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MICROSTRUCTURE DEGRADATION AFTER PROLONGED EXPLOITATION OF HEAT RESISTANT STEEL 14MoV6-3

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ABSTRACT
Metallographic testing of material microstructure represents important method for characterization of material behaviour. In case of heat resistant steels that are used for steamlines and boiler components of thermal power plants for a long period of service time, under the influence of mechanical and thermal loads their microstructure will be changed. As a result, it will have significant influence on mechanical properties of such material. Metallographic testing can be used for following of microstructure evolution and estimation of components further safe service time, but at the same time knowing of changes in material microstructure is necessary for better understanding of mechanical properties degradation mechanism. Microstructure as indicator of material degradation of heat resistant steamline steel 14MoV6-3 after almost 200.000 hours of exploitation at steam temperature 540 °C and pressure 13,5 MPa has been investigated in this paper. It is necessary to emphasize that this steamline has been designed for service life time of 100.000 hours for mentioned steam parameters.
Keywords: Microstructure evolution, prolonged exploitation, 14MoV6-3

1. INTRODUCTION
Components of power plant boiler are exposed to elevated temperatures, aggressive environment, creep, fatigue, and other damage mechanisms that can cause degradation, deformation or cracking of components. Under such conditions microstructure and mechanical properties of metallic materials degrade, causing sometimes significant reduction of high-temperature components life. The steel 14MoV6-3 concept goes back to the dawn of creep resistant steels. Experiments with single alloy molybdenum-vanadium steel go back to the time prior to World War II and this steel appears to have stood the test already during the war. The difficult post-war supply situation contributed essentially to the evolution of this low-alloy, but cheap steel of the West German Edelstahl and Roehrenwerke. Creep rupture strength of steel 14MoV6-3 was clearly superior to that of the higher alloyed steel 10CrMoV9-10 which was adopted in West Germany, [1]. Because of microstructure evolution and degradation of properties of this steel in exploitation the inspection measures should be planned and started depending on evaluation of the exhaustion degree. According to the German Codes VGB-R 509L and TRD 508 the start or extended material inspection is required after about 70.000 h for steel 14MoV6-3 and about 100.000 h of exploitation for the other heat-resistant steels, [2]. Investigated material 14MoV6-3 is taken from the Unit 5 main steamline (ø245×28mm) that was in exploitation

194.207 hours at steam temperature 540 °C and steam pressure 13,5MPa, in thermal power plant TE Kakanj, Bosnia and Herzegovina. Samples of steamline exploited material 14MoV6-3 were cut in 2008 because of residual life estimation and microstructure inspection was a just part of overall investigation conducted on this material. Virgin material used for comparing of investigated properties was also cut from the same steamline material 14MoV6-3 (ø245×28mm).

2. MICROSTRUCTURE EVOLUTION ACCORDING TO TECHNICAL NORMS

Metallographic methods have been developed that can correlate either cavitations evolution or changes in carbide spacing with creep-life expenditure. It has been observed that, in many structural applications, cavitation is the principal damage mechanism in brittle zones, and high-stress regions in the base metal. In other cases, carbide coarsening can provide a better indication of life consumption, [3]. The determination of the structural condition and materials exhaustion of creep exposed power plant components is increasingly carried out by field metallography, examining the relevant components. VGB-TW 507 represents guideline for the assessment of microstructure and damage development of creep exposed materials for pipes and boiler components. The microstructure is primarily dependent on the operating temperature, while the damage is mainly controlled by stress or strain. This guideline is therefore restricted to creep exposed components. Depending upon the provision of materials it was anticipated to present microstructures of pipes, bends, fittings and headers. The assessment of the structure was performed on selected components, with heat treatments in accordance with the respective standard. The structures often stabilize and unify after prolonged thermal exposure. For this reason service exposed materials exceeding 100.000h were selected in VGB-TW 507 guideline, [4].

3. CHEMICAL COMPOSITION OF 14MoV6-3

Chemical composition of investigated material 14MoV6-3 (virgin and exploited) was accomplished in order to confirm that all delivered specimens of steamline are made from the same material, so the results of predicted investigation on virgin and exploited material could be comparable. Method for determination of chemical composition was spectral analysis.

Chemical composition of material 14MoV6-3 according to normative DIN 17175/79, [5], is presented in Table 1, and for virgin and exploited material in Table 2 and Table 3, respectively. From the results of chemical composition analysis it is obvious that investigated steamline specimens (virgin and exploited) are made of the same material 14MoV6-3.

