MICROSTRUCTURAL DEGRADATION OF BOILER HEADERS STEELS UNDER LONG TERM EXPOSURE TO HIGH TEMPERATURE

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ABSTRACT
This paper describes the process of degradation of the structure of the inlet header of the intermediate reheater (MPr) 2 input header at the boiler of Unit 7 of the Thermal Power Plant Kakanj, determined on the basis of tests of replicas and hardness at characteristic places of the header. Headers, with minor delays, have been in continuous operation since 1988. Hardness was tested at replica pickup sites, on the basis of which the correlation between structure degradation and hardness drop resulting from exploitation during the long-term high-temperature operation was estimated.
The change in hardness is certainly one of the most reliable indicators of the structure degradation degree, which is directly related to the service life of the installed components. The subject of the test was the inlet header of the intermediate heater made of low alloy steel 15Mo3, consisting of ferrite-pearlite microstructure, and having calculated values for the allowed hardness in the range from 133 to 176 HB. The structure degradation assessment was performed according to VGB-S-517 by comparing the microstructure of the replicates with the corresponding standards, and the hardness was tested according to ASTM A 956/1996-method A.
The examination has shown that in the exploitation life achieved so far, there has been a partial or complete degradation of the structure, which is reflected in the initial and delayed coagulation of the perlite lamellae (Grades 2a and 3a). The hardness at the test sites is at or below the lower than the prescribed 133HB. The tests confirmed that there is a good correlation between the degree of degradation of the structure and the hardness, which can be used in assessing the condition and planning the extent of testing on critical components.

1. INTRODUCTION

As part of the regular tests of critical components of the headers and steam lines on boiler unit 7, limited NDT tests were carried out. The headers have been in continuous operation from 1988 to 30th April 2019 [1] with minor downtime and partial reconstructions in operation for a total of 136.930 hours, which exceeds the projected service life of approx. 100.000 hours.

Assessments of the condition of the materials were made based on the results of tests performed on the condition of the materials in accordance with applicable standards and regulations and primarily based on the assessment of the material structure degradation of the headers and the decrease in hardness in the period from commissioning to the tests carried out as part of this work. Processes of structural degradation and changes in hardness are certainly the most reliable indicators, which are directly related to the service life of the installed components. A schematic view of the section of the boiler of block 7, with sections of the superheater and reheated is given in Figure 1 [1].

