Achievements in Mechanical and Materials Engineering

COMMENT Worldwide Congress on Materials and Manufacturing Engineering and Technology

16th - 19th May 2005
Gliwice-Wisła, Poland

COMMITTEE OF MATERIALS SCIENCE OF THE POLISH ACADEMY OF SCIENCES, KATOWICE, POLAND
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE, POLAND
ASSOCIATION OF THE ALUMNI OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, MATERIALS ENGINEERING CIRCLE, GLIWICE, POLAND

13th INTERNATIONAL SCIENTIFIC CONFERENCE
ON ACHIEVEMENTS IN MECHANICAL AND MATERIALS ENGINEERING

The classification method and the technical condition evaluation of the critical elements' material of power boilers in creep service made from the 12Cr-1Mo-V

J. Dobrzański

Institute for Ferrous Metallurgy, 44-100 Gliwice, Poland,
email: jdobrzanski@imz.gliwice.pl

Abstract: Metallographic examinations were carried out on ferritic 12Cr-1Mo-V steel with tempered martensite structure after 68,000 - 150,000 hr service in creep conditions. Structural evolution related to the form of martensite, carbide precipitation and internal damage due long-term action of thermally activated processes was discussed. A generalised scheme of structural evolution and progress of the internal damage was developed in correlation with the life exhaustion ratio. Principles of a classification for ferritic 12Cr-1Mo-V steel after long-term-service were proposed together with a method for evaluation of the state of the material for the industrial practice.

Keywords: Steel X20CrMoV121, Residual life, Creep

1. INTRODUCTION

High-pressure power installations in service at the elevated temperature are designed according to the regulations intended to ensure them the adequately long life. The condition of elements in service in the harshest temperature and stress parameters, which can get damaged or destroyed earlier than others, decides life and availability of the power station boiler. These elements are called the critical components of the power station boiler.

The component's long-term creep service, affected by temperature and pressure, results in changes of the material structure, degradation of its functional properties, and in development of the damage processes.

Evaluation of the material condition is one of the main components of the element evaluation. It calls, however, for the knowledge of the ongoing changes in the material structure, and resulting changes of its functional properties caused by its long-term service.

Evaluation of the condition of the power units in service has, therefore, the very important engineering and economical justification.

Steel of the 12Cr-1Mo-V type has been used in the high power rating (≥ 360 MW) power boilers at higher superheating stages. Changes occurring in its structure and evaluation of the material condition after the long-term service in creep regime are the subject of research of the Institute for Ferrous Metallurgy since a dozen of years or so. The investigation results presented below pertain to the structure changes in connection with the life exhaustion and relative deformation, as well as to the development of the12Cr-1Mo-V type steel classification after long-time service in creep condit.

2. COMPARISON OF THE MECHANICAL PROPERTIES AND STRUCTURE OF THE MATERIAL IN THE INITIAL STATE AND AFTER 100.000 HR OF SERVICE IN CREEP REGIME.

Comparison of the mechanical properties and structure was made on the material taken from the primary steam superheater output chamber shell of the 1150 power boiler's III° of the 360 MW power unit , with the dimensions of f 324x46mm, in service at the temperature of 540°C and pressure of 20 MPa.

2.1. Mechanical properties at room temperature

The test results obtained in the initial state and after 100,000 hr of service in creep regime meet the demands made to the mechanical properties of steel products from this steel [1].

Long-term service caused the investigated steel's impact transition temperature shift from -40°C to +30°C. The impact transition temperature shift indicates to the increase of probability of damages occurring during the pressure tests and restarting the power boiler.

2.2. Mechanical properties at elevated temperature

The obtained results of the yield point tests at the elevated temperature meet the requirements of the pertinent standards for products made from this steel, albeit their values are clearly lower after 100,000 hr of service. Creep tests are still the main source of information for evaluation of life and residual life.

The forecasted time of the further material service after long-time work is several times shorter than the forecasted material life in the initial state.

2.3. Structure and fractures

Results of the microstructure examinations carried out on the scanning electron microscope revealed that both the material in the initial state (before service) and after the long-time service for about 100,000 hours is characteristic of the structure composed of the lathe martensite and precipitations of carbides on the former austenite grain boundaries and on the boundaries of the tempered martensite lathes.

One can observe a contiguous carbide network on the former austenite grain boundaries in the material after service, which was not revealed for the material in the initial state.

Material in the initial state is characteristic of the plastic fracture. Inclusions occur on bottoms of big pits, and in those fine ones precipitations of carbides are visible. This fracture nature corresponds to the relatively high impact strength of about 150 J/cm^2. However the fracture of the impact strength test pieces after service is highly developed, stony, with the dominating portion of the cleavable fracture. The form of the cleavage surface visible at higher magnifications attests that cracking occurred both along the former austenite grain boundaries and also in a transcrystalline way.

