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HARDNESS AS INDICATOR OF MATERIAL DEGRADATION AFTER LONG-TERM EXPLOITATION OF STEAMLINE IN THERMAL POWER PLANT

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ABSTRACT
Hardness testing is perhaps the simplest and the least expensive method of mechanically characterizing a material since it does not require an elaborate specimen preparation, involves rather inexpensive testing equipment, and is relatively quick. The theoretical and empirical investigations have resulted in fairly accurate quantitative relationships between hardness and other mechanical properties of materials. Hardness, though apparently simple in concept, is a property that represents an effect of complex elastic and plastic stress fields set up in the material being tested. Hardness as indicator of material degradation of 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.
Keywords: Hardness, material degradation, steamline

1. INTRODUCTION
Many of the critical components in thermal power plants are made of steels developed to resist deformation and failure under service conditions and they are expected to serve reliably for 100.000 hours of exploitation (10-15 years). Today, as a result of development of new steels with improved properties, designed life time of some components such as main steamlines for thermal power plants is much longer and it is 200.000 hours.
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. Because of microstructural 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 hours for steel 14MoV6-3 and about 100.000 hours of exploitation for the other heat-resistant steels, [1].
Nevertheless to the very long history of low-alloyed steel 14MoV6-3, this material is still built in the numerous power plants, particularly in the boilers and its belonging high-temperature components.
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 hardness test 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. HARDNESS AS INDICATOR OF MATERIAL DEGRADATION

Hardness testing is perhaps the simplest and the least expensive method of mechanically characterizing a material since it does not require an elaborate specimen preparation, involves rather inexpensive testing equipment, and is relatively quick. The theoretical and empirical investigations have resulted in fairly accurate quantitative relationships between hardness and other mechanical properties of materials. Hardness, though apparently simple in concept, is a property that represents an effect of complex elastic and plastic stress fields set up in the material being tested, [2].

The hardness can be used as an indicator for the state of the steel in its life cycle. Changes in hardness occur due to recovery, coarsening of carbide particles and recrystallisation. All creep resistant power plant steels are severely tempered before they enter service. They are therefore beyond the state where secondary hardening is expected and the hardness can, during service, be expected to decrease monotonically, [3]. Since the first study developed for the assessment of residual life in high temperature serviced components, attention has been paid to hardness value in order to find numerical correlation with service and expected time of the component. In the research studies hardness has been measured through standard instruments as Vickers or Brinell indenter based, but for in plant direct monitoring of serviced component some instruments based on energy absorption during impact or indentation combined with ultrasonic measurements are available as corelation for standard unit conversion. Due to this fact it is thus possible to obtain also results directly from in-service components. Actually at the moment although hardness measurement in plant is commonly applied technique during maintenance inspection (especially in combination with replica) the most of the published studies are based on laboratory measurement made on test specimens with standard hardness measurement techniques, [4].

3. CHEMICAL COMPOSITION AND MICROSTRUCTURE 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. Slightly less content of Molybdenum, comparing with chemical composition according to DIN 17175, is probably error of measuring without influence on further investigation, because content is almost the same for virgin and exploited steamline material.

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

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 is ferrite with rather homogeneously distributed precipitations inside grains and chains of the significant amount of precipitations on their boundaries, [7]. In addition to mentioned microstructure evolution, there is also a significant growth of ferrite grain size after long-term operation at elevated temperature.

4. RESULTS OF HARDNESS TESTING

In order to investigate decrease of hardness value of exploited steamline material, hardness test was accomplished at room temperature. This was done in laboratory by testing and comparison of hardness values of virgin material and exploited material 14MoV6-3 after 194.207 hours of exploitation.
For hardness test 1 specimen per material condition (virgin and exploited) was used and method was Brinell hardness test (HB30). Hardness test was done on outer surface, 1.5 mm under the outer surface, and at longitudinal and transversal cross section of steamline pipe.
According to European normative EN 10216-2:2002, [8], material 14MoV6-3 are delivering as seamless steel tubes for elevated temperatures with acceptable value of hardness in range of 145 – 190 HB30 at room temperature. Acceptable hardness value at elevated temperatures is not defined by this normative.
Schemes of hardness tested specimens at room temperature (20 °C) of virgin and exploited steamline material 14MoV6-3 are shown in Figure 1 and Figure 2, respectively. Figures 1 and 2 also show places of indentation during hardness test.