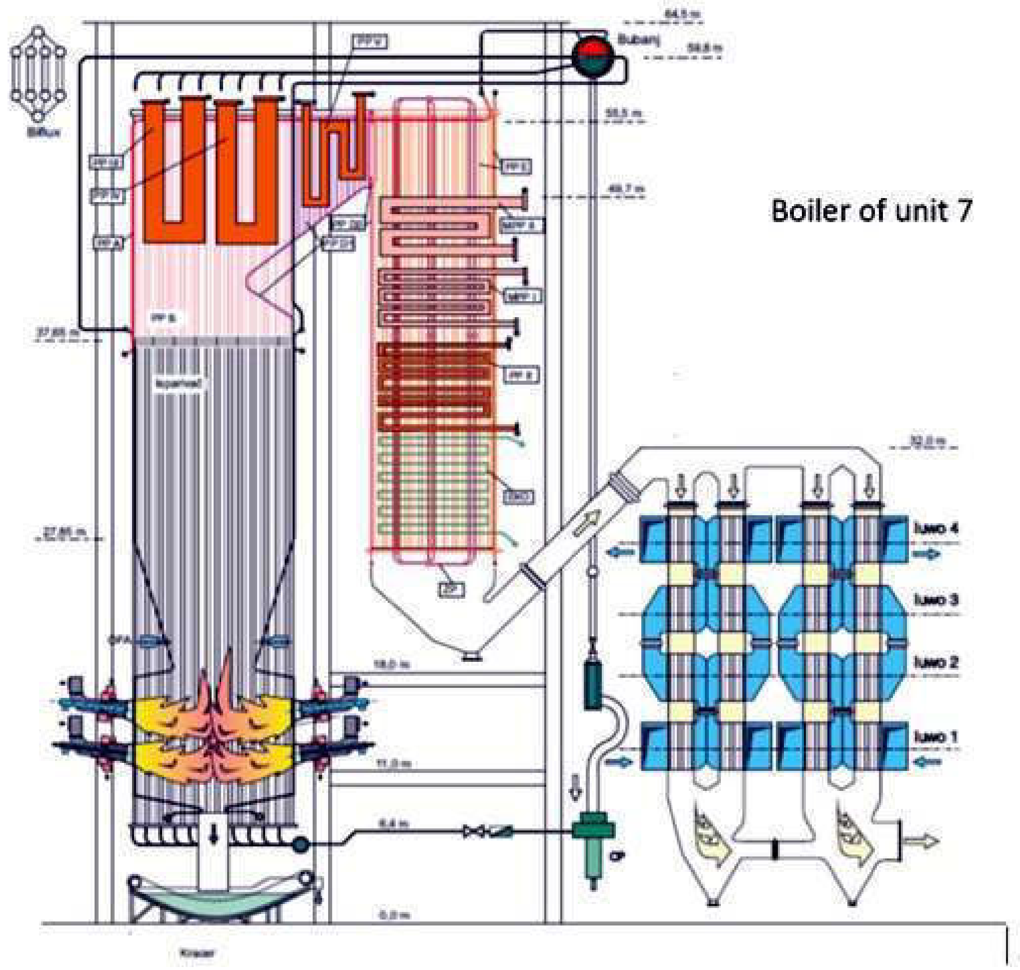


Figure 1. Schematic representation of the section of the boiler of unit 7[1]

2. MATERIALS AND METHODS

2.1. Materials

The inlet headers of the reheated MPr 2 of boiler unit 7, dimensions Ø508x25 mm (hereafter MPr 2 header), are made of low-alloy steel with the addition of molybdenum, marking 15Mo3 according to the standard DIN 17175 [2]. The prescribed chemical composition and mechanical properties are given in Table 1.

Table1. Chemical composition and mechanical properties of 15Mo3 steel according to the DIN 17175 standard

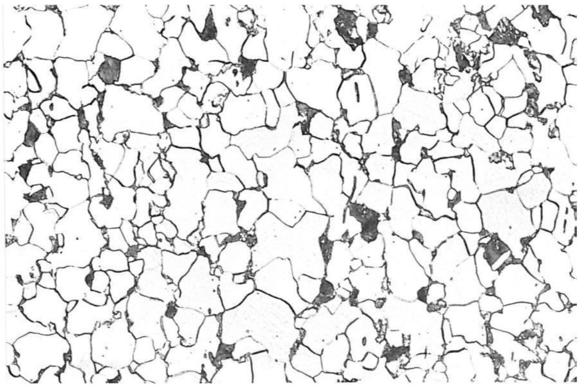
Steel	Standard	Chemical composition, mass %						R_m	Hardness
		C	Si	Mn	P, max	S, max.	Mo	MPa	HB
15Mo3	DIN17175	0,12 - 0,20	0,10 - 0,35	0,40 - 0,80	0,035	0,035	0,25 - 0,35	450 - 690	133-176*

**The hardness is calculated from the tensile strength according to the DIN 50150 standard because No hardness is prescribed [3]*