3. STRUCTURE CHANGES AFTER LONG-TERM SERVICE IN CREEP CONDITIONS – CLASSIFICATION METHOD

3.1. Changes of the 12Cr-1Mo-V steel structure without the internal damages:

Obtained material examination results after service with no internal damages made it possible to develop a sequence of structure changes from the initial state structure, like the tempered martensite, to the ferrite with carbides and Laves phase.

The schema illustrating changes developing in structure, along with the relevant phase composition of precipitations and life exhaustion extend is shown in Fig. 1. [2, 3].

The initial state structure (before service) is the tempered martensite with the clearly marked, mostly at the lathes' boundaries, and locally fine precipitations of the $M_{23}C_6$ type carbides on the former austenite grain boundaries.

The image of the first stage of changes is the structure characteristic of the slight decay of the tempered martensite, which is demonstrated by: partial decay of the martensite lathes, chain like precipitations on boundaries of the former austenite grain boundaries, slight growth of subgrains and of the amount and size of the $M_{23}C_6$ type carbides. The next stage of the structure changes is the significant disintegration of the tempered martensite with the decay of the martensite lathes, numerous chains of precipitations on the former austenite grains borders, significant amount of precipitations of carbides in the former martensite lathes boundaries, further growth of subgrains and size of the $M_{23}C_6$ type carbides.

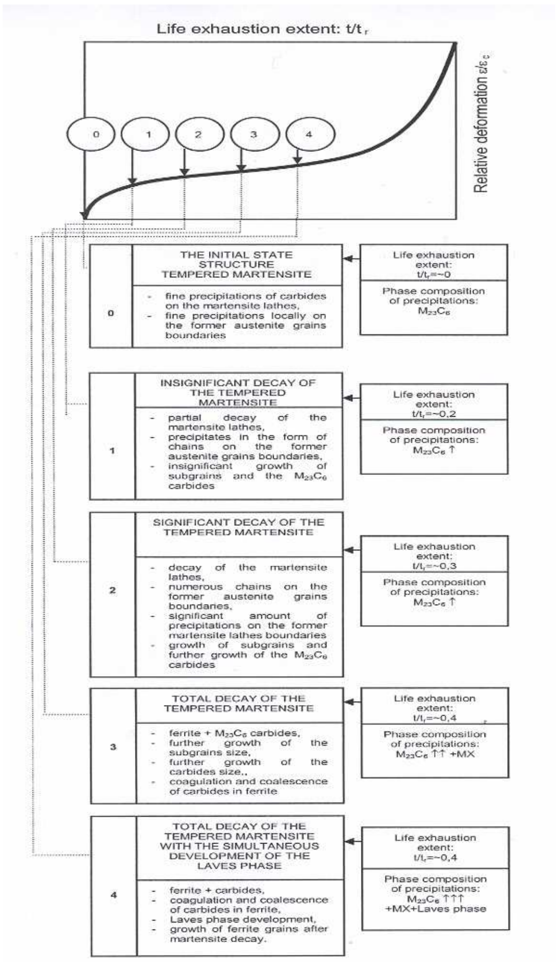

Figure 1. Structure changes depending on the life exhaustion extent during the long-term service of the12Cr-1Mo-V steel in creep conditions [2, 3]

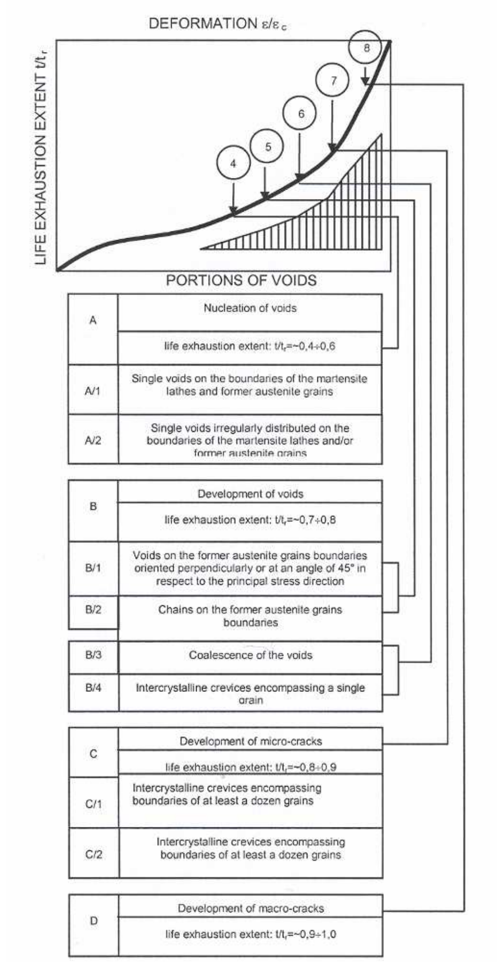

Figure 2. Classification of internal damage of the 12Cr-1Mo-V steel depending on the life exhaustion extent [2, 9]

The structure characteristic of the total decay of the tempered martensite, consisting of ferrite and the $M_{23}C_6$ type carbides as well as of the fine-dispersive MX type phases, in which one can observe the continued growth of subgrains and size of carbides by their coagulation and coalescence corresponds to the next stage of the ongoing changes. In the last stage of changes occurring due to the long-time creep service the structure consists of ferrite and carbides undergoing further coagulation and coalescence. This is accompanied by the ferrite grains growth after martensite disintegration and origination of the Laves phase.

