ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.2478/afe-2013-0040
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
ISSN (2299-2944)
Volume 13
Issue 2/2013
75–79

Study of the BA1044 Alloy Properties and Their Interpretation with the Use of Fuzzy Logic

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Received 23.04.2013; accepted in revised form 07.05.2013

Abstract

The study presents the results of research aimed at the construction of a model of the relationship between the physical properties of metal and the types of toughening treatment and modifiers used in the modification of BA1044 alloy.
Samples of melts were subjected to four variants of the heat treatment and to five types of modification. Studies of the samples consisted in measurements of five physical parameters. Consequently, it was necessary to seek a relationship between the nine input parameters and five output parameters. With this number of the variables and a limited number of samples, searching for the relationships by way of statistical methods was obviously impossible, so it was decided to create an approximate model through the use of fuzzy logic. This study describes the process of creating a model and presents the results of some simulation experiments that confirm the validity of the correct approach.

Keywords: Modification, Heat treatment, Ccopper alloy, Artificial intelligence, Fuzzy logic, Simulation studies

1. Introduction

Within the framework of long-lasting research of cast aluminium bronzes, recently the effect of heat treatment of BA1044 alloy modified with calcium carbide and C + Ca additives has been studied.

With large number of the variables and a limited number of samples - search for the relationships and creating an approximate model becomes nearly impossible.

2. Description of experiment

The aim of the study was to create a model of relationship between the properties of metal and the type of heat treatment and modification, mainly to determine which one of these processes has the most significant impact on the examined mechanical properties.

The results of the investigations were collected on 72 samples cast from the BA1044 alloy. Samples were designated in the following way:

1(L) sample without modification
2(M) modification with CaC
3 (N) modification with CaC_2
4 (P) modification with Ti+Ca
5 (S) modification with Zr+B
6 (T) modification with mischmetal

It has been assumed that the samples can be divided into 6 different types. Additional division is in respect of the heat treatment type, and here the following variants can be distinguished:

- as-cast state,
- quenching with the use of microjet,
- quenching with the use of microjet and tempering at 700°C,
- quenching with the use of microjet and tempering at 350°C.

For each sample type, at least two tests were performed. Table 1 shows the results obtained for samples 2 (M), 3 (N), 4 (R), 5 (S), 6 (T). The type of the heat treatment has been marked with numbers. Number 1 denotes quenching and tempering at 700 degrees, number 2 denotes quenching and tempering at 350 degrees, number 3 denotes quenching, and number 4 denotes as-cast state of the sample (without heat treatment)

Table 1.
Comparison of selected experimental results

Sample no	Heat treatment type	$R_{p0,2}$ MPa	R_m MPa	A %	Z %	Hardness Measurement 1	Hardness Measurement 2	Hardness Measurement 3
2	1	420	765	16,9	15,8	214	214	214
2	1	368	747	16,4	15,4	210	214	223
2	2	620	884	2,6	2,4	285	299	299
2	2	700	930	3	1,2	334	340	316
2	2	685	856	1,8	2	320	300	328
2	3	556	822	3,4	5,1	249	248	249
2	3	540	826	3	3,6	270	271	290
2	3	400	754	15,8	15	211	211	211
2	4	321	658	9,9	8,2	208	205	201
2	4	316	616	7,7	7,4	200	199	205
2	4	304	646	9,7	9,4	196	195	204

2. Fuzzy inference rules

To build a model, fuzzy inference was used. Simulation and visualisation of the results was carried out in a Matlab programme. This article depicts the existing relationships only for the $R_{p0.2}$, and A% parameters and for the modification with Ca + C and CaC_2.

The fuzzy reasoning mainly consists in the use of an implication in which both the premises and the conclusion are represented in the form of fuzzy sets.

Fuzzy implication is stored in the form of rules:

IF [(x1 is A1) AND (x2 is A2) ...... AND (xn is An)] THEN (y is B)

where:

x1 ... xn - premises attached to the corresponding fuzzy sets A1 ... An;

y - conclusion attributed to the fuzzy set B.

The operation of the assignment of variables (expressed numerically or linguistically) to fuzzy sets is called fuzzification or blurring.

On the other hand, the conclusion of a rule is usually subjected to a reverse operation, i.e. defuzzification or sharpening, which consists in assigning to it a numerical value (or a word).

It should be noted that in fuzzy rules, the quantities difficult to measure (or non-measurable) are expressed in a linguistic form (e.g. large, small, high, low, etc.).

A set of fuzzy rules describing a model of the process makes a fuzzy knowledge base.

Reasoning in the fuzzy knowledge base is the same as in a classic expert system; what is characteristic is the technique of the composition of rules.

The input variables were defined with a conventional measure determining the presence or absence of the heat treatment process or metal modification. This is a typical case where the nature of the considered variables makes assigning to them the individual numerical values (or ranges of values) impossible. Therefore, the determination of the specific areas of parameter changes and of the corresponding fuzzy sets is based on the use of linguistic variables.

