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REGENERATIVE HEAT TREATMENT OF HEAT RESISTANT STEEL 14MoV6-3

Doc. Dr. Damir Hodžić, Dipl.ing.
Faculty of Mechanical Engineering Sarajevo
Vilsonovo šetalište 9, Sarajevo
Bosnia and Herzegovina

Doc. Dr. Ismar Hajro, Dipl.ing.
Faculty of Mechanical Eng. Sarajevo
Vilsonovo šetalište 9, Sarajevo
Bosnia and Herzegovina

Univ. Assist. Mr Petar Tasić, Dipl.ing.
Faculty of Mechanical Eng. Sarajevo
Vilsonovo šetalište 9, Sarajevo
Bosnia and Herzegovina

ABSTRACT
After prolonged exploitation under service conditions heat resisted steels that are used for power plant boiler components are exposed to microstructure evolution. As a result of material changed microstructure significance decrease of mechanical properties is expected and critical components must be removed before failure. 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 mechanical properties. 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. This steel was in exploitation as a main steamline in power plant boiler almost 200.000 hours under service conditions. Exploited material is exposed to regenerative heat treatment and microstructure of virgin, exploited and regenerative heat treated material 14MoV6-3 is presented in comparative way.
Keywords: Heat resistant steel, Regenerative heat treatment, Microstructure

1. INTRODUCTION
Long-term exploitation of low alloyed heat resistant Cr-Mo-V steels at elevated temperatures causes decrease of material strength properties, greater in the case of yield strength than in the case of tensile strength, but also decrease of material impact toughness. Decrease of mechanical properties 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 impact energy decrease 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 mechanical properties, [1, 3, 4].
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. According to published investigations material of turbine frame G21CrMoV4-6 was in exploitation 186.000 hours with steam temperature 540 °C and pressure 13,5 MPa, while material of turbine frame G17CrMoV5-10 was in exploitation 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.

2. MATERIAL AND EXPERIMENT ASSUMPTIONS

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 194.207 hours of exploitation, has been compared with virgin and regenerative heat-treated material. 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 turbine frame cast steels in introduction. 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].

3. REGENERATIVE HEAT TREATMENT OF STEEL 14MoV6-3

The goal of regenerative heat treatment of exploited steel 14MoV6-3 was obtaining improved mechanical properties that were degraded, particularly impact toughness. For this reason some changes are necessary in the structure degraded by long-term exploitation. These changes are, [1]:

- 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.

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.

Regenerative heat treatment cycle that was used for exploited steel 14MoV6-3 is shown in Figure 1.

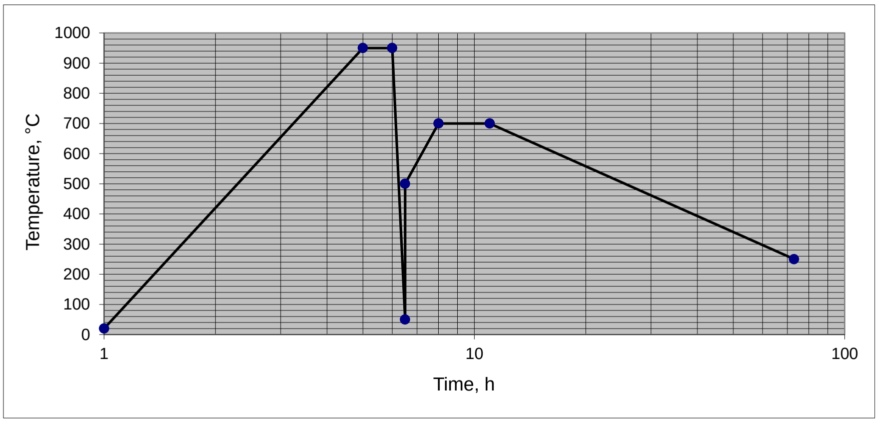

Figure 1. Regenerative heat treatment cycle of exploited material 14MoV6-3, [6]

In order to investigate microstructure of steamline material, metallographic testing was accomplished. This was done in laboratory at IWS Institute TU Graz, Austria, by testing and comparison of microstructure of virgin, exploited and regenerative heat treated material 14MoV6-3. Metallographic testing of material microstructure by optical microscope was done with magnifications 500x. Figures 2, 3, and 4 shows microstructure of investigated material 14MoV6-3 at transversal cross section of steamline pipe with same magnifications.