3.2. Changes of the 12Cr-1Mo-V steel structure with the internal damages

Structure changes due to long-term creep service generate and development of the internal defects. Generation processes and development of damages mark transition of the material into the III creep stage, i.e., accelerated creep [4÷6]. The effect of investigation and observations of the successive stages of the development of internal damages is the developed classification for steel with the initial structure of the tempered martensite correlated with the life exhaustion extent t/t_r (Fig. 2). The observations carried out reveal that the dominating way of cracking during the long-term creep is the transcrystalline cavitation cracking connected with generation of voids on boundaries of the martensite lathes and the former austenite grains, and also on the matrix-inclusion interstitial boundary, their growth and coalescence, origination of crevices in areas not bigger than boundaries of a single grain and next of micro-cracks encompassing the area of more than one grain.

It was revealed that nucleation of voids during creep of the steel with the tempered martensite structure in the initial state may be connected with the material decohesion on the interstitial phase boundary between matrix and particles of the carbide precipitates or non-metallic inclusions.

It was observed that the voids nucleate most often on grain boundaries of the former austenite and of the martensite lathes oriented at an angle of 45° or perpendicularly to the principal stress axis. The next stage of the transcrystalline cavitation cracking is growth of voids and their occurrence in the form of chains on the former austenite grains boundaries. The voids undergo coalescence adjoining to each other and merging, initiating the fine surface transcrystalline crevices. The material bridges left among the interconnected voids undergo the intensive plastic deformation, losing finally the capability to these deformations, developing the surface transcrystalline crevices encompassing initially a single and then several or dozen grains, developing in consequence the micro-cracks. Presence of the internal damages, independently from the structure changes development phase decides the material's usefulness for further service.

4. THE ASSESSMENT OF MATERIAL CONDITION

The generalised schema, developed basing on the own research, of the development of structure changes and internal damages depending on their life exhaustion extent is shown in Fig. 3 [1, 9]

The life exhaustion extent is the effect of superposition of structure changes and internal damages during the long-time service. Therefore, the relevant classes of structure observed on the scanning electron microscope on the metallographic microsections or matrix replicae made on the examined unit were attributed to various life exhaustion extents.

The evaluation method using the developed classification is shown in Fig. 4. Knowing the material structure image one can determine the martensite form, development stage of the carbide precipitation and damage processes, determine the main structure class and evaluate the life exhaustion extent. This classification is successfully employed in the engineering practice. Its accuracy and reliability depend on the correct interpretation of the observed structure images, calling for hiring the experienced and professional staff.

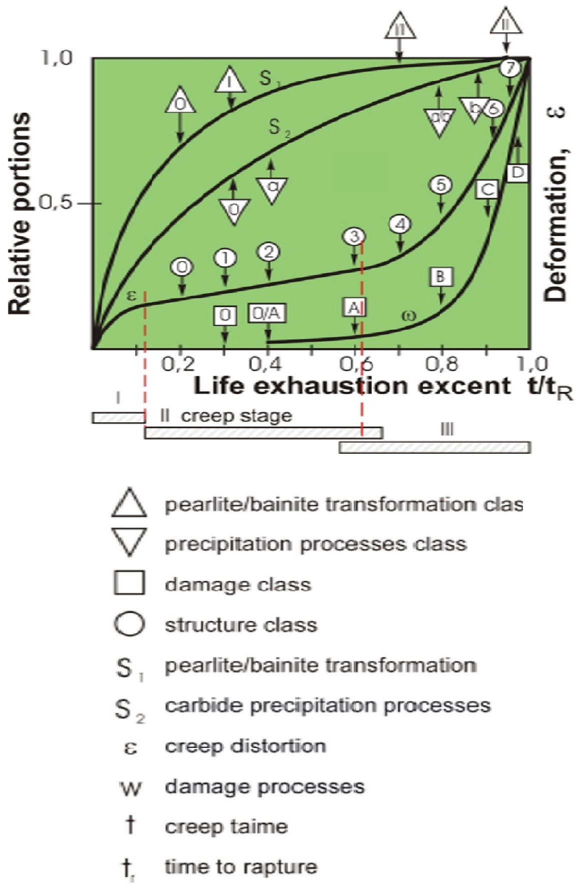

Figure 3. Classification of structure changes and ongoing internal damages due to the long-term service of the12Cr-1Mo-V steel with the tempered martensite structure in creep conditions [1, 9].

