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Application of neural networks to classification of internal damages in steels working in creep service

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Methodology of research

ABSTRACT

Purpose: The goal of the paper is the presentation of computer assisted method for analysis of the metallographic images obtained in the scanning electron microscope (SEM) from the low alloyed steel 13CrMo4-5 elements in different states of internal damages after long time creep service.
Design/methodology/approach: Investigations of the structure and morphology of internal damages resulting from creep were made by the use of light microscope and scanning electron microscope. Their topography were observed by the use of confocal laser scanning microscope. There was proposed a method based on analysis of images, shape coefficients and neural networks as a tool to evaluate the internal damage classes of materials used for the high-pressure installations elements working in creep conditions.
Findings: The better efficiency of class recognition of damages developed in the material can be achieved as a combining of several methods making use of the image analysis, shape coefficients, and neural networks.
Practical implications: The presented method can be use in industrial practice for evaluation and qualification of creep-damage of power station boiler components operating in creep regime (e.g., steam boilers, chambers, pipelines, and others).
Originality/value: Applying of the artificial intelligence method for the classification of internal damage in the steel during creep service.
Keywords: Images analysis, Neural networks; Steels

1. Introduction

Low alloyed steels are from many years used in powder industry as constructional elements of installation long-time working in creep conditions. High costs of installations, increase of working parameters, efficiency and reliability cause intensification in the area of modernization, diagnostic and durability extension of devices and their elements[1-5].

Metallographic structure from light microscope, scanning electron microscope and confocal laser scanning microscope are the base of information about material's structure, properties and processes proceeding in the material. So the method of determining of materials' usability to further exploatation on the base of material's structure is purposeful.

To increase efficiency of researching works numerical, mathematical and statistical methods are used. There was shown that artificial intelligent methods like expert systems, neural networks, fuzzy logic, genetic algorithm give better results than classical modelling. The special attention is devoted to integrated models including few modern tools and different hybrid systems being their compilation [6-11].

The development in artificial neural networks in last years gives effective and universal tool which is more often used in materials science. The widely use of neural network comes from possibility of approximation of nonlinear transformation, parallel information processing, ability to learn and adaptation. Advantages of neural networks result on their more commonly use in solving many different and difficult tasks. Neural networks are tools which among the other allows to associate and analyse data, prediction, signal filtration, optimisation, image classification or integrate all previous stages of preliminary digital image processing[12-17].

Computer assisted method allowing the automatic classification of internal damages of power station boiler components operating in creep regime (e.g., steam boilers, chambers, pipelines, and others) is presented. Application of this system in practice gives better efficiency of class recognition, automation of the process and allows to eliminate errors in forecasting of residual durability of installation working in creep service.

2. Material

Material for investigation was acquired from chambers and collectors of the pressure part as well as from the main and crossover steam pipelines of the power station boilers operating in creep service. Elements were made from the 13CrMo4-5 steel and their working conditions were as follows: operating temperature 520-560°C, real stress 35-120MPa, working time 60000-250000h. The chemical composition of this steel is shown in Table 1.

Table 1.
Chemical composition of 13CrMo4-5 steel (PN-EN 10028-2:2005)

Mass chemical composition [wt.%]							
C	Mg	Si	P	S	Cr	Mo	Al
0,08-0,18	0,40-1,00	<0,35	<0,03	<0,0025	0,70-1,15	0,40-0,55	<0,04

Investigations of the structure and morphology of internal damages of elements working in creep condition, were made on light microscope Leica MEF4A (Fig.1) and scanning electron microscope SUPRA25 Zeiss (Fig. 2). Analysis of damages topography was made on confocal laser scanning microscope LSM 5 Pascal Zeiss. There was determined the geometry of damages, calculated the volume and area of damaged surface (Fig. 3).

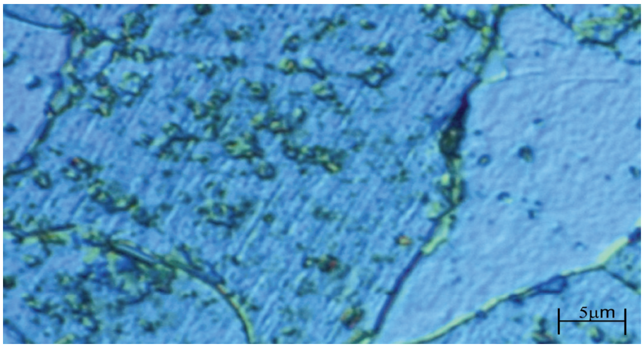

Fig. 1. Structure with internal damages of 13CrMo4-5 steel(LM)