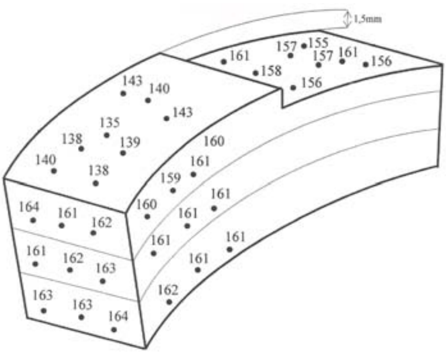

Figure 1. Tested specimen of virgin steamline material 14MoV6-3, [6]

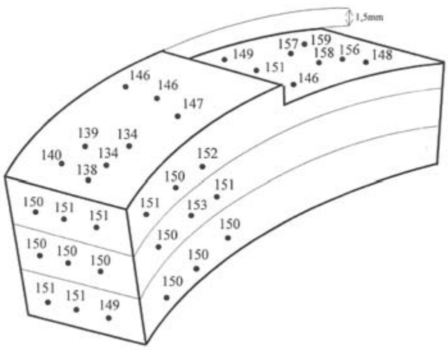

Figure 2. Tested specimen of exploited steamline material 14MoV6-3, [6]

Results of measured hardness values (HB30) for virgin and exploited steamline material 14MoV6-3 are presented in Table 4.

Table 4. Results of measured hardness values for virgin and exploited material 14MoV6-3, [6]

Steamline material 14MoV6-3	Hardness, HB30 (Acceptable value 145 – 190 HB30 according to EN 10216-2:2002)			
	Outer surface	1,5 mm under outer surface	Transversal cross section	Longitudinal cross section
Virgin	135 - 143	155 - 161	159 - 162	161 - 164
Exploited	134 - 147	146 - 159	150 - 153	149 - 151

According to results of Brinell hardness test of virgin steamline material 14MoV6-3 it is noticed that hardness values at outer surface are slightly below acceptable values according to EN 10216-2, but it could be explained by decarburisation in manufacturing process of steamline pipe. Hardness values 1.5 mm under outer surface, at transversal and longitudinal cross sections are in acceptable range according to EN 10216-2.
According to results of Brinell hardness test of exploited steamline material 14MoV6-3 it is noticed that hardness values at outer surface are partly below acceptable values according to EN 10216-2, but at the same time there is no significant difference in comparing with virgin steamline material. Hardness values 1.5 mm under outer surface are in acceptable range according to EN 10216-2 but they are lower in comparing with virgin material. Hardness values at transversal and longitudinal cross sections are also in acceptable range according to EN 10216-2, but there is more significant decrease of hardness in comparing with virgin material.

5. FINAL REMARKS

Considering the fact that hardness as mechanical propertie of material is in corelation with characteristics of strength and implicitly indicate strength of material, it is possible to assume that during exploitation of steamline material 14MoV6-3 there was not only decrease of hardness, but also significant decrease of strength. For serious investigation of material degradation and residual life assessment such assumption must be proved and quantified by tensile testing of material.
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. Microstructural changes under the influence of temperature, stress and environment in exploitation cause the substantial degradation of mechanical properties.
Hardness test cannot be used for the final assessment of the further steamline safe service time and it is not quite useful for the residual life assessment and for determining of the exhaustion extent, but obviously it should be included together with the other diagnostic methods as an important indicator. However, if we use hardness as indicator of material degradation it is also necessary to take in account some factors that make additional uncertainities during hardness test and complicate residual life assessment. Among others some of such factors are effect of material ageing, local variations of material structure, material surface conditions etc.

6. REFERENCES

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