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Computer aided classification of internal damages the chromium-molybdenum steels after creep service

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Analysis and modelling

ABSTRACT

Purpose: The aim of the paper is to present the computer assisted method for analysis of scanning electron microscope metallographic images of elements after long time operating in creep conditions.
Design/methodology/approach: The development of internal damages in low alloyed chromium-molybdenum steels were discussed and illustrated. As a tools of evaluation of the internal damages' classes of power industry installation elements from 16Mo3 steel operating in creep conditions a method based on image analysis, geometrical coefficient and artificial neural networks was used.
Findings: Combining of several methods making use of the image analysis, geometrical coefficients and neural networks will make it possible to achieve the better efficiency of class recognition of damages developed in the material.
Practical implications: This method can find a practical application for evaluation and classification of creep-damages of elements power industry installations.
Originality/value: The use of images analysis and neural networks to identification and classification of internal damages of low alloyed chromium-molybdenum steels working in creep conditions.
Keywords: Image analysis; Neural networks; Steels; Creep

1. Introduction

Low alloyed chromium-molybdenum steels are the one of base materials used in power industry for construction elements of installations long-time working in creep conditions [1-3, 13]. Exploitations in these conditions caused changes of the material's structure, decreasing of properties and the development of damage processes of materials. These materials should characterize good ability to remain mechanical properties in conditions of elevated temperature under loading and the resistivity of the materials on the acting of chemical factors in elevated temperature, mainly on the acting of oxidizing gases. 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 [2-6].

Artificial neural networks have wider application possibilities in the area of materials science that allow to their use in solving new and classical problems and matters. Models created by neural networks are characterized by non-linearity, that influences on the bordering of their use. Classical techniques of mathematical description of models and process are based on linear modelling. In materials science a lot of phenomena are characterized by nonlinearly so artificial neural networks allow to quick solving of these problems. Neural networks allow to create models for phenomena, which mechanism are very complicated or not fully known [8-12].

The goal of the paper is the development of the computer assisted method employing image analysis, shape coefficients and neural networks for the automatic classification of damages of materials used for power systems in creep service. They are the continuation of the own research on developing internal damage classification method [4-7].

2. Experimental procedure

Material for investigation was acquired from elements of power industry pressure installation long-time operating in creep conditions: chambers, collectors, pipelines, boilers with different degree of internal damages caused by creep acting. Elements were made from the 16Mo3 steel and their working conditions were as follows: calculation temperature 480-520°C, real stress 35-120MPa, working time 80000-220000h. The chemical composition of this steel is shown in Table 1.

Table 1.
Chemical composition of 16Mo3 steel (PN-EN 10028-2:2005) [15]

Mass chemical composition [wt.%]								
C	Mn	Si	P	S	Cr	Mo	N	Cu
0,12-0,2	0,4-0,9	<0,35	≤0,025	≤0,01	≤0,3	0,25-0,35	<0,012	≤0,3

During long-time exploitation of elements in creep conditions in the material structure at the end of II and III period of creep are formed internal damages. The structure changes during simultaneous elevated temperature acting and stresses have direct influence on their creating and growth during exploitation in such conditions. Damages of the material's structure can be reveal by metallographic methods. On the Fig. 1 the structure of the pipeline's knee from the 16Mo3 steel after long-time acting of elevated temperature 495°C, under the real stresses 81MPa for 125000h is shown. In the structure of this steel there were observed singular voids. The next step of internal damages of material's structure is appearing of few voids. That was observed in the entry chamber of the steam superheater I° from 16Mo3 steel working 127000 hours under the real stresses 63MPa at real temperature 530°C (Fig. 2).

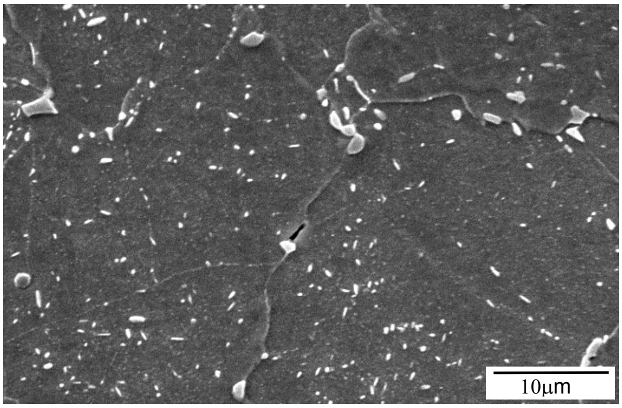

Fig. 1. Singular voids irregular displaced on the boundaries of ferrite grains (SEM)

