14th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2010, Mediterranean Cruise, 11-18 September 2010

IMPACT TOUGHNESS OF STEAMLINE MATERIAL 14MoV6-3 AFTER LONG-TERM EXPLOITATION

Damir Hodžić, Dr.Sc. Mech.Eng.
Faculty of Mechanical Engineering
Vilsonovo šetalište 9, Sarajevo
Bosnia and Herzegovina

Ismar Hajro, Dr.Sc. Mech.Eng.
Faculty of Mechanical Engineering
Vilsonovo šetalište 9, 71000 Sarajevo
Bosnia and Herzegovina

ABSTRACT
Long-term operation of thermal power plant main steamline material at elevated temperature (540 °C) 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. In order to investigate decrease of impact toughness of material 14MoV6-3, following temperatures were selected for impact testing: 20 °C, 150 °C, 400 °C and 540 °C (operating temperature). This was done by testing and comparison of impact toughness of virgin and serviced material 14MoV6-3 after 194.207 hours of exploitation. Irrespective to the fact that impact tests cannot be used for assessment of the further steamline safe service time, it is indispensable for assessing the materials deformability and its capability to carry the load in its further service process.
Keywords: Steamline, steel 14MoV6-3, impact toughness, long-term service

1. INTRODUCTION

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. 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 h for steel 14MoV6-3 and about 100.000 h of exploitation for the other heat-resistant steels, [1]. In order to investigate decrease of impact toughness of material, low-alloyed steel 14MoV6-3 exposed 194.207 hours of exploitation, has been compared with same, but virgin material. The low-alloyed steel was chosen for this investigation, because it is widely used for steamlines in power plants in Bosnia and Herzegovina, and also because it has been used for long service period (from 1968), so that significant decrease of structure and properties can be expected.

Investigated material is taken from the Unit 5 main steamline (ø245×28mm) that operated at temperature 540 °C and pressure 13,5MPa, in thermal power plant TE Kakanj, Bosnia and Herzegovina. Sample of steamline exploited material 14MoV6-3 was cut in 2008 because of residual life estimation. Virgin material was also cut from the steamline material 14MoV6-3 (ø245×28mm).

2. CHEMICAL COMPOSITION AND MICROSTRUCTURE

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, [2], 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 of Molybdenum is almost the same for virgin and exploited steamline material.

Table 1. Chemical composition of steel 14MoV6-3, according to DIN 17175, [2]

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, [3]

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, [3]

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

Long-term operation of thermal power plant main steamline material at elevated temperature (540 °C) 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. Microstrutural changes under the influence of temperature, stress and environment in exploitation cause the substantial degradation of mechanical properties.

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 first stage of the structure changes in exploitation is characteristic of the slight decay of the bainite (pearlite) areas. This is accompanied by coagulation of precipitations in these areas, [4]. The significant decay of the bainite (pearlite) areas due to the long term creep is the next stage of structure changes. On the other hand, on the ferrite grains boundaries precipitations occur forming chains. The final structure image is ferrite with rather homogeneously distributed precipitations inside grains and chains of the significant amount of precipitations on their boundaries, [4]. In addition to mentioned microstructure evolution, there is also a significant growth of ferrite grain size after long-term operation at elevated temperature.

3. RESULTS OF IMPACT TOUGHNESS TESTING

In general, notch toughness is measured in terms of the absorbed impact energy needed to cause fracturing of the specimen. The change in potential energy of the impacting head (from before impact to after fracture) is determined with a calibrated dial that measures the total energy absorbed in breaking the specimen. Other quantitative parameters, such as fracture appearance and degree of ductility/deformation, are also often measured in addition to the fracture energy.

Impact tests may also be instrumented to obtain load data as a function of time during the fracture event. The Charpy V-notch test continues to be the most utilized and accepted impact test in use in the industry, [5]. According to the European technical regulations, the impact toughness test is defined in normative EN 10045 [6], where V-notched specimen (also, other type of notches are possible), 10x10x55mm in size, is loaded to impact bending by Charpy pendulum.
According to normative DIN 17175/79 material 14MoV6-3 were delivering as seamless steel tubes for elevated temperatures with minimum impact toughness 41 J (transverse specimens) and 55 J (longitudinal specimens) at room temperature. Minimum impact toughness at elevated temperatures is not defined by this normative.
In order to investigate decrease of impact toughness of exploited steamline material 14MoV6-3, following temperatures were selected for impact testing: 20 °C, 150 °C, 400 °C and 540 °C (operating temperature). This was done by testing and comparison of impact toughness values of virgin material and exploited material 14MoV6-3 after 194.207 hours of exploitation. For every testing temperature 3 Charpy V-notch specimens were used. Results of average (3 specimens) impact toughness values (KV) per testing temperature for virgin and exploited material 14MoV6-3 are presented in Figure 1. Tested Charpy V-notch specimens at room temperature (20 °C) of virgin and exploited steamline material 14MoV6-3 are shown in Figure 2 and Figure 3, respectively.

