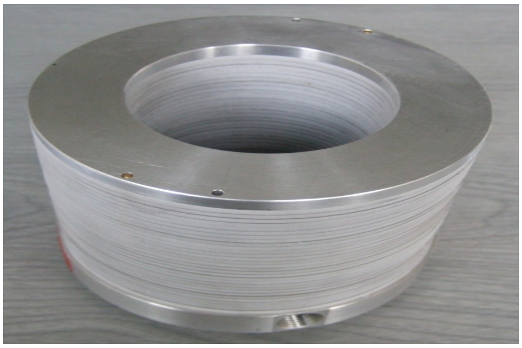

Fig. 1. General view of microjet module

Based on the microjet unit, a prototype work stand was designed. Its basic elements and components in the initial version are shown in Figure 2.

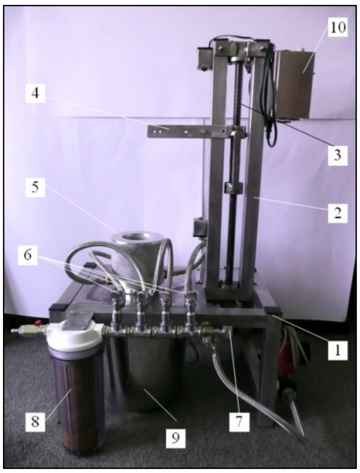

Fig. 2. General view of the stand in its initial version: 1 – base; 2 – guide; 3 – drive screw; 4 – mould holder; 5 – microjet module; 6 – control valves; 7 – shut-off valve; 8 – filter; 9 – tank for liquid; 10 – control box

The designed and constructed stand is used in the Foundry Research Institute in Cracow for the heat treatment (solution treatment) of aluminium bronze samples and for the directional cooling of aluminium alloys in the ceramic test moulds (cylindrical or conical shape).

3. Experimental studies and module design

In this particular case, samples were tested in several conditions of the heat treatment, the symbols of which are given in Table 1.

Table 1.
Types of samples examined

F – as-cast;
P – solution treatment in water (the temperature of ~20^{o}C) by immersion, after solution treatment: 530[^{o}C]; 2 [h];
M - solution treatment using microjet water cooling (the temperature of ~20[^{o}C]), after solution treatment: 530[^{o}C]; 2[h];
S1 – aging at a temperature of 155 [^{o}C] for 10 [h];
S2 - aging at a temperature of 175 [^{o}C] for 8 [h];
S3 - aging at a temperature of 205 [^{o}C] for 6 [h];

The aim of the experiments was to determine which of these technological processes has the greatest positive impact on the values of the examined metal parameters and how to choose the treatment regime to get the metal with the required properties. Laboratory tests were conducted. Some of the results obtained during those tests are presented in Table 2.

The results were used to build a model, whose task was to show a relationship between the heat treatment conditions and the values of the investigated metal parameters. The model is intended to facilitate the selection of the heat treatment conditions that will enable producing metal with the required properties.

The number of the tested samples was significantly restricted by the cost of their manufacture and performance of the required laboratory measurements. The use of well-known statistical methods or other formal methods describing the relationship between physical quantities was in this case impossible, due to the small amount of available results. Under these conditions, it was decided to construct a heuristic model [4,5] based on the use of fuzzy logic [6], in which the relationships between the properties of metal and the types of heat treatment would be represented by a set of fuzzy rules. The model input quantities are variants of the investigated alloy heat treatment. Outputs determine the value of the selected mechanical property of the alloy. Using the constructed model, a simulation (in a simplified version) was carried out for all the measured parameters using MATLAB packet; a three-dimensional visualisation was also performed to reveal relationships between the selected solution treatment parameters. The purpose of this visualisation was to extract the most favourable variants of the alloy treatment and identify the possible function extrema (the maximum values of the examined parameters)

Table 1.
Examples of the test results

No	Design ation of sample condition	Sample designation	R_m, [MPa]		$R_{p0.2}$, [MPa]		A, [%]		Z, [%]	
			Individual measure-ments	Mean value	Individual measure-ments	Mean value	Individual measurements	Mean value	Individual measure-ments	Mean value
1.	**F**	1.0.1	180	**182**	118	**117**	5,3	**6,2**	6,4	**6,8**
		1.0.2	183		114		7,1		9,8	
		1.0.3	182		122		6,2		4,8	
		1.0.4	183		115		6,3		6,3	
2.	**F + S1**	1.1.1	203	**197**	141	**135**	3,6	**3,2**	4,0	**3,6**
		1.1.2	191		130		2,8		3,2	
3.	**F + S2**	1.2.1	pz*)	**182**	pz*)	**173**	pz*)	**2,0**	pz*)	**2,0**
		1.2.2	182		173		2,0		2,0	
4.	**F + S3**	1.3.1	216	**212**	156	**145**	5,8	**5,6**	3,3	**2,2**

An important step in creating the model is to define a membership function characterising the magnitude of the input quantities. In the case under consideration, the following interpretation of each model input was adopted:

The ranges of membership function for the input *no solution treatment*:
Range 180 -216 [°C]
Membership function no aging 180-182-183
Membership function aging S1 191-195-203
Membership function aging s2 182-182-182
Membership function aging S3 208-212-216

The ranges of membership function for the input *standard solution treatment*:
Range: 209-290 [°C]
Membership function no aging 209-224-238
Membership function aging S1 243-248-270
Membership function aging s2 254-273-290
Membership function aging S3 233-240-245

The ranges of membership function for the input *modified solution treatment*:
Range: 232-282 [°C]
Membership function no aging 232-234-241
Membership function aging S1 242-252-254
Membership function aging s2 280-281-282
Membership function aging S3 233-238-240

A graphical interpretation of thus defined module is presented in Figure 3.