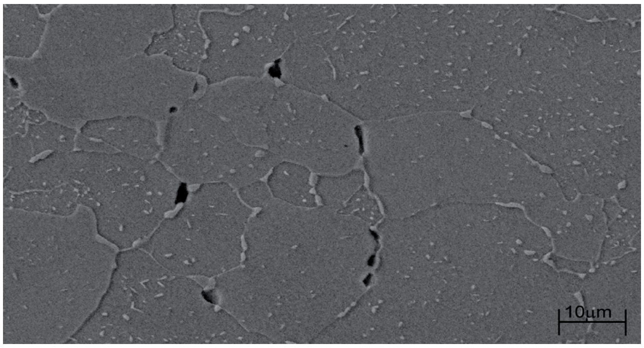

Fig. 2. Structure with internal damages of 13CrMo4-5 steel(SEM)

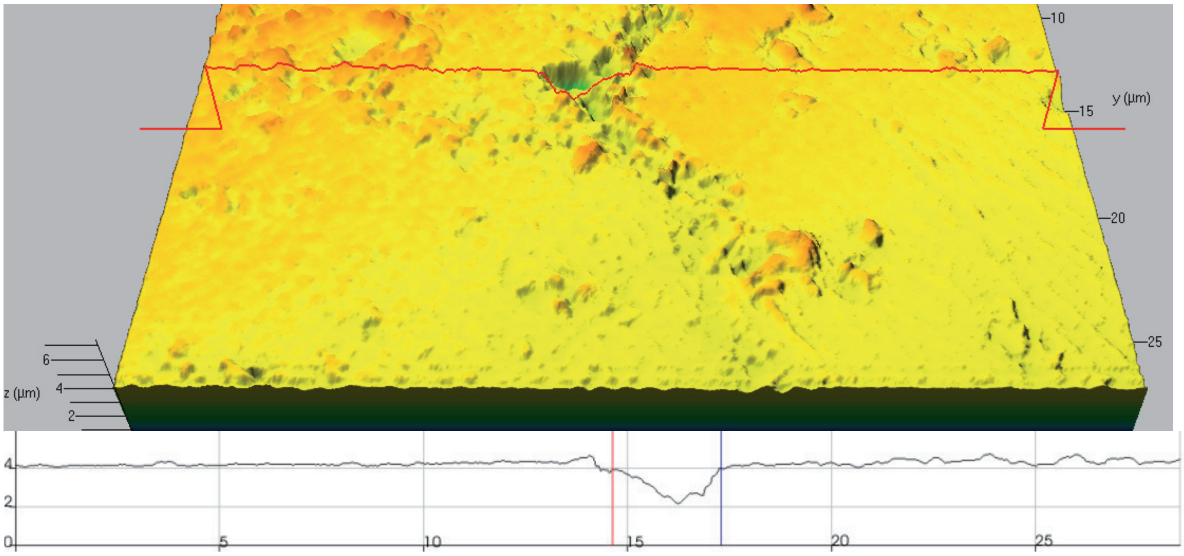

Fig. 3. Structure of the internal damage: a) topography b) profile in selected place

3. Methodology of classification

The photos which were used in computer program of internal damages classification were taken employing the scanning electron microscopy (SEM) and converted to the digital format with 256 levels grey scale. There was created the database of standard images with the development phases of the damage processes. The standard classification of internal damages consist of four main classes A, B, C, D. Additionally 0 class with no internal damages of the structure was introduced:

- class 0 - structure close to the initial state,
- class A – single voids,
- class B – directed voids, chains of voids, merging of voids,
- class C – microcracks,
- class D – macrocracks

To meet the needs of neural network model the classification of internal damages was only based on these main classes. The model is under construction and it will be improved in the future.

The following methodology of image acquisition and transformation was applied :

- acquisition of images on scanning electron microscope,
- unification of the images format, contrast and resolution,
- median filtration,
- binarisation (the threshold was chosen experimentally),
- binary erosion,
- calculation of circumferences (Ob) and area (Po) of chosen elements,
- calculation of minimum distance between objects (MinOd),
- evaluation of shape coefficient of circularity1 (W_{c1}) and circularity2 (W_{c2}),
- calculation of Malinowska coefficient (Wm) and coefficient of roundness (Wk) [18],
- application of neural networks to classification of internal damages degree.

For the parameters and coefficients were evaluated minimum (min), maximum (max) and mean (sr) values.

The task of the development of a neural network required to determine the following quantities: type of the neural network, the number of hidden layers and the number of neurons in individual layers, the type and form of the activation function, variable scaling procedure, function of error and neural network training technique and parameters. All the parameters mentioned above were selected after the analysis of their influence on the assumed quality coefficients.