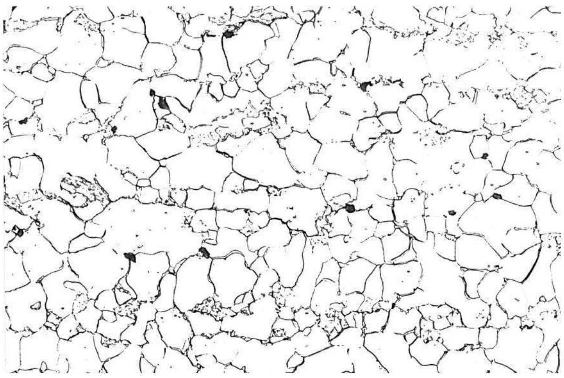
The initial microstructure of steel 15Mo3 in the normalized state consists of ferrite and a smaller proportion of pearlite and during exploitation, it changes due to long-term work at elevated temperatures. In 15Mo3 steel, structural degradation begins with the breakdown of pearlite lamellae and gradual coagulation of the initial pearlite lamellar structure, followed by gradual carbide coarsening. These processes mainly consist of changes in the carbide structure of the steel. The addition of molybdenum affects the stabilization of the carbide phase, and very stable molybdenum carbides have a favorable effect on slowing down the creep process. During exploitation, coagulation and solidification of carbides occur, which separate along the grain boundaries, which leads to structural degradation and a decrease in mechanical properties. These processes take place in the stationary creep region and are noticed by observation of the microstructure from replicas on a light microscope (further LM). Degradation processes in the stationary region dominantly affect the creeping flow in the tertiary phase, in which the formation of microcracks and fracture occurs.

In the main, in low-alloyed ferritic-pearlite steels, under conditions of elevated temperatures, the most obvious process is the degradation of cementite Fe_3C, which in the initial degradation process changes the morphology, but not the composition. The composition of the initial mixture of cementite and M_2C-type carbides in the matrix develop into a more complex carbide conglomeration that includes M_7C_3, $M_{23}C_6$, and finally M_6C carbides. In addition to changes in carbide geometry, other structural changes occur at high temperatures, depending on the temperature, such as recrystallization, grain growth, the evolution of the dislocation structure, and oxidation and decarburization.

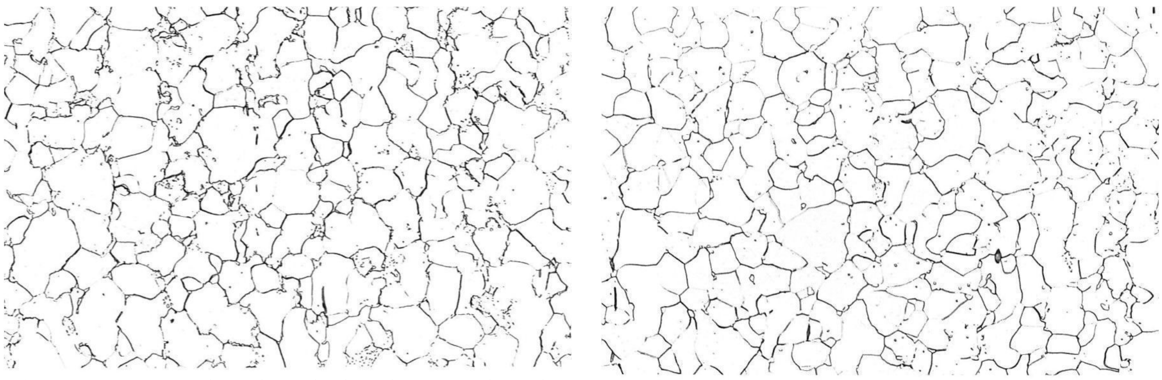
In the research of Salonen and Auerkari [4], experimental tests on and scanning electron microscope (SEM), the mechanism of degradation of the structure of 15Mo3 steel after treatment at high temperatures in simulated exploitation conditions was determined. From these investigations, microstructures LM are shown in Figures 2a, b, c, d, and in Figure 3a, b with SEM, which indicate the degree of degradation of 15Mo3 steel according to the modified VGB-S-517 scale [4,5].



