J. KASIŃSKA, P. MATUSIEWICZ, P. MALINOWSKI, L. BARWICKI

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MATRIX REPLICA-BASED ASSESSMENT OF THE MICROSTRUCTURE OF PRIMARY STEAM PIPING ELBOWS AFTER LONG-TERM OPERATION

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The degree of degradation of ferritic-pearlitic steels is assessed by describing the size, dispersion and distribution of carbides along the grain boundaries, grain growth and the occurrence of microcracks. The article reports the results of the microstructural assessment of primary steam pipeline elbows made of 13HMF steel. Digital image analysis of matrix replicas was performed. It included the classification of microstructures in terms of pearlite/bainite change classes (fragmentation of cementite plates, spheroidization, coagulation) and the evaluation of carbide precipitation processes and damage processes (presence of isolated oriented creep pores and microcracks). The perlite/bainite areas were found to disappear completely after long-term operation.

Keywords: 13HMF steel, piping elbows, damage processes, scanning electron microscopy (SEM), phase

INTRODUCTION

Cr-Mo-V steels are extensively used in power generation and petrochemical industries primarily due to their good high-temperature corrosion and creep resistance. The production cost to benefit ratio is favourable and the Cr-Mo-V steel application range includes pressure components for boilers and pipelines.

In spite of their superior strength properties, these steels degrade at elevated temperatures and in variable pressure service. To ensure safe operation, the power generation or petrochemical industries require that plant components are subject to periodic inspection.

Currently, there is no standardised/calculation-based assessment of ferritic-perlitic steel degradation. The procedure used involves a descriptive assessment of the size and dispersion of precipitates, carbide release along grain boundaries, grain growth and the occurrence of micro-cracks [1-4]. The microstructure bainitic or ferro-bainitic steels may not show such significant changes while ageing [5,6], which makes degradation level assessment even more difficult. Here, the processes of coagulation of carbides containing alloying elements deplete the matrix of these elements. A reduction of the solid solution occurs and the evaluation of the material without knowledge of the primary microstructure is significantly hampered [7]. Several studies reported attempts made to apply computational methods of perlite assessment using image analysis and machine learning algorithms [8-11].

MATERIALS AND EXPERIMENTAL METHODS

Assessment of the microstructure degradation was performed on micrographs of replicas of bends/elbows of the primary steam pipelines made of 13HMF steel (external surfaces, elbow tensile zones and straight sections). The elbows were in service for 245 000 hours at 540 ° C and a pressure of 13,8 MPa. The replicas fabricated using the matrix method were observed in a scanning electron microscope at magnifications x 1000 and x 2000. The assessment was performed in accordance with the guidelines of the Office of Technical Inspection in force in the Polish supervision system for power units [12]. The class of demage for 13HMF steels according to [12] are summarized in Table 1. The grain size was measured on 21 photos of 13HMF steels representing the microstructure classes assigned by an expert

Table 1 **Classification of internal damage in materials operating under creep conditions**

Class of damage	Type of damage
0	a mixture of ferrite with bainite, incl. perlite
1/2	coagulation of precipitates in bainite, numerous minor precipitates evenly spaced in ferrite, and few large precipitates at the boundaries of ferrite grains
3	almost complete disappearance of bainitic areas and chains of significant size precipitates at the boundaries of ferrite grains
4	coagulated carbides in ferrite and chains of significant size precipitates at the boundaries of ferrite grains

J. Kasińska (kasinska@tu.kielce.pl, Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering Kielce, Kielce, Poland
P. Matusiewicz, AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Krakow, Poland
P. Malinowski, AGH University of Science and Technology, Faculty of Foundry Engineering, Krakow
L. Barwicki, Enrem Połaniec Sp. z o.o. Połaniec, Poland

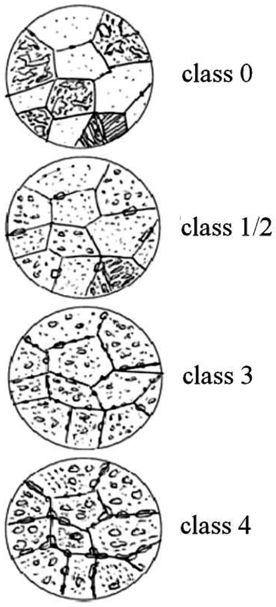

Figure 1 Microstructre patterns with classes assigned according to [12].

from class 1 to class 4. The length of the grain chords was measured using a semi-automatic linear method in SigmaScan Pro computer image analysis software. Microstructure images used in the measurements were magnified 1000x and calibrated to obtain results in micrometers. On each image, six secant lines were randomly projected with a length equal to the long side of the image. Then, the intersections of the grain boundaries with the secants that cut off subsequent chords on the secant were indicated. The lengths of the chords were obtained automatically.