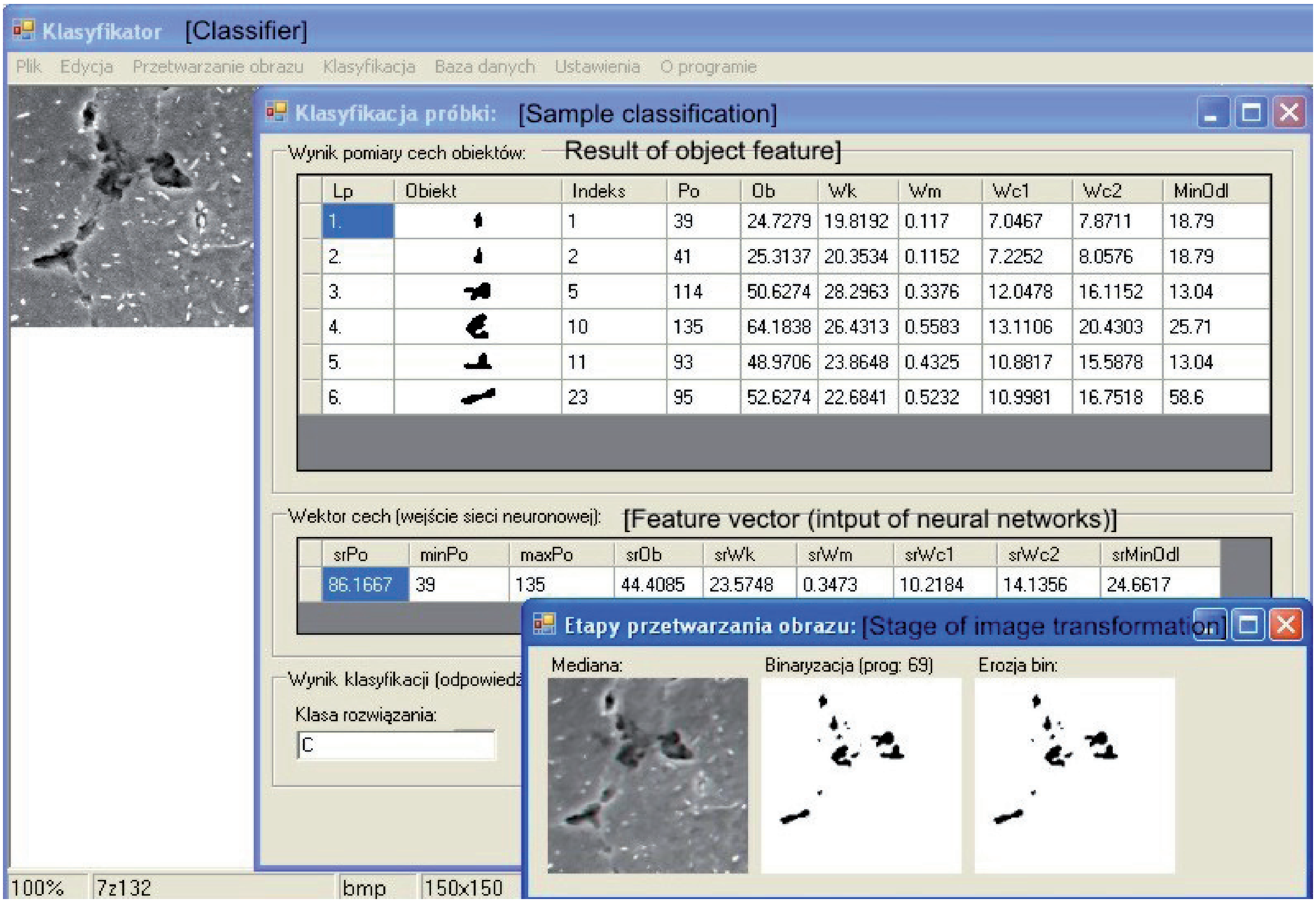

Fig. 4. The programme window for the image classification and the calculations of geometrical parameters

The number of neurons in both the input (9) and output (5) layers were established. The neural activation level in the input layer was made dependent upon the: minimum area (minPo), maximum area (maxPo), mean area (srPo), mean circumference (srOb), mean coefficient of roundness (srWk), Malinowska coefficient (srWm), mean coefficient of circularity1 (srW_{c1}), mean coefficient of circularity2 (srW_{c2}), mean minimum distance (srMinOd). The neural network was trained using the Back Propagation algorithm for the next 4000 training epochs.

In order to quantify the classes of internal damages of steel working in creep condition a multilayer perceptron (MLP) network with a six hidden layer and bipolar continuously activation function were chosen. The data set employed in the model development process using the neural network was split into three subsets: training, validation, and the test one. The parameters of the best network are presented in Table 2.

Table 2.
The parameters of the best network

Input vectors	Training method	Network structure	Number of training epoch
minPo, maxPo, srPo, srOb, srWk, srWm,, srW_{c1}, srW_{c2}, srMinOd	Back Propagation	MLP 9-6-5	4000

There was made a computer program which allows to identification and classification of integral damages of steels working in creep condition. (Fig.4.).

4. Conclusions

Proposed computer program with neural network support can be used with success as a tool for classification of internal damages in steel operating in creep service. Connection of computer program and neural networks may allow to obtain greater effectiveness in recognition an classification of material internal damages.

The accuracy of the traditional method vastly depends on the place choosing to take the metallographic structure, the proper interpretation of observed metallographic structure and the need of engagement of expert with sufficient practical knowledge. Computer assisted method lower the human factor and allows to objective assessment of material's structure.

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