Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 25
ISSUE 1
November
2007

Structural changes in low alloy cast steel Cr-Mo-V after long time creep service

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Received 23.04.2007; published in revised form 01.11.2007

Materials

ABSTRACT

Purpose: of this publication is to present the changes of the structure in the power station boiler and turbine components made of low cast steel Cr-Mo-V after long time creep service.
Design/methodology/approach: The material of the research studies has been obtained from Polish power stations. All examined elements have exceeded their assessed life of 100.000 hours. The microstructures of the elements have been observed using a scanning electron microscope. The investigation of the development of the precipitation processes has been done by X-ray diffraction phase analysis.
Findings: The microstructures and phase compositions of the residues, obtained from the elements, depend on life exhaustion extent.
Practical implications: The presented method can be used for evaluation and qualification of structural changes in power station boiler and turbine components operating in creep conditions.
Originality/value: The observed changes in the structure and in the precipitation composition are applied to evaluation of the condition of the components in further industrial exploitation.
Keywords: Metallic alloys; Phase analysis; Low alloy cast steel Cr-Mo-V; Degradation after service

1. Introduction

Literature review and experience gathered so far indicate that – so far – the problem of the residual life of the cast steel elements in creep service, i.e., above the limiting temperature related to the real element load condition, has not been described satisfactorily. Mechanisms of crack initiation and effect of the material structure degradation processes on service life of cast steel elements are little known in particular [9].

The problem of forecasting the life of the cast steel elements like: valve housings, T-connections, and pipe crosses, used in power industry nowadays are the matter of interest currently of many research centers, this refers in particular to investigation of the regenerating heat treatment of the steam turbines made from the Cr-Mo-V low alloy cast steel [3-8].

Nowadays, in Poland, the significant majority of power units have reached or exceeded significantly their design life of 100.000 or 200.000 hours. Therefore, development of the diagnostic examinations of the critical elements of power boilers is justified for admitting them for their futher safe and failure-free service [1, 2, 10-16].

The main problem to solve in materials' diagnostics of the pressure elements of power boilers and turbines has been not only deciding the further usability of the element in service for its further safe service, but also evaluation of the time of its further safe operation time at the analysed element's hitherto existing service parameters [15]. Therefore, a number of methods are used in forecasting of such elements' lifes, which – together – make it possible to set forth the credible forecast of their further safe service [3, 4, 12].

The so called critical elements of the power boiler and turbine pressure parts have the main effect on their reliability and life. These are the elements in service at the most difficult conditions and at the most stringent temperature-stress parameters. Elements in service above the limiting temperature, i.e., in creep conditions, often under the low-cycle fatigue, to which the elements from the Cr-Mo-V type low-alloy cast steel belong should be counted into this class first [9]. These elements may fail or wear out first.

Therefore, the very important issue is development and implementing in practice methods of the diagnostic examinations making it possible to evaluate their exhaustion extent [13].

In practice, it is essential to search for the material investigation methods making it possible to evaluate the structure degradation level and to determine the exhaustion extent, defined as the ratio of the service time to the total forecasted time to damage for the service parameters (σe, Te).

The way to assess the material state is shown below, based on the results of the structure image state and on the X-ray analysis of the phase composition of the precipitations. Carrying out such examinations for cast steel after different service time and for the varying structure degration level made it possible to work out a schema of structure changes in connection with the exhaustion extent. The particular structure states were assigned with the sequences of the changes of the carbides' precipitation processes.

2. Material

The subject of the investigation was the material of the constructional elements of the pressure parts of the power boilers made from the Cr-Mo-V low-alloy cast steel in the intial state and after various service times.

Table 1.
Material for investigation

Grade	No	Life time	Steam parameters	
			Temperature [°C]	Pressure [MPa]
Cast steel Cr-Mo-V	1	Initial state	-	-
	2	100 000	550	13.8
	3	172 257	535	12.7
	4	182 709	535	13.0
	5	186 211	540	13.5

Designations of the investigated materials, their service parameters and service times are presented in Table 1. The chemical composition analyses of the investigated cast steels, referring to the PN-89/H-83157 standard requirements are listed in Table 2.