Microstructures corresponding to the classes in [12] are shown in Figure 1.

RESULTS AND DISCUSSION

Microstructure

Matrix replicas were observed under a scanning electron microscope. According to the guidelines in [12], the main class of the structure involves the assessment of:

- perlite/bainite change classes: 0; 1/2; 3; 4 (fragmentation of cementite plates, spheroidization, coagulation;
- carbide precipitation processes,
- damage processes (presence of isolated creep pores, oriented pores, microcracks)

Qualitative analysis of microstructure images on the matric replicas showed a significant degree of degradation of the primary material with the ferritic-perlitic initial microstructure. Perlite disappeared after 245 000 operating hours (Figure 2a, b). Numerous voids were observed at the grain boundaries and inside the grains, proving the occurrence of precipitation processes (Figure 2a). The released carbides also formed “chains” of the precipitates along the grain boundaries (Figure 2b).

Grain size measurement

The statistical analysis of the chord length measurement results for individual microstructure classes assigned by the expert is given in Table 2. The limiting

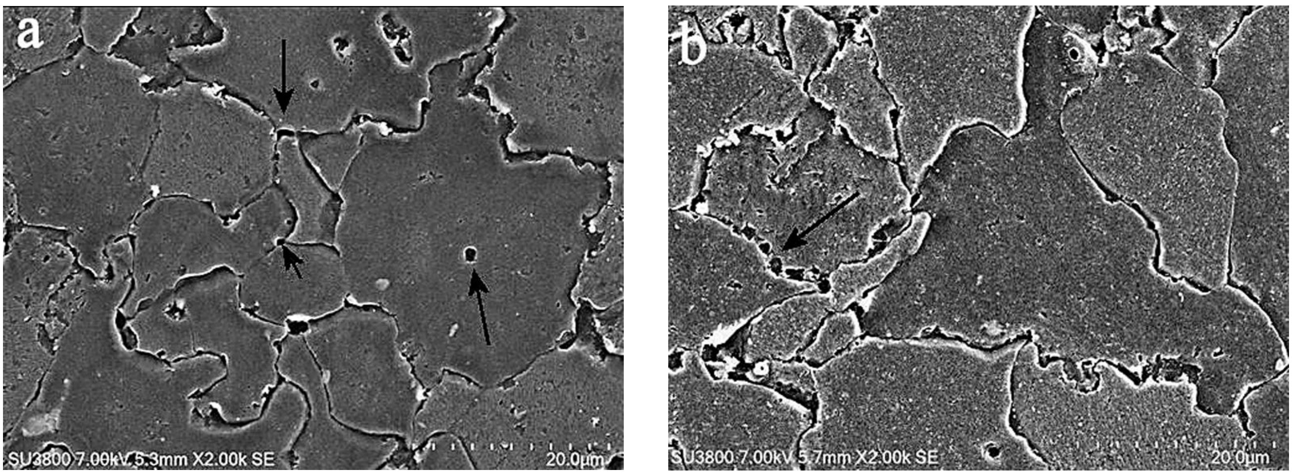

Figure 2 Example of a 13HMF steel microstructure after long term in service, replicas, SEM

Table 2. **Statistical parameters for chord lengths of the microstructure grains**

Microstructure class	The number of measured / chords	Mean chord / μm	Median chord / μm	Standard deviation / μm	Limiting error / μm
Class 1	373	12,70	10,29	9,10	0,92
Class 2	236	14,71	11,95	9,32	1,19
Class 3	234	14,86	12,88	9,51	1,22
Class 4	417	14,63	12,89	9,31	0,89