a) Initial ferrite-pearlite structure



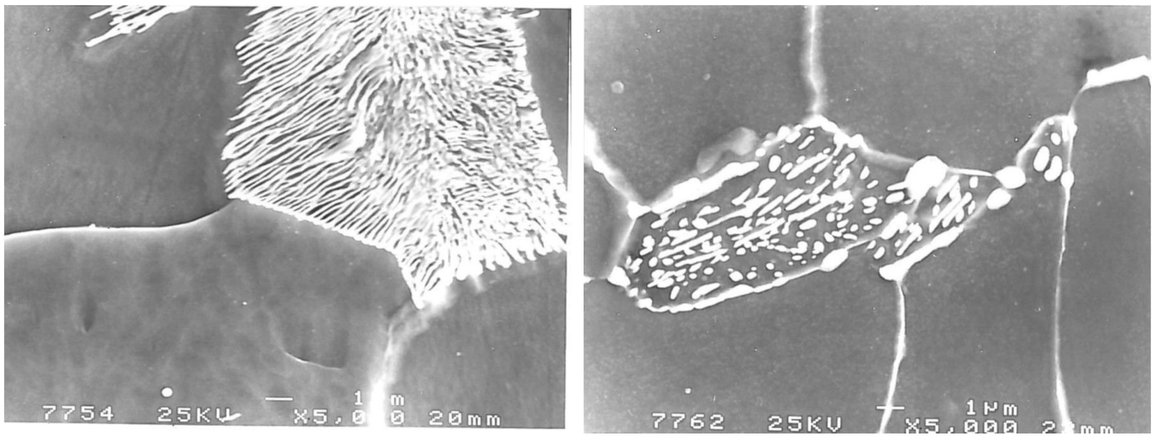
b) Coagulated carbides in pearlite



c) Coarse coagulated carbides dispersed in the matrix and degraded pearlite grains

d) Coarse coagulated carbides and completely degraded pearlite grains

Figure 2. Degradation process microstructure of 15Mo3 steel



a) b)

Figure 3. Initial ferrite-pearlite structure (a) and coagulated carbides in degraded pearlite grains (b)

2.2. Methods

At critical points of the reheater MPr 2, non-destructive testing (NDT) was performed. In particular, the structure was examined using the method of taking replicas (R) at identified critical points of headers and welded joints (FW). For a more exact assessment of the state of the material, the hardness was also tested in the same places, so it was possible to compare the degradation of the structure and the corresponding decrease in hardness. The test results were compared with the ratings and results of earlier tests (tests performed at the same places in previous tests) and the measured hardness values according to DIN 50150 [2].

3. EXAMINATION

3.1 Microstructure

The degradation degree of 15Mo3 steel microstructure in the MPr 2 header was tested according to the ASTM E 407-07 [6] and BAS ISO 3057:1998 standards [7]. The position of the replicas is marked on the scheme of the MPr 2 header in Figure 4 where the tested parts of the header are shown and photographed. The assessment of the degradation degree of the microstructure was carried out according to the regulations of VGB-S-517, by comparing it with standards valid for similar steel 14MoV6. Figures 5a, b, c, d, e, and f show the microstructures of the tested replicas with magnifications of x150 and x750. The replicas marked R1 and R2 have an initial degradation degree of microstructure, with partially coagulated carbides in the boundaries of the pearlite grains (Figures 5a, b, and 5e, f), and were graded according to the VGB-S-517 scale with grade 2a. The structure of replica R3 was rated 3a, and in the microstructure, increased degradation of pearlite lamellae and coarsening of carbides were noted in comparison to replicas R1 and R2 (Figures 5d, and c).

