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IMPACT TOUGHNESS OF REGENERATIVE HEAT TREATED STEEL 14MoV6-3

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ABSTRACT
In this paper heat resisted steel 14MoV6-3 in conditions as a virgin, exploited and regenerative heat treated material is investigated. This steel was used for the main steamline of thermal power plant for a prolonged life time period under service conditions. As a consequence of microstruture evolution through long period of exploitation at elevated temperature there was a significant decrease of mechanical properties. Some published investigations reports about possibility of regenerative heat treatment after prolonged exploitation of low alloyed Cr-Mo-V cast steels. Considering this assumption exploited steamline steel 14MoV6-3 is exposed to regenerative heat treatment in order to improve decreased mechanical properties. Microstructure of regenerative heat treated material 14MoV6-3 implicitly indicated increase of strength properties, but not toughness properties at same time. In order to investigate impact toughness following temperatures were selected: 20°C, 150°C, 400°C and 540°C (service temperature) for virgin, exploited and regenerative heat treated steamline steel 14MoV6-3. Further investigation related to regeneration of exploited 14MoV6-3 should be directed to more adequate heat treatment cycle.
Keywords: 14MoV6-3, Regenerative heat treatment, Impact toughness

1. INTRODUCTION
Considering assumption that post service regenerative heat treatment could change microstructure and improve decreased mechanical properties, heat resisted steel 14MoV6-3 is investigated in this paper. Low-alloyed steel 14MoV6-3 exposed to 194.207 hours of service, has been compared with virgin and post service regenerative heat-treated material. Decrease of mechanical properties of exploited material is caused by changes in the steel microstructure due to long-lasting service operation. Reduction of impact toughness caused by long-term exploitation of the steel at elevated temperature depends to a large extent on the initial steel microstructure. Some published investigations reported that decrease of impact toughness caused by long-lasting operation is the least in the case of tempered bainite structure, [1]. Metallographic examinations of various steel grades after long-term service at elevated temperature revealed that transformations of carbides and morphological changes of phases have the most significant effect on service properties degradation, [2]. Results of some published investigations with low alloyed Cr-Mo-V cast steels reports about possibility of regenerative heat treatment after prolonged exploitation and influence of microstructure on properties, [1, 3, 4].
The low-alloyed steel 14MoV6-3 was chosen for this investigation, because it has been used for long service period with similar exploitation history and microstructure evolution as a mentioned cast steels. 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 Kakanj, Bosnia and Herzegovina. Chemical composition testing of investigated material 14MoV6-3 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, exploited and regenerative heat treated material could be comparable. Method for determination of chemical composition was spectral analysis. Chemical composition of material 14MoV6-3 was in accordance to normative DIN 17175/79 for all material conditions, [5, 6].

2. HEAT TREATMENT AND MICROSTRUCTURE

According to published investigations regenerative heat treatment was accomplished with relative success on cast steels G21CrMoV4-6 and G17CrMoV5-10 that were used for turbine frame at power plants. Material of turbine frame G21CrMoV4-6 was in service 186.000 hours with steam temperature 540 °C and pressure 13,5 MPa, while material of turbine frame G17CrMoV5-10 was in service 251.678 hours with steam temperature 535 °C and pressure 9,0 MPa before regenerative heat treatment. After long-term exploitation in both cases cast steels had significant decrease of mechanical properties (strength, toughness) and degraded ferrite-bainite/pearlite structure with numerous carbide precipitations located on grain boundaries and inside ferrite grains [1, 3, 4].

The goal of regenerative heat treatment of exploited steel 14MoV6-3 was obtaining improved mechanical properties that were degraded, particularly impact toughness. Regenerative heat treatment (hardening and tempering) was done according to normative DIN 17175/79 for high-temperature seamless tube steel 14MoV6-3 on specimen of exploited steel:

- hardening, heating to temperature 950 °C (1 hour) and accelerated cooling in oil “RAPID 90E” because greater tube wall thickness, and
- tempering, heating to temperature 700 °C (3 hours) with slow cooling together with furnace for heat treatment.