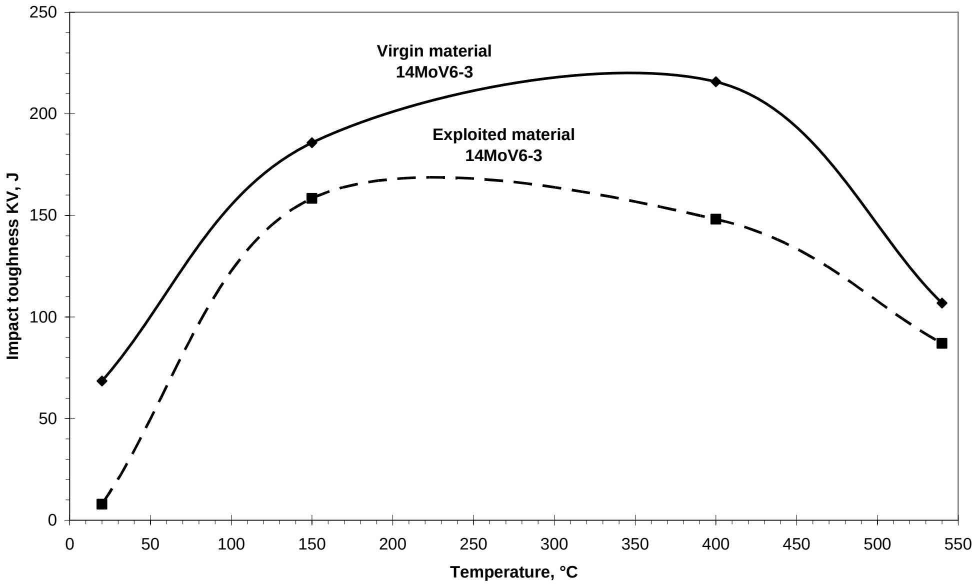

Figure 1. Impact toughness testing results of virgin and exploited material 14MoV6-3

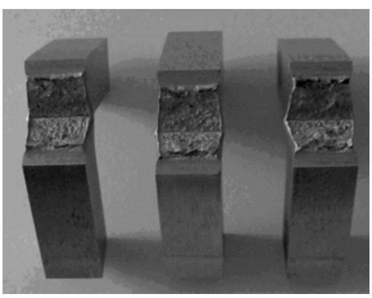

Figure 2. Tested V-notch specimens of virgin steamline material 14MoV6-3 at 20 °C

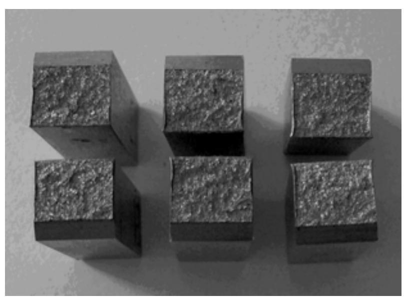

Figure 3. Tested V-notch specimens of exploited steamline material 14MoV6-3 at 20 °C

From the results of impact toughness testing shown in Figure 1 it is notable that the total impact energy (impact toughness) increases slightly up to 400 °C for virgin material 14MoV6-3 and up to 150 °C for exploited material 14MoV6-3. It is reduces significantly, but not drastically above 400 °C for virgin material and above 150 °C for exploited material, so that its values are still more than sufficient at steamline service temperature 540 °C.

The most important result of exploited steamline material impact toughness testing is extremely low value of total impact energy (impact toughness) at room temperature 20°C (average value is 7,89 J), which is significantly beneath the allowed value of 41 J according to normative DIN 17175/79. Also, in Figure 3 tested specimens of exploited steamline material shows exceptionally brittle character of fracture at room temperature (20 °C). Anyhow, at higher temperatures the impact energy of exploited steamline material is sufficient, and character of specimens fracture is more ductile.

According to results of impact toughness testing it is also possible to notice that the transitional temperature of exploited material 14MoV6-3 has increased above room temperature, indicating significant change in the material behavior at impact load.

4. FINAL REMARKS

Boiler components and belonging steamlines of thermal power plants have exceeded most often significantly their design service time being most often 100.000 hours long. They require forecasting their further safe service for the conditions in exploitation. Evaluation of their residual life, integrity, and safe service demand proven diagnostic methods. Characterization of materials condition in service also belongs to these methods, and assessment of material is probably one of the most significant factors in assessment of the condition of the examined components. Impact toughness value of steamline material 14MoV6-3 depends mostly on development of the precipitation processes and also on development of the microstructure changes and structure discontinuities, as well as grain growth, originated during the long period of exploitation at elevated temperature.

Impact toughness testing of the steamline material 14MoV6-3 test specimens with the V-notch carried out at temperatures 20 °C, 150 °C, 400 °C and 540 °C was made to determine usefulness of the material after the long time service. As already explained significant change in material behavior occurs at room temperature (20°C), whereas differences are smaller but expressed at higher temperatures. Comparing with the initial state of virgin steamline material, the fracture appearance transition temperature for investigated exploited steamline material 14MoV6-3 is increased toward higher value. Moreover, exploited steamline material 14MoV6-3 after long-term exploitation (194.207 hours) has lower impact toughness value at room temperature than the minimum one required for this material as delivered from the steel plant, according to standard DIN17175/79.

Impact toughness 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, it is indispensable for assessing the material’s deformability and its capability to carry the load connected with the pressure tests, as well as in limiting the number of banking and setting to work the steamline in its further service process.

5. REFERENCES

[1] ECCC Recommendations – Volume 9, Part II: High Temperature Component Analysis Overview of Assessment & Design Procedures, ECCC, 2005

[2] Normative DIN 17175/79: Seamless steel tubes for elevated temperatures, DIN, 1979

[3] D. Hodzic: PhD Dissertation “Contribution to integrity assessment of power plant steam pipeline constructed of 14MoV6-3 material”, Faculty of Mechanical Engineering Sarajevo, 2010

[4] J. Dobrzanski, A. Zielinski, H.Krtzon: Mechanical Properties and Structure of the Cr-Mo-V Low-alloyed Steel After Long-term Service in Creep Condition, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 23, International OSCO World Press, 2007

[5] ASM Handbook Vol. 8 – Mechanical testing and evaluation, Impact toughness testing, ASM International, 2000

[6] Normative EN 10045-1:1990, Charpy impact test on metallic materials - Part 1: Test method (V-and U-notches), CEN - European Committee for Standardization