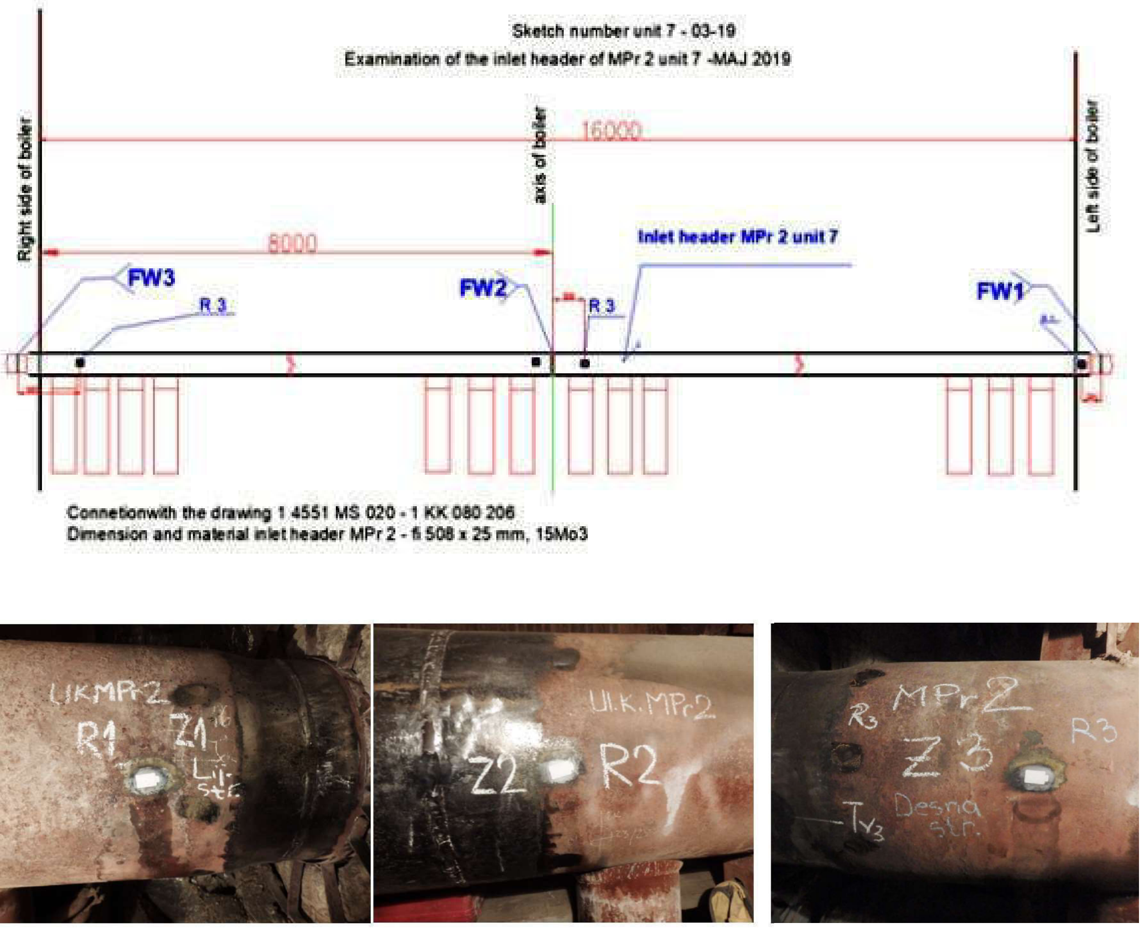
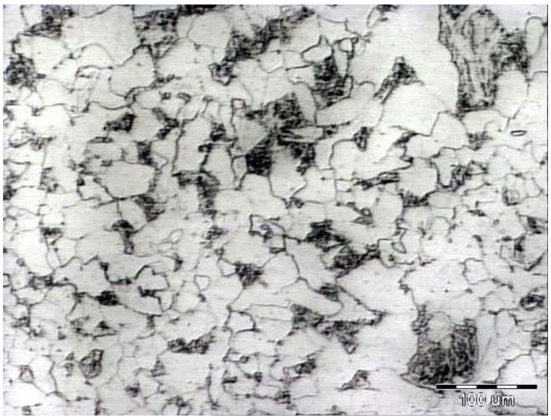
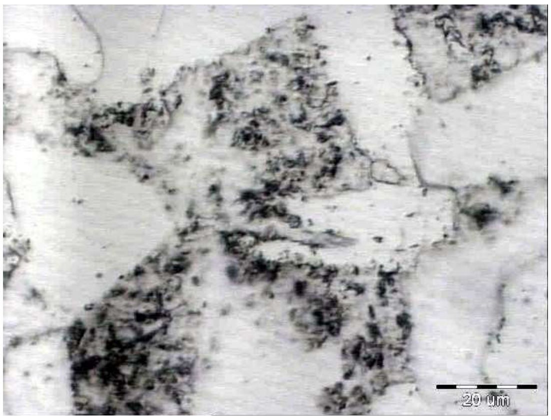