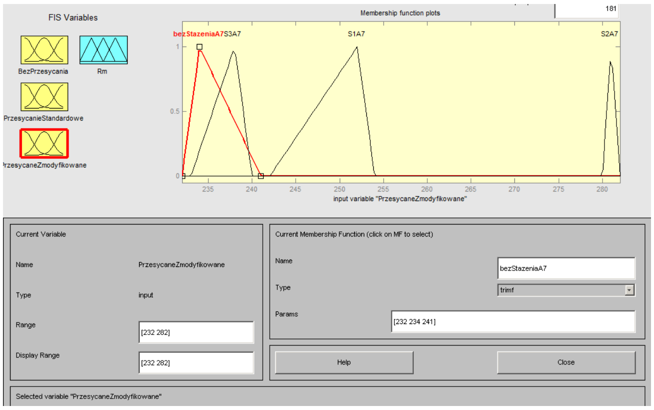

Fig. 3. Membership functions for samples treated with the use of Microjet

The character of membership function for the output Rm is determined by the following quantities (graphical interpretation is shown in Figure 4):
Range 180-220 [MPa]:
Membership function small 180-185
Membership function medium 183-190-200
Membership function large 192 -210-220

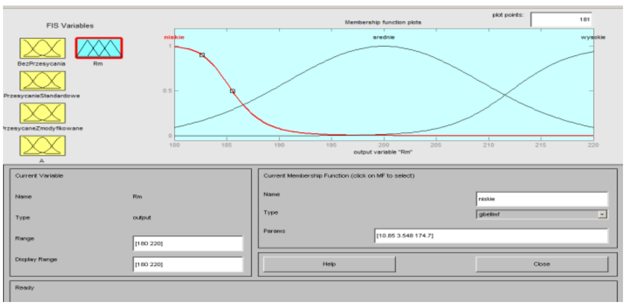

Fig. 4. The output quantity Rm

Full picture of the relationships between input and output data is obtained when all the rules are introduced into the inference system, which determines the degree of membership of output variables in the highlighted areas. These rules are based on the expert knowledge of the expected result which will be achieved for an output parameter and on the analysis of the measurement data. It should be noted that at the output of the model, the examined parameters occur in a fuzzy form, and therefore, to obtain their numerical values, the operation of defuzzification must be carried out. In MatLab system, this operation is performed by setting the so-called centre of gravity of the solid obtained after adding the appropriate degrees of membership.

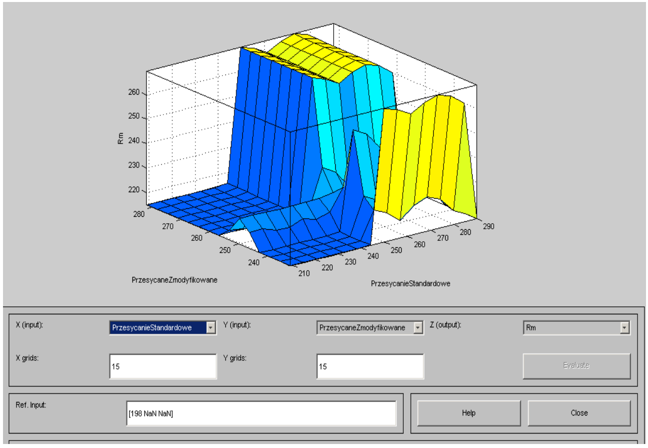

Fig. 5. Relationship between the tensile strength Rm and heat treatment variants

The most clear form of representation of the results obtained from a fuzzy model are graphs in 3D space illustrating the relationships between the three selected parameters. A chart depicting the relationship between Rm and the common heat treatment process vs microjet is shown in Figure 5.

4. Conclusions

The mechanical properties of hypoeutectic AlSi7Mg0,3 silumin measured in a tensile test (Rm) largely depend on the application of solution treatment. The microjet treatment has a positive effect on these properties, but this effect depends on parameters such as the temperature and time of aging in variants S1, S2 or S3. The best mechanical properties were obtained with the application of artificial aging of the S2 type, i.e. 175°C, 8 h. Slightly worse performance (although also maintained at a high level) corresponds to the artificial aging of S1 type, i.e. 155°C, 10 h. The lowest level of Rm was recorded in the case of artificial aging of the S3 type (205oC, 6 h), i.e. the highest temperature and the shortest heating time. The microjet cooling has proved to be the most beneficial for the F and M + S2 states, in other cases the immersion cooling combined with solution treatment has yielded better results.

These conclusions were formulated using a heuristic model of heat treatment (based on the use of fuzzy logic), with verification of the results based on experts' knowledge.

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