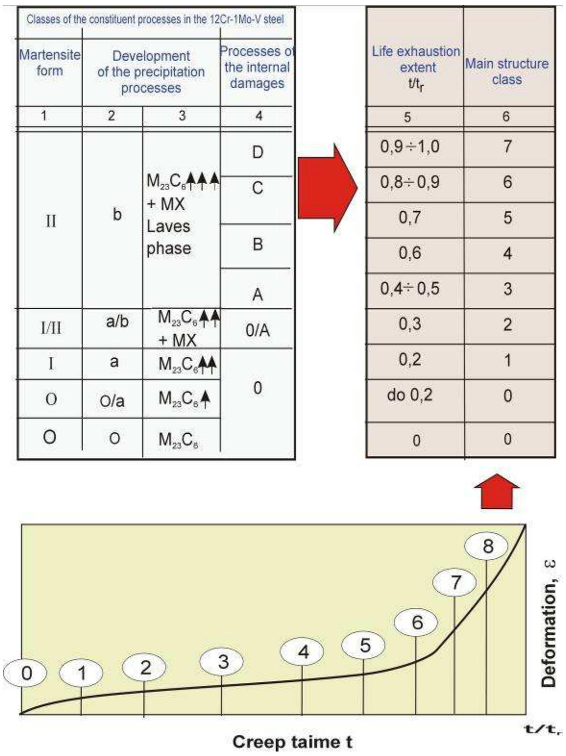

Figure 4. Classification rules for the 12Cr-1Mo-V steel after its long-term service in creep conditions, basing in the constituent processes of structure changes related to the life exhaustion extent [9].

5. SUMMARY

One can attribute to the structure a level of its functional usefulness by examination of the unit's material structure and using the material characteristics worked out basing on destructive tests. One can evaluate the material state basing on them and determine the time of the further safe service in real conditions, using the non-destructive evaluation methods [7, 8].

The objective evaluation of the material structure state and is internal damage after the particular service time in creep regime calls for the correct interpretation of test results, especially of the structure. The ongoing structure changes and nucleation of voids may be analysed in an objective way by the experienced researcher only when carrying out the structure observations of the microsections or matrix replicae on the scanning electron microscope. Both the resolution, depth of field, and limited range of magnifications (to about 1000x) of the light microscope are not sufficient [1, 3].

The obtained results of the many years long own research of the 12Cr-1Mo-V steel, their analysis and interpretation are of practical significance. They were verified in many research projects and expert appraisements carried out, they were the basis for formulating the decisions about admission of the investigated elements from the 12Cr-1Mo-V steel for further safe service for a precisely specified period of time outside of the design period [7÷9].

BIBLIOGRAPHY

1. J. Dobrzański „Complex evaluation and further service forecasting of the power boilers pressure part critical elements in creep service". Report IMŻ N-00322/BM/00, unpublished (in Polish).
2. J. Dobrzański, A. Zieliński, A. Maciosowski „Determining the high-temperature properties and micro-structure of the material of the elements from the 20H12M1F steel and its direct equivalents as the basis for forecasting the residual life using the non-destructive evaluation methods". Report IMŻ S-00355/BM/01, unpublished (in Polish)
3. J. Dobrzański „Development of guidelines for evaluation of the material degradation extent and pressure elements of the BB-1150 power boilers". Report IMŻ Nr N-06698/BM/01, unpublished (in Polish)
4. D.B. Hahn, D.W. Bendick, VGB Kraftwerks Technik 11 (2000) 85.
5. Z.-F. Hu, Z.-G. Yang, „An investigation of the embrittlement in X20CrMoV12.1 power plant steel after long-term service exposure at elevated temperature" Materials Science&Engineering 93/2004 p.224.
6. B. Neubauer, Creep damage evolution in power plants, Proc. Symp. Creep and Fracture of Eng. Mat. And Structures, Swansea, 2.
7. J. Dobrzański, A. Zieliński, A. Tokarz „Evaluation of the technical condition and analysis of the AP 1650 power boiler life", Volume III „Diagnostic material tests of the selected elements". Report IMŻ N-06395/2000, 2001, unpublished (in Polish)
8. J. Dobrzański, A. Zieliński, A. Tokarz „Evaluation of the technical condition and analysis of the BB 1150 power boiler life", Volume III „Diagnostic material tests of the selected elements". Report N-06395/1996÷2004, unpublished (in Polish)
9. J. Dobrzański, A. Zieliński, K. Zieliński „Modernization of the power installation superheater units of the high-pressure power boilers". Final report PC 7 T08B 254 2000 C/5153 Gliwice 2003, unpublished (in Polish).