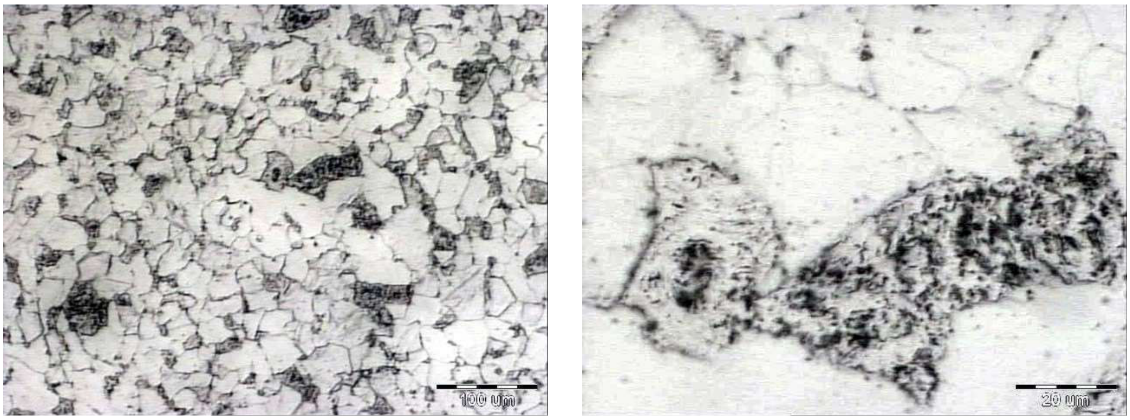
Figure 4. The position of the replicas on the header MPr 2 and photos taken from the investigated places