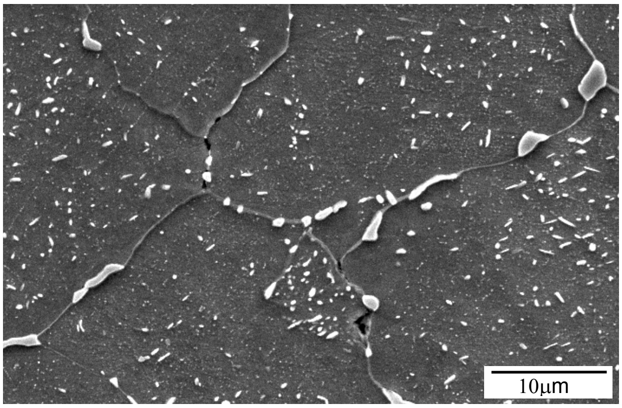

Fig. 2. Voids oriented by the angle 45° or 90° to the stresses direction acting axis (SEM)

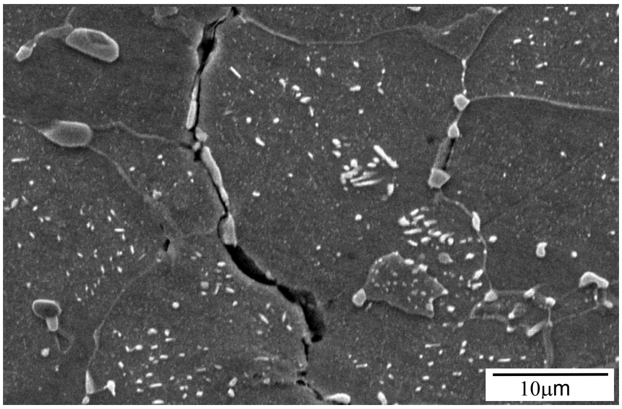

Fig. 3. Coalescence of voids (SEM)

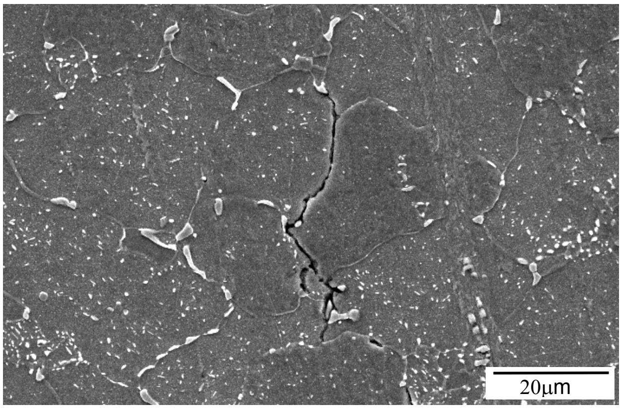

Fig. 4. Intercrystalline crevices occurring on few grains a dozen or so grains (SEM)

Table 2.
Result of nonparametric tests of the significance of correlation for the damages class and calculated r Spearman's test

Kind of geometrical coefficients	Sample size N	Correlation	Value of test t/Z	Level of significance for test	Result of test
r Spearman correlation					
Po	140	0.7932	15.3599	0	essential
Ob	140	0.7650	13.9538	0	essential
Wk	140	0.8086	16.1471	0.0012	inessential
Wm	140	0.6165	9.1997	0	essential
Wc1	140	0.7937	15.3850	0	essential
Wc2	140	0.7700	14.2288	0	essential
MinOdl	140	0.5330	7.4270	0	essential
SFpoz	140	0.7653	14.0205	0	essential
SFpion	140	0.7545	13.5574	0	essential
Wz	140	0.6837	11.0469	0	essential
MaxOdl	140	0.3199	3.9816	0.0011	inessential
Wbb	140	-0.0398	-0.4648	0.6427	inessential
Wf	140	0.5561	0.6567	0.5124	inessential
Wh	140	0.2896	3.5676	0.0049	inessential
Ws	140	0.6837	11.0469	0	essential

Table 3.
The parameters of the best neural network used for the classification of internal damages

Input vectors	Network structure	Training method	Number of training epochs
Po, Ob, Wm, Wc1, Wc2, MinOdl, SFpoz, SFpion, Ws, Wz	Multilayer Perceptron 10-31-5	Back Propagation, Conjugate Gradient Descent	466