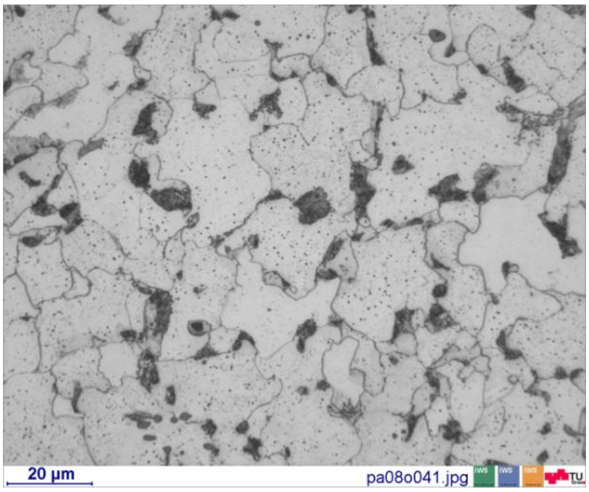

Figure 2. Microstructure of virgin steamline material 14MoV6-3, magnification 500x, [6]

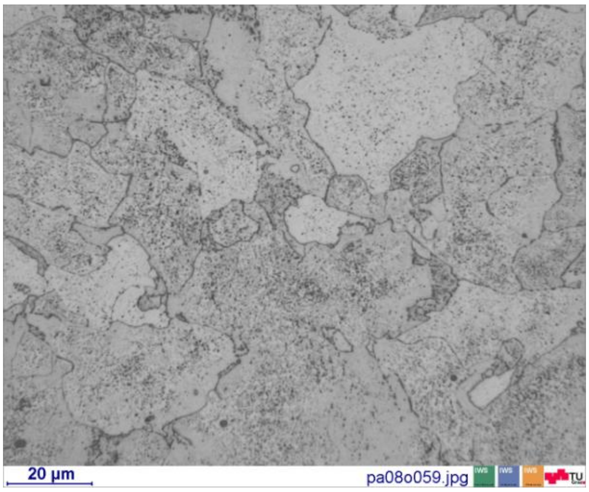

Figure 3. Microstructure of exploited steamline material 14MoV6-3, magnification 500x, [6]

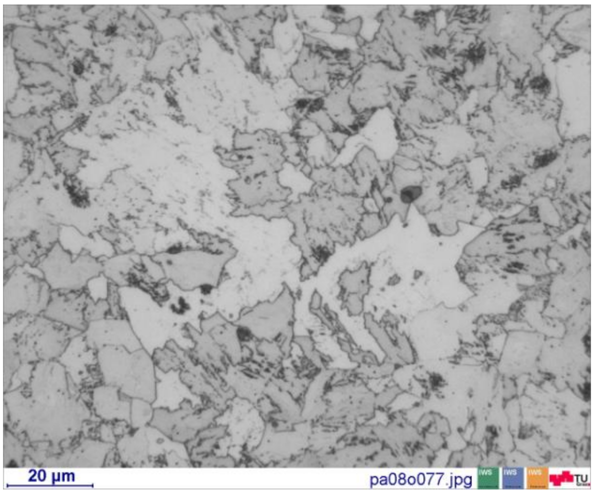

Figure 4. Microstructure of regenerative heat treated material 14MoV6-3, magnification 500x, [6]

For hardness test 1 specimen per material condition 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, [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. Acceptable hardness value at elevated temperatures is not defined by this normative. 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]

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
Heat treated	270 - 288	252 - 265	288 - 293	290 - 293

4. FINAL REMARKS

In accordance with previous investigations of Cr-Mo-V heat resistant steels with similar service conditions and microstructure evolution, 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 materials. 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].

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. As a consequence, grain growth has a significant influence on decrease of steel 14MoV6-3 impact toughness properties, [8].

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.

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, [9]. Considering the fact that hardness as mechanical property of material is in correlation 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, [10]. 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. For serious investigation such assumptions must be proved and quantified by mechanical testing of material. However, further investigation related with possibility of exploited 14MoV6-3 material regeneration by heat treatment should be directed to search for more adequate heat treatment cycle.

5. REFERENCES

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