a) Microstructure of the replica R1 (2b)x150

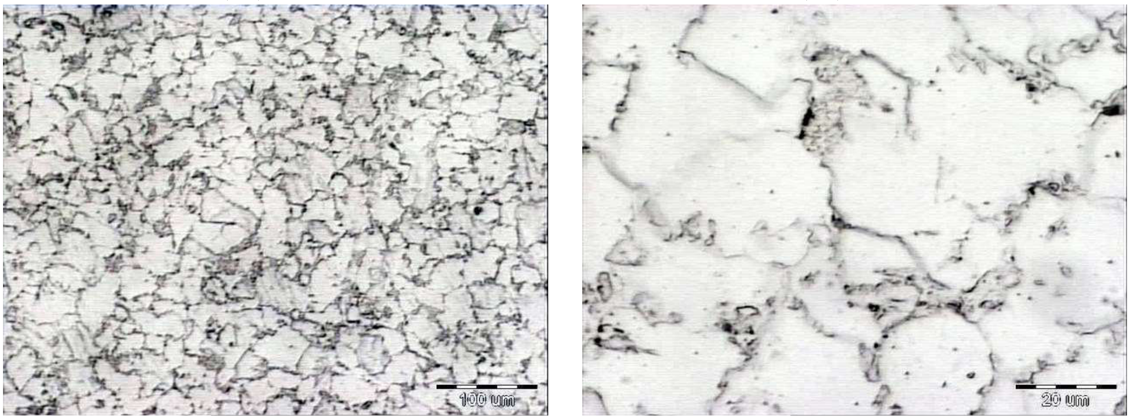


b) Microstructure of the replica R1 (2b)x750



c) Microstructure of the replica R2 (2b)x150

d) Microstructure of the replica R2 (2b)x750



e) Microstructure of the replica R2 (3a)x150

f) Microstructure of the replica R2 (3a)x750

Figure 5. Ferritic and degraded pearlite microstructure with spheroidized coarse carbides inside pearlite grains, with advanced weathering and individual micropores without orientation (a, b, c, d), and more advanced weathering with numerous micropores with orientation (e,f)

3.2. The hardness of the MPr 2 header at the points of taking replicas

The test of the hardness of the steel of the header MPr 2 was carried out according to the standard ASTM A 956/1996- method A by the Brinell method [8]. The test was carried out at the points where the replicas were taken (scheme in Figure 3). The test results are given in Table 2, where the individual and average measured hardness values are listed. The results of the hardness test are graphically presented in Figure 6. The average value of the measured hardness values, which ranged from 125 to 136 HB, is 133 HB.

Table 2. Test results of the hardness of the inlet header of the reheater MPr 2

Replica (VGB)	Hardness at the point of taking replicas [HB]					
	Individual					Average
R1 (2b)	128	134	136	133	132	133
R2 (2b)	130	128	131	131	128	130
R3 (3a)	126	127	127	126	125	126

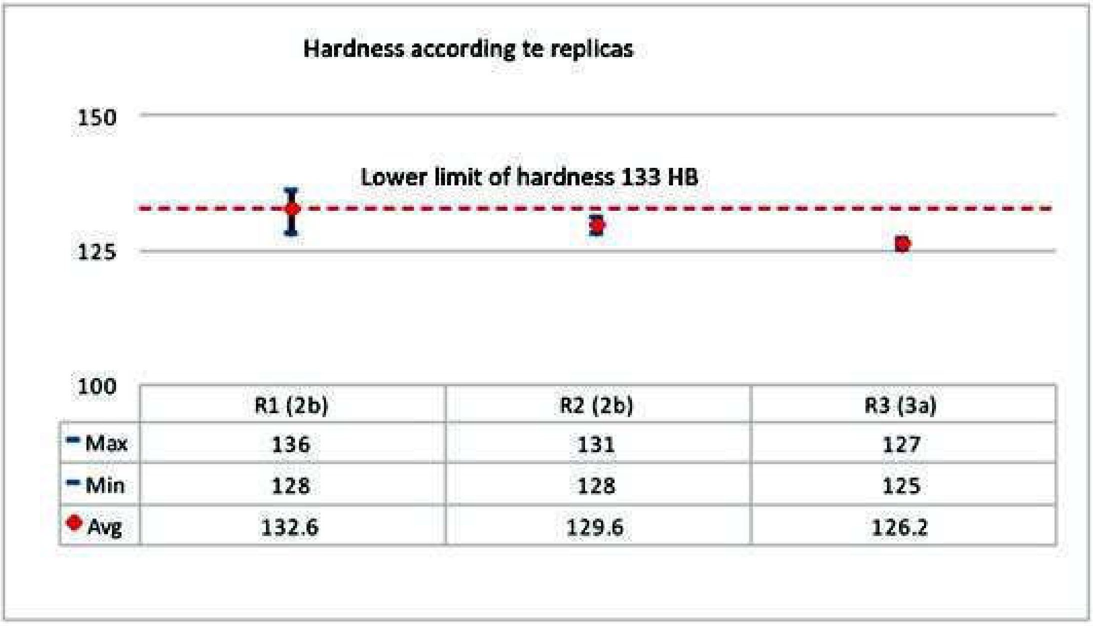


Figure 6. Scattering of MPr 2 header hardness results measured at replicate locations

Based on the results from Table 2 and from the diagram of the hardness range in Figure 6, it can be seen that all the mean values of the measured hardnesses are below the lower prescribed limit of 133 HB. A particularly low hardness was measured in replica R3, where the degree of degradation is 3a.