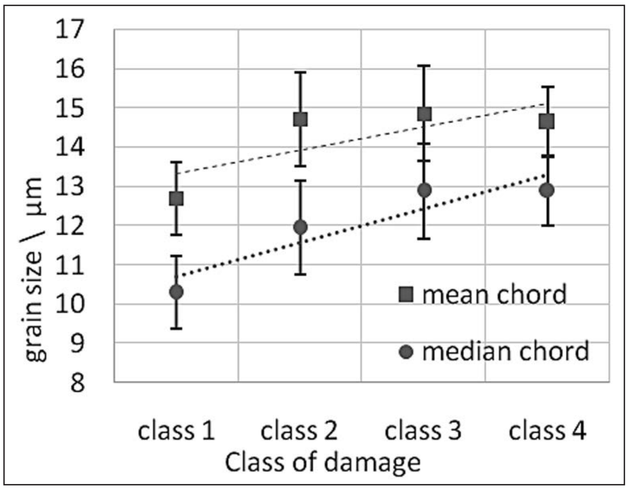

Figure 3 Microstructure grain size for 13HMF steel, represented by the mean chord and the median chord in the classes assigned by the expert

error was calculated as a half of the confidence interval for the mean. The relationship between the microstructure class assigned by the expert and the grain size represented by the mean chord length and the median chord length is shown in Figure 3. The mean chord length increases with the degree of microstructure degradation level represented by the assigned class. The largest grain size differences are between class 1 and class 2 and then decrease in subsequent classes.

As in the case of the mean chord length, the median chord length increases but this upward trend is more pronounced. This may be due to the insensitivity of the median to extreme values.

CONCLUSION

Assessment of steel degradation level based on matrix replicas is a challenging task that depends on the replica fabrication quality. Generally, it consists of a qualitative description of the microstructure and as such, it is subjective and relies on the inspector's experience. For this reason, it is advisable to show a correlation between the degree of degradation and stereological parameters. It was demonstrated that the median chord can be used to describe the microstructure grain size in terms of its degradation degree, especially in connection with other quantitative parameters such as geometric and shape coefficients describing the structure (area, perimeter, shape factors, Feret diameters, etc.). Describing all classes of structures on replicas with stereological parameters, e.g. using an artificial neural network for a large database could provide a tool for more precise qualification of the serviceability of tested elements.

REFERENCES

[1] R. Molenda, R. Kuziak, Physical metallurgy foundations of DP steel plates. Structure and properties formation in the process of continuous annealing IMŻ 2 (2011), 29 – 41.

[2] D. Hauserová, J. Dlouhý, Z. Nový, Accelerated spheroidisation of carbides in medium carbon steels, Inżynieria Powierzchni (2011) 2 , 28-32

[3] A. Czarski, T. Skowronek, W. Osuch, Influence of orientation relationship between ferrite and cementite in pearlite on stability of cementite plates. Archives of Foundry Engineering 33 (2007) 1, 41 – 49

[4] Toft LH, Marsden RA. Structural processes in creep: special report no. 70. London: Iron & Steel Institute; 1961, 238-244.

[5] Bhadeshia HKDH, Honeycombe RWK. Steels: Microstructure and Properties. 3rd ed. Oxford: Butterworths-Heinemann; 2006.

[6] Bhadeshia HKDH. Bainite in Steels. Cambridge: Cambridge University Press; 2001.

[7] Bhadeshia HKDH. Bainite in Steels. Cambridge: Cambridge University Press; 2001.

[8] N. Nutal, C.J Gommes, S. Blacher, P. Pouteau, J.P. Pirard, F. Boschini, K. Traina, R. Cloots, Image Analysis Of Pearlite Spheroidization Based On The Morphological Characterization Of Cementite Particles, Image Anal Stereol. 29 (2010); 91 – 98.

[9] Lis, J. Wieczorek, P. Łyszczarz, P, Quantitative estimation of microstructure of ribbed bars from low carbon steel after QTB process, Hutnik, Wiadomości Hutnicze, 77 (2010) 9, 494 – 497.

[10] J. Kasińska, P. Matusiewicz, A. Czarski, L. Barwicki, Assessment of pearlite degradation in power industry cast steel after long-term exploitation, Inżynieria Materiałowa 38 (2017) 5, 212 – 216.

[11] P. Malinowski – Casting production management system. Metalurgija 60 (2021) 3-4, 451-453,

[12] Guidelines of the Office of Technical Inspection, Rules for the diagnostics and service life assessment of boiler and pipeline components operating under creep conditions - Annex B, UDT, 2015, 1- 72.

Note: English translation by Nina Kacperczyk