The input and output data were related with the use of fuzzy rules, built on the data derived from measurements taken on the samples on which the experiment was conducted. In a model described here, only the values of $R_{p0.2}$ and A were included.

3. Methodology for inference module construction

Below some rules are presented for the construction of a fuzzy model to determine the application of a heat treatment and modification for an improvement of the material parameters (BA1044 alloy).

The design and implementation of a module based on the use of fuzzy logic involves the following steps, which combined together form the proposed methodology of the module construction:

1. Selecting input and output variables, which are the premises and conclusions of the rules, respectively;
2. Determining rules for the fuzzification of these variables, i.e. defining fuzzy sets representing the respective quantities, including:
— selection of a number and name of the fuzzy set characteristic of a given variable;
— assignment of a corresponding membership function describing each of the featured sets.
3. Determining the conclusion of inference rules, i.e. defining fuzzy sets representing the output variable, namely:
— selection of a number and name of the set,
— assignment of a corresponding membership function.
4. Using the results described under items 1,2,3, construction of decision rules corresponding to a specific technological situation.
5. Defining defuzzification procedures, i.e. determining the outcome of reasoning (in a numerical or linguistic form).

The input and output variables are connected by the rules. These rules represent the effect of modification and heat treatment on the obtained values of the A% and Rp0.2 parameters. Rules were constructed on the basis of experimental results presented on figure 1.

If modification Ca+C and heatTreatmentwithoutheatTreatment then A% medium
If modification Ca+C and heatTreatmentquenching then $Rp_{0,2}$ *medium*
If modification Ca+C heatTreatmenttempering350 then A% veryLow
If modification CaC_2 *heatTreatmentwithoutheatTreatment then A%low*
If modification CaC_2 *heatTreatmenttempering700 then* $Rp_{0,2}$ *low*
If modification CaC_2 *heatTreatmenttempering700 then A% medium*

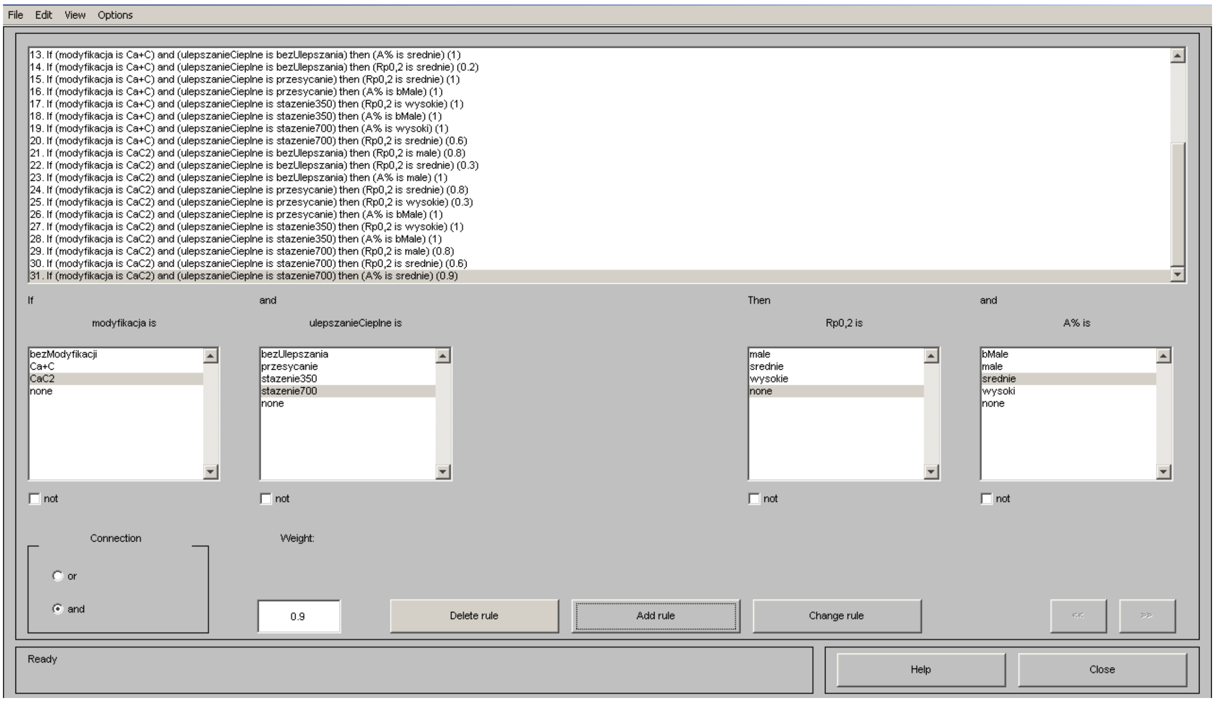

Fig. 1. Sample dialogue window of an inference system

To investigate the quality of modelled relationships, the MATLAB package offers the possibility to generate a three-dimensional visualisation, illustrating the dependence of the examined parameter on the two selected technological treatments, taken as input variables.