Metallographic testing was accomplished for virgin, exploited and regenerative heat treated material 14MoV6-3 by optical microscope with magnifications 500x. Figures 1, 2, and 3 shows microstructure of investigated material 14MoV6-3 at transversal cross section of steamline pipe with same magnifications, [6].

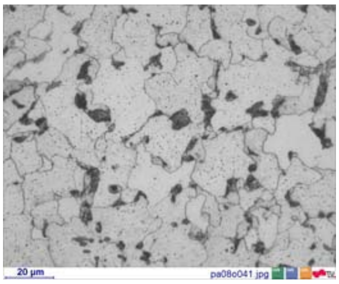

Figure 1. Virgin material 14MoV6-3

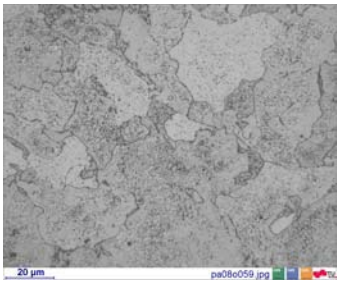

Figure 2. Exploited material 14MoV6-3

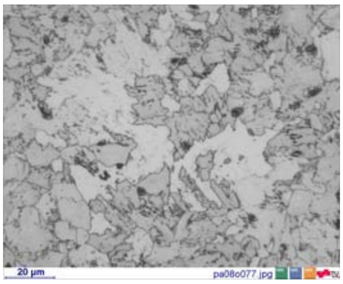

Figure 3. Regenerative heat treated material 14MoV6-3

Brinell 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, [7], 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. Results of measured hardness values (HB30) for virgin, exploited and regenerative heat treated steamline material 14MoV6-3 are presented in Table 1.

Table 1. Results of measured hardness values for investigated material 14MoV6-3, [6]

Hardness	Virgin, HB30	Exploited, HB30	Heat treated, HB30
Outer surface	135 – 143	134 – 147	270 – 288
1.5 mm under outer surface	155 – 161	146 – 159	252 – 265
Transversal cross section	159 – 162	150 – 153	288 – 293
Longitudinal cross section	161 – 164	149 – 151	290 – 293

3. RESULTS OF IMPACT TOUGHNESS TEST

Impact toughness test is defined in normative EN 10045 [8], 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, [5]. Minimum impact toughness at elevated temperatures is not defined by this normative.

In order to investigate impact toughness of steamline material 14MoV6-3, following temperatures were selected for impact toughness test: 20 °C, 150 °C, 400 °C and 540 °C (service temperature). This was done by testing and comparison of impact toughness values of virgin, exploited and regenerative heat treated material 14MoV6-3. 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, exploited and regenerative heat treated material 14MoV6-3 are presented in Figure 4.