3.3. Hardness of welded joints

The hardness test on the welded joints of the MPr 2 header was carried out at the places marked on the diagram of the MPr 2 header in Figure 4. The hardness was measured on both sides of the welded joint, on the base material (BM), the heat-affected zone (HAZ), and the weld metal (WM). The results of the test, for the mean values of the measured hardness in all zones of the welded joint, are given in Table 3, and the range of the measured values is shown in the histograms in Figure 7. From Table 3, and from Figure 7, it can be seen that all welded joints FW1, FW2, and FW3 have in the zones of the base material low hardness, which are at the lower prescribed limit, or below that limit, and corresponding to the hardness measured at the points of taking the replicas.

Table 3. The hardness of the welded joints on the inlet header of the reheater MPr 2

Place	Hardness [HB]				
	BM	HAZ	WM	ZUT	OM
FW1	134	176	183	189	132
FW2	130	172	165	159	138
FW3	126	191	183	184	133

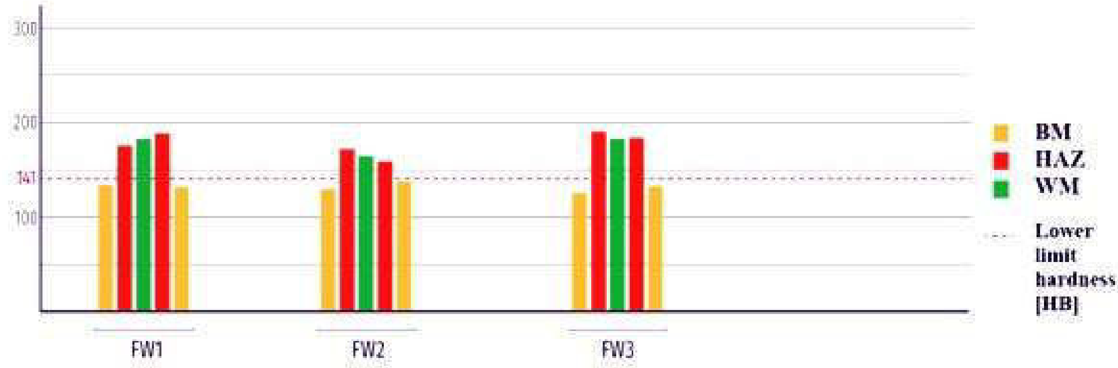


Figure 6. Scattering of hardness on the welded joints of the inlet header of the reheater MPr2

4. CONCLUSION

The conducted tests provided very useful data, which are important for assessing the material condition of critical components after long-term exploitation, which exceeds the designed life span. These data are very important because they can significantly contribute to a safer and more efficient assessment for the next period of exploitation. This does not exclude the application of other NDT methods, which in combination with the conducted tests can contribute to more reliable conclusions, especially when it comes to fractional errors on the tested components.

Examination of the microstructure revealed that there was a degradation of the structure, which was more pronounced in replica R3, compared to replicas R1 and R2. The microstructure mainly consists of ferrite and degraded pearlite, in which there are spheriodized coarse carbides formed by the decomposition of pearlite lamellae, with locally present disoriented micropores (replicas R1 and R2), and numerous oriented micropores in replica R3. Hardness testing of the replicas and welds showed low hardness values at or below the lower prescribed limit of 133 HB for 15Mo3 steel.

In this way, it was confirmed that there is a harmonious relationship between the degradation of the microstructure and the decrease in hardness. It can be stated with certainty that the assessment of the degree of microstructure degradation and the decrease in hardness are reliable methods for assessing the condition of the tested components, in non-destructive testing. This can be important if in this way the scope of the tests can be reduced in some cases, and thus reduce the time required for the tests.

5. REFERENCES

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