The shape of the visualisation depends on the defined membership functions and rules applied, which determine mutual relationships between given quantities with other process parameters kept stable. A form of visualisation is presented in Figure 2 for the parameter A%, which assumes different values treated as an input variable, depending on whether the sample is subjected to modification or heat treatment.

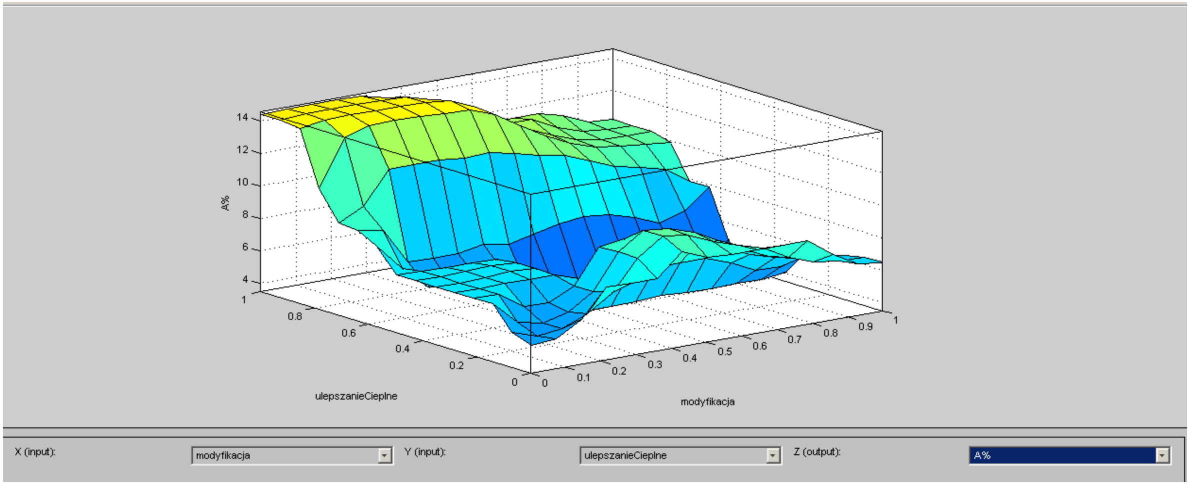

Fig. 2. Parameter A%

The purpose of the visualisation is finding maximum values of the parameter A% in relation to the other two quantities.

For quenching and tempering, the Gaussian-shaped membership function is operating in the ranges showing the actual state of the sample. The following ranges are for the highest values of the function:

- without heat treatment from 0 to 0.3;
- quenching from 0.3 to 0.55,
- tempering at 350 from 0.55 to 0.75;
- tempering at 700 the membership function from 0.75 to 1.

For the modification parameter there are three ranges of the Gaussian-shaped function, reflecting the actual state of the sample:

- without modification (function value from 0 to 0.3),
- modification with Ca + C (function value from 0.1 to 1),
- modification with CaC_2 (function value from 0.6 to 0.9).

For the parameter A%, four Gaussian-shaped membership functions have been selected. Below the ranges are given within which these functions assume the highest values:

- very small (membership function from 1 to 5);
- small (membership function from 5 to 9);
- medium (membership function from 9 to 13);
- high (membership function from 13 to 16).

Taking into consideration the values that the parameter A% can adopt, as well as the application of heat treatment and modification, after analysis of the graph in Figure 3, of interest seem to be the following extrema:

— the first extremum is marked in yellow. In the case of this graph it represents parameter A% "high", while for other parameters is pointing out to the area “modification”/“withoutModification” and “heat treatment” "tempering700". This maximum can be interpreted as high values of A% (i.e. within the range from 13 to 16), obtained in the BA1044 sample which has not been modified, but subjected to a heat treatment in the form of quenching and tempering at 700°C,

– the second interesting extremum is marked in green. It corresponds to the area where the parameter A% is still referred to as "high" (i.e. within the range from 13 to 16), while the parameter “modification” assumes the value of "CaC_2", and the parameter “heat treatment” assumes the value of "tempering 700". This means that the parameter A% has assumed the values defined as high in samples which have undergone modification with CaC_2 and heat treatment in the form of quenching and tempering at a temperature of 700°C,

– one more interesting area is marked in light blue. It is the parameter A% assuming “medium” values and heat treatment "without heat treatment", while modification is done with "Ca + C". This is the situation in which the parameter A% is determined as medium (i.e. within the range from 9 to 13) and the sample has not been subjected to heat treatment only to modification with Ca + C.

4. Conclusion

The, outlined in this study, procedure for constructing an approximate model of complex physical processes using fuzzy logic can be applied to other processes, for which the amount of available information (experimental results) is very limited, and at the same time creating an accurate mathematical description is not possible.

The results of simulation experiments lead to the conclusion that the proposed approach can be used as an aid by process engineers in selecting an appropriate variant of metal heat treatment, allowing for the specific requirements concerning physical properties of this metal.

Acknowledgements

Study financed from the science budget as an own Research Project No. N-N507 5940038

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