Table 1. Chemical composition of steel 14MoV6-3, according to DIN 17175, [5]

Grade	C, %	Si, %	Mn, %	P, %	S, %	Cr, %	Mo, %	V, %
14MoV6-3	0,10-0,18	0,10-0,35	0,40-0,70	Max. 0,035	Max. 0,035	0,30-0,60	0,50-0,70	0,22-0,32

Table 2. Chemical composition of virgin material 14MoV6-3, [6]

Grade	C, %	Si, %	Mn, %	P, %	S, %	Cr, %	Mo, %	V, %
14MoV6-3	0,149	0,30	0,57	0,013	0,015	0,59	0,475	0,28

Table 3. Chemical composition of exploited material 14MoV6-3, [6]

Grade	C, %	Si, %	Mn, %	P, %	S, %	Cr, %	Mo, %	V, %
14MoV6-3	0,139	0,32	0,56	0,013	0,013	0,50	0,47	0,28

4. RESULTS OF METALLOGRAPHIC TESTING

In order to investigate microstructure of exploited steamline material, metallographic testing was accomplished. This was done in laboratory at IWS Institute TU Graz (Institute for materials and welding at Technical University Graz), Austria, by testing and comparison of microstructure of virgin material and exploited material 14MoV6-3 after 194.207 hours of exploitation.

One specimen per material condition (virgin and exploited) was used and metallographic testing of material microstructure by optical microscope was done with different magnifications of 200x, 500x and 1000x. Figures 1, 2, 3, 4, 5 and 6 shows microstructure of investigated material 14MoV6-3 at transversal cross section of steamline pipe with different magnifications.

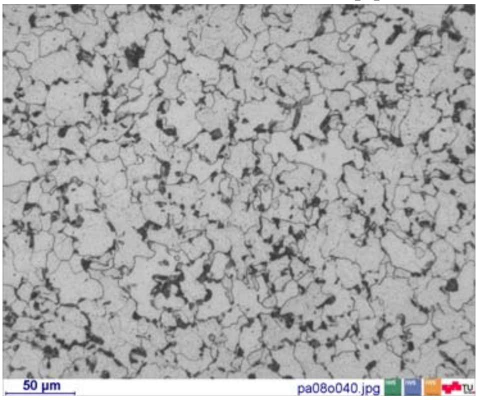

Figure 1. Microstructure of virgin steamline material 14MoV6-3, magnification 200x, [6]

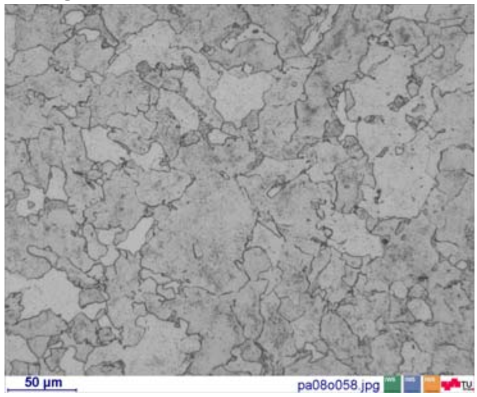

Figure 2. Microstructure of exploited steamline material 14MoV6-3, magnification 200x, [6]

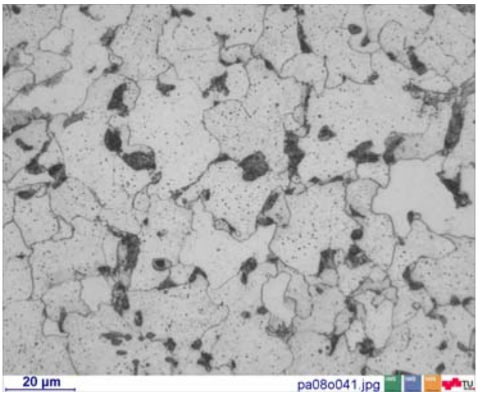

Figure 3. Microstructure of virgin steamline material 14MoV6-3, magnification 500x, [6]