3. Structure changes

Material of the Cr-Mo-V low-alloy cast steel in the initial state observed on the metallographic microsection on the scanning electron microscope is characteristic of the ferritic-pearlitic structure with the very fine, rather homogeneously distributed carbides precipitations inside of the ferrite grains and of the fine precipitations on the grain boundaries (Fig. 1). Microstructure of the Cr-Mo-V cast steel after about 100,000 h service in creep conditions (No 2) obeserved on the scanning electron microscope at magnifications of up to 5000x is characteristic of the notable of the pearlite-bainite areas decay. Coagulation of precipitations is observed inside of the pearlitic areas with the simultaneous growth of their size. On the other hand, carbides form chains of precipitations at some locations on the ferrite grains boundaries. Coagulated precipitations of the significantly bigger size develop in place of the fine dispersive precipitations distributed rather homogeneously in ferrite (Fig. 2).

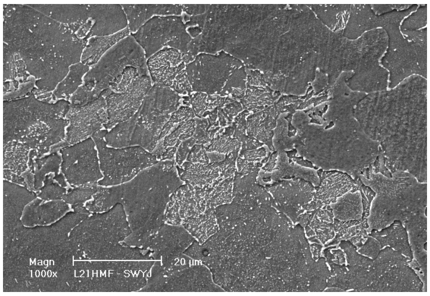

Fig. 1. Structure of the Cr-Mo-V low-alloy cast steel in the initial state, No 1, magnification 1000x

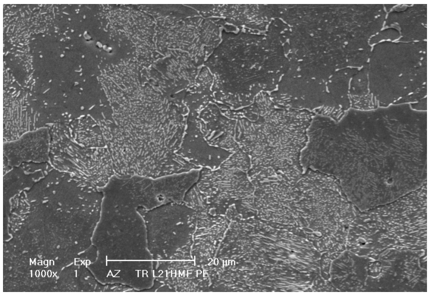

Fig. 2. Structure of the Cr-Mo-V low-alloy cast steel after about 100,000 hours of service, No 2, magnification 1000x

Table 2.
Chemical composition of the cast steel

Sample No	Chemical composition [%]									
	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu
PN-89/H-83157	0.18-0.25	0.40-0.70	max. 0.50	max. 0.03	max. 0.03	0.90-1.20	0.30	0.05-0.70	0.20-0.35	max. 0.30
1	0.19	0.64	0.32	0.019	0.015	1.23	0.060	0.75	0.32	0.078
2	0.22	0.54	0.39	0.025	0.018	1.19	0. 060	0.61	0.22	0.090
3	0.22	0.52	0.31	0.012	0.016	1.06	0.058	0.60	0.32	0.10
4	0.20	0.45	0.28	0.013	0.015	0.95	0.055	0.64	0.22	0.076
5	0.20	0.73	0.32	0.014	0.017	1.10	0.057	0.60	0.27	0.11

A similar structure of the material after 100,000 hours service (No 2) was observed for the material after 172.000 hours service (No 3). The difference in the structure image of these materials one may observe at magnifications of 2000-5000x only. Material after 172,000 hours long service time is characteristic of a lower degradation level of the pearlite/bainite areas, compared to the material after 100,000 hours long service time. Its structure is ferrite with the notably coagulated pearlite/bainite areas (Fig. 3). Another structure image is observed for the cast steel material after the long-term service of 182,000 hours (No 4). The pearlitic areas corresponding to those characteristic for the material in its initial state attest that the long-term effect of the temperature and stress is low on the investigated material's structure. This is probably connected with the real service parameters much lower than the assumed design ones.

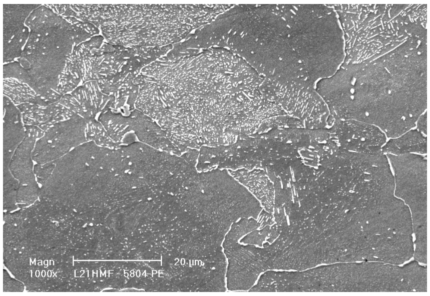

Fig. 3. Structure of the Cr-Mo-V low-alloy cast steel after about 172,257 hours of service, No 3, magnification 1000x

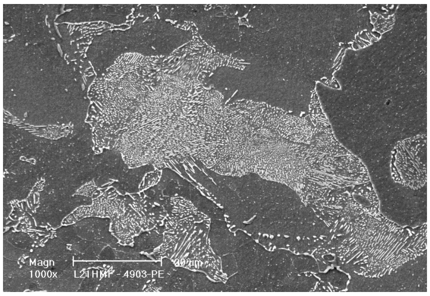

Fig. 4. Structure of the Cr-Mo-V low-alloyed cast steel after 182,709 hours of service, No 4, magnification 1000x.