The coalescence of voids, as a result of contacting and joining of voids' chain was observed in the structure of this steel as shown in Fig. 3. As a consequence of this phenomena the small intercrystalline crevices are observed. At the beginning they are observed only in one grain, then they are widen to some grains creating micro-cracks (Fig. 4). This Figure shows the structure of an element working in creep conditions under real stress 51MPa, for 206000 hours at the temperature 510°C. The simultaneously acting of internal damages in different area leads to macro-cracks. The presence of internal damages, independent of the degree of structure changes, decides the possibilities of the element exploitations. Based on the investigations carried out, the observation of the internal damages growth and the literature studies the classification of damages versus the degree of material exhaust were made. The additional 0 classes with no internal damages of the structure is introduced [1,4,7]:

- class 0 – structure close to the initial state,
- class A – nucleation of voids,
- class B – development of voids,
- class C – development of micro-cracks,
- class D – development of macro-cracks

The classification of internal damages was simplified to 5 main classes to meet the needs of neural network model. The model is under construction and it will be improved with used all the classes in the future.

The image of the low alloyed chromium-molybdenum steel's structure, obtained as a results of investigations carried out in scanning electron microscope, morphology of damages, geometrical coefficient's obtained based on the images analysis and the methods of artificial neural networks training influence on the damages classification by the use of artificial neural networks.

To solve the problem of internal damages classifications in steels working in creep conditions, the metallographic structure images from scanning electron microscope were used and the following methodology was applied:

- initial processing of images (unification of format, contrast and resolution),
- analysis of image,
- calculation of area and circumferences of chosen elements,
- calculation of distances between objects,
- evaluation of geometrical coefficients,
- application of neural networks to degree of internal damages classifications.

Correct classification is able thanks to use of many geometrical coefficients. They allow to distinguish damages with the same values of geometrical coefficients (classification to the same class) and with the different ones (classification to different class).

In worked out initial model of artificial neural network on the entry there was 15 geometrical coefficients: area (Po), circumferences (Ob), coefficient to roundness (Wk), Malinowska's coefficient (Wm), coefficient of circularity1 (Wc1) and circularity 2 (Wc2), maximum (MinOdl) and minimum distance (MaxOdl), horizontal and vertical Feret's diameters (SFpoz, SFpion), Blair-Bliss coefficient (Wbb), Feret coefficient (Wf), Haralick's coefficient (Wh), nondimensional coefficient (Ws), coefficient of contents (Wz) [14].

Based on nonparametric tests of significance and interval of trust artificial neural network with 10 input neurons with calculated geometrical coefficients was worked out. The data set was split into three subsets: raining, validation and the test one.

The task of the development of a neural network required to determine the following quantities: type of the neural network, the size 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.

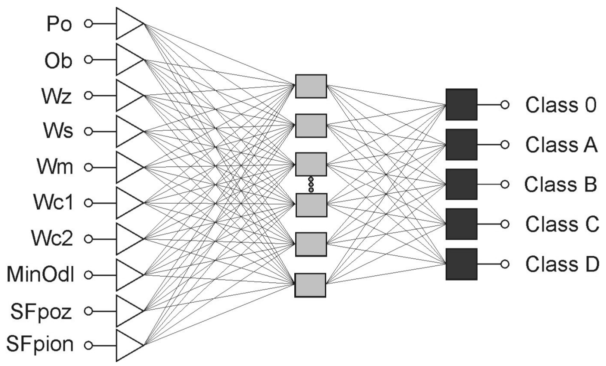

Fig. 5. Schema of neural network MLP 10-31-5

A single neuron within the output layer meant the 5 classes of internal damages. A multilayer perceptron (MLP) network with a 31 hidden layer and bipolar continuously activation function were chosen. The neural network was trained using the Back Propagation and Conjugate Gradient Descent algorithms for the next 466 training epochs. Parameters of the best neural network MLP 10-31-5 is shown in table 3 while its schema in Figure 5. MLP 10-31-5 neural network was the best from the worked out artificial network and classified internal damages of this kind of steel on the degree of 93%.

The best worked out artificial neural network was use in he computer program which allows the classification of internal damages of low alloyed chromium-molybdenum steels on the based on images from scanning electron microscope [7].

3. Conclusions

Computer classification of the internal damages can be used with success as forecast support tools in engineering practice. The accuracy and the dependability of this 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.

The advantage of worked out methodology is automation and computer assistance of decision concerning identification and classification of internal damages of low alloyed chromium-molybdenum steels. This methodology in connection with computer program allows to more objective and quicker identification and classification in comparison with classical metallographic method.

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