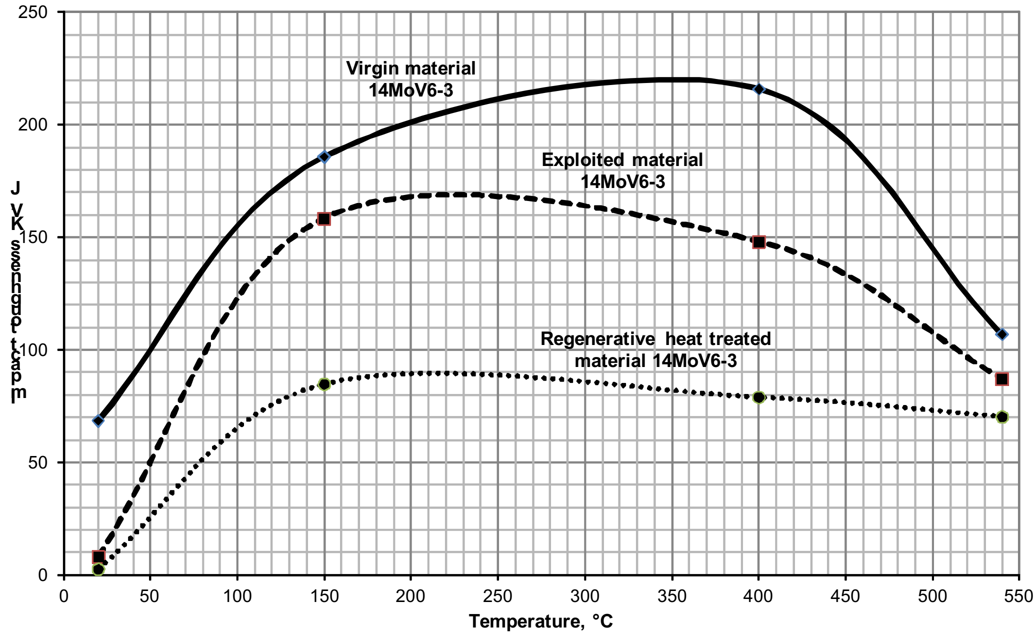

Figure 4. Impact toughness testing results of material 14MoV6-3, [6]

Tested Charpy V-notch specimens at room temperature (20 °C) of virgin, exploited and regenerative heat treated steamline material 14MoV6-3 are shown in Figures 5, 6 and 7, respectively, [6].

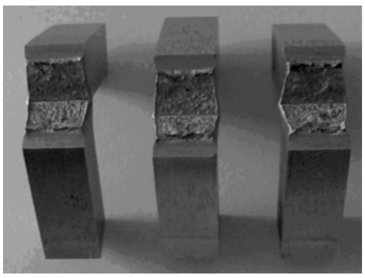

Figure 5. Virgin material 14MoV6-3 at 20 °C

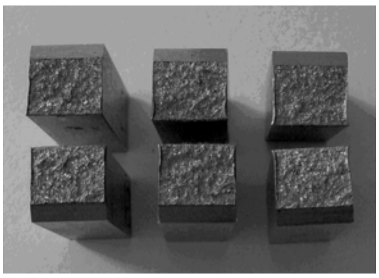

Figure 6. Exploited material 14MoV6-3 at 20 °C

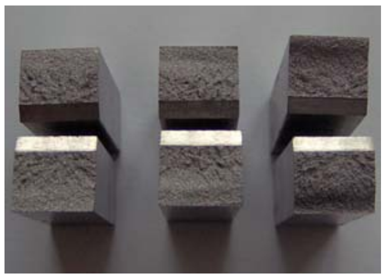

Figure 7. Reg. heat treated material 14MoV6-3 at 20°C

In accordance with results of impact toughness test it is also possible to notice that the transitional temperature of exploited and regenerative heat treated material 14MoV6-3 has increased above room temperature, indicating significant change in the material behavior at impact load.

4. FINAL REMARKS

Results of microstructure investigation that are presented in this paper mainly can confirm facts that the initial microstructure of the 14MoV6-3 low-alloyed steel features the mixture of bainite with ferrite, sometimes with a small amount of pearlite and significant amount of the M_3C carbides and numerous, very fine MC type ones. The final structure image after long-term exploitation under service conditions is ferrite with rather homogeneously distributed precipitations inside grains and chains of the significant amount of precipitations on their boundaries, [2]. But in addition to mentioned microstructure evolution, there is also a significant growth of ferrite grain size after long-term operation at elevated temperature. As a consequence, grain growth has a significant influence on decrease of steel 14MoV6-3 impact toughness properties, [9]. Microstructure of regenerative heat treated material 14MoV6-3 is ferrite structure with pearlite/bainite constituents on ferrite grain boundaries but also with insufficiently tempered constituents created by accelerated cooling. Comparing with virgin material there is a less carbide precipitates in ferrite grains, less amount of ferrite at all and very small amount of pearlite and bainite. Considering the highly increased hardness of regenerative heat treated material 14MoV6-3, that is obviously consequence of large amount of insufficiently tempered constituents, it implicitly indicate increase of strength properties, but also significant decrease of toughness properties after regenerative heat treatment, [10].

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. For this reason some changes are necessary in the structure degraded by long-term exploitation. These changes are:

- grain size reduction allowing to increase the crack resistance, decrease the transition temperature and raise yield strength;
- dissolving of carbides in austenite, particularly the carbides precipitated on grain boundaries;
- obtaining of tempered ferrite/bainite structure.

Further investigation related with possibility of exploited 14MoV6-3 material post service regeneration by heat treatment should be directed to search for more adequate heat treatment cycle.

5. REFERENCES

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