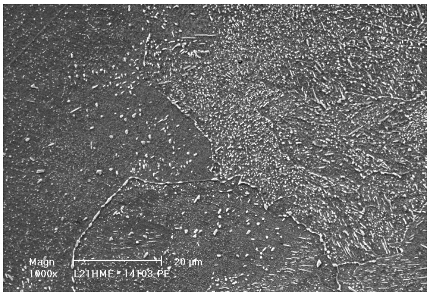

Fig. 5. Structure of the Cr-Mo-V low-alloy cast steel after about 186,211 hours of service, No 5, magnification 1000x

However, the cast steel material after the long-term service for 186,000 hours (No 5) is characteristic of the significant structure degradation. Its structure is the ferrite with the coagulated precipitations of carbides in the former pearlite/bainite areas and within the ferrite grains. Chaining precipitations of the significant size were observed on the ferrite grains boundaries 5).

4. X-ray powder diffraction analysis

The precipitation processes have been investigated by means of X-ray diffraction using the residues, obtained from the boiler and turbine components. The residues have been dissolved from the steel matrix in water solution of HCl. The powder diffraction patterns of the residues have been measured using Philips diffractometer PW 1140 with Co K_α radiation and a graphite monochromator on the diffracted beam. The identification of the components of the residues has been done according to the rules of qualitative phase analysis with JCPDS-ICDD PDF-4 file as a reference base. The results of identification have been summarized in the Table 3.

The positions of the diffraction lines of the identified carbides (excluding cementite M_3C with M=Fe) show the shifts to the standard positions, included in the ICDD data. This effect is concerned with some changes in the chemical composition of the carbides in comparison to the data in the ICDD cards.

The carbide marked as $M_{23}C_6$, identified according to $Cr_{23}C_6$ data, is the main component in all examined residues. The second main component – cementite – is present in similar quantities in the samples, described as being in the initial state and after 100.000 and 172,000 hours of service. The initial state is characterized by the presence of the greatest variety of different kinds of carbides. This is the only state, in which small quantities of M_6C has been found. The diffraction lines of MC carbides are broad, suggesting small dimensions of the carbides and their complex chemical composition, with V as the main element. There is also small fraction of M_2C carbide, formed on the base of Mo. In the residue from the material after 100,000 hours of service, the amount of the MC is lower than in the initial state and is also lower than in the residue taken from the material after 172,000. The diffraction lines of MC are sharper in both these residues than in initial state.

Table 3.
The results of qualitative phase analysis of residues

Material	Phase composition of the residues
Initial state (No 1)	The main components: $M_{23}C_6$, M_3C, MC Other components: M_2C, M_6C, MnS
100.000 (No 2)	The main components: $M_{23}C_6$ and M_3C Other components: MC, MnS
172,000 (No 3)	The main components: $M_{23}C_6$ and M_3C Other components: MC, MnS
182,000 (No 4)	$M_{23}C_6$ – the main component Other components: M_3C, MC, M_2C, MnS
186,000 (No 5)	$M_{23}C_6$ – the main component Other components: M_3C, MC, M_2C, MnS

There are also slightly lower intensities of the diffraction lines of cementite, concerned with lowering contribution of this kind of carbide. This lowering is more pronounced in the material after 100,000 hours of service.

The lowest fraction of cementite is observed in residue, obtained from material after 186,000 hours of service. There are also diffraction lines of small intensity, identified as the lines of M_2C type of carbide. Two types of MC carbides can be found in the diffraction pattern in this residue; one MC carbide can be described as a carbide with dominating V concentration, the second type – with the main presence of Mo. The residue, concerned with the material after 182,000 of service, has got the lowest fraction of MC carbide (with V). In this sample, only traces of M_2C carbide can be identified.

5. Conclusions

Structural examinations carried out and analysis of phase composition of the carbides precipitations of the Cr-Mo-V cast steels after various service time and with the varying degradation levels have made it possible to work out the provisional shema of structure changes in connection with the exhaustion extent. Investigation consisiting in examinations of the qualitative phase composition analysis of precipitations have made it possible to attribute sequences of the carbides precipitation processes changes to the partuclar structure states. Detailed investigation results will be presented in the next publication. The obtained investigation results feature the basis for assessment of the material state of the power boilers elements inservice at elevated temperature using the non-destructive testing methods, including the matrix replicae method, as well as the X-ray phase analysis method, which are used in industrial practice for assessment of the usefulness for operation of cast steels in creep service.

Acknowledgements

The authors wants to acknowledge the Polish Ministry of Since and High Education for funding part of this research project.

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