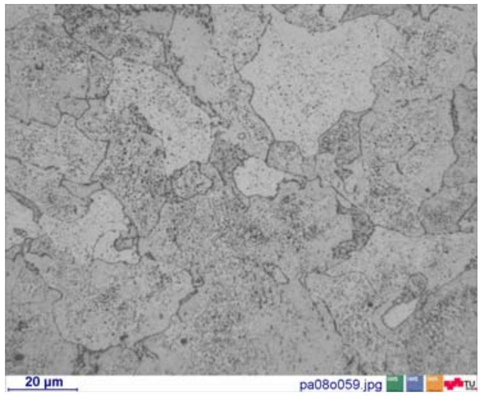

Figure 4. Microstructure of exploited steamline material 14MoV6-3, magnification 500x, [6]

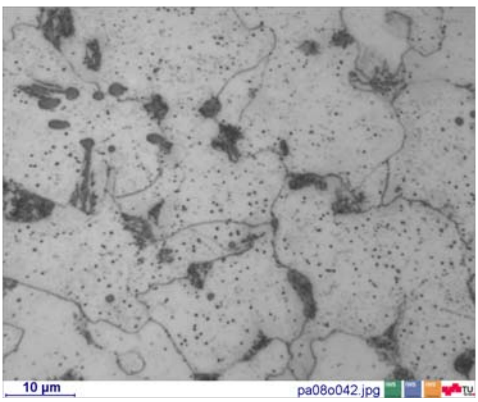

Figure 5. Microstructure of virgin steamline material 14MoV6-3, magnification 1000x, [6]

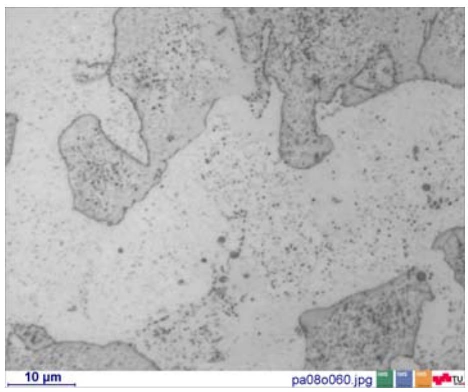

Figure 6. Microstructure of exploited steamline material 14MoV6-3, magnification 1000x, [6]

5. FINAL REMARKS

Long-term operation of thermal power plant main steamline material at elevated temperature causes decrease of strength, greater in the case of yield strength than in the case of tensile strength, but also significant decrease of impact toughness. Deterioration in functional properties is caused by changes in the steel microstructure due to long-lasting operation. Microstructure changes under the influence of temperature, stress and environment in exploitation cause the substantial degradation of mechanical properties.

According to previous investigations of this material with similar service conditions, that are published in scientific journals, the initial microstructure of the 14MoV6-3 low-alloyed steel features the mixture of bainite with ferrite, sometimes with a small amount of pearlite. Occurrences of the significant amount of the M_3C carbides and numerous, very fine MC type ones, are identified in such material. The final structure image after prolonged exploitation is ferrite with rather homogeneously distributed precipitations inside grains and chains of the significant amount of precipitations on their boundaries, [7]. Results of microstructure investigation that are presented in this paper mainly can confirm previous facts, but in addition to mentioned microstructure evolution, there is also a significant growth of ferrite grain size after long-term operation at elevated temperature.

Among the different aspects that can be observed the evaluation of microcavitation presence and creep damage evolution seems to be, for the widely applied ferritic low alloyed steels, the most consolidated approach and the evolution of Neubauer classification with subclassification in particular of grade 2 and 3 (that corresponds to the longest part of a component life) should be continued and encouraged, [8]. Revision of Neubauer classification is presented in the German VGB-TW 507 “Guidelines for the assessment of microstructure and damage development of creep exposed materials for pipes and boiler components” that is considered as one of the most updated reference document in European countries.

For every other microstructural aspect (except microcavities), whatever is the monitored one it is very important that the evaluation is made by comparison with the original (virgin material) status.

Major limitation of the metallographic testing is the necessity to reduce the examined area to a very limited extension if compared to actual component dimension. The preliminary correct identification of the position in component that should be investigated is thus a very critical phase, in order to be sure that the examined sample of material is representative of the most probabilistic damaged area.

Evaluation of microstructural evolution in exposed to service materials is a key tool for a correct evaluation of material status and allowable service extension. The knowledge of the structure and degree of damage could be essential for the assessment of residual service life and damage analysis respectively. It should however be pointed out that the above mentioned knowledge alone does not allow a prediction of the residual service life. A reliable life assessment should be made not only by means of microstructural inspection but it’s preferable that together with other inspections the same is included.

6. REFERENCES

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