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The Assessment of the Structural Degradation Level of an Used Thermoenergetic Pipe Made out of 12CrMoV3 Steel, Using the Metallographical Replica Method

Generally, the metallographical replica method is applied on the external surface of the energetic pipes in order to assess the structural degradation. This nondestructive method allows to obtain information regarding the grow and sheroidization of carbides, as well as the propagation of cavities leading to cracks. Considering the analysed pipe a thick-walled cylinder, from the theory of maximum tangential unit stress, the permanent deformations appear, firstly, in the neighborhood of the cylinder internal surface. Thereby, the aim of the paper is to evaluate and compare the structural degradation of the external and, respectively internal surface of a pipe made out from 12CrMoV3 steel, with the dimensions of ∅273x38mm, using the metallographical replica method. The pipe worked at the temperature of 540^{0}C and the pressure of 140 bar, for 44,827 hours. The obtained results showed that the structural degradation level of the internal surface is higher with about 11 – 18 % than the structural degradation level of the pipe external surface. Thus, by applying the metallographical replica method, a certain level of structural degradation of the material external surface is established; the degradation level at the internal surface of the pipe is equal or higher than the one determined on the external surface.

1. Introduction

The thermoenergetic components working at high temperatures and pressures are subjected to characteristic degradation phenomena such as: creep, fatigue, corrosion, erosion, structural transformations. Generally, these phenomena take place simultaneously, and the predominance of one phenomenon is given by the initial state and structure of the material and by the temperature, time and stress conditions during service.

Among the structural degradation indicators, the carbides transformation is the most representative and adequate indicator of the thermal degradation. This transformation can be determined directly or indirectly. Thus, the creep degradation by cavities (pores) can be directly measured.

The metallographical replica method is applied on the external surface of the energetic pipes in order to assess the structural degradation. The obtained information refers to the state of degradation (grow of precipitations and sheroidization) and to deterioration (cavities development and cracking). The metallographical replica offers information regarding the state of the alloyed steel from which the thermoenergetic pipes are made out. The metallographical replica method is a nondestructive method and can be used in any accessible zone of the analysed component.

The "A" parameter method is the most important and frequently used method for the quantitative assessment of the microstructure. The "A" parameter is defined as the ratio of the number of cavity affected grain boundaries, along a parallel line to the direction of the maximum principal stress, to the total number of the grain boundaries within the microscopic field.

The analysed materials did not worked in creep conditions which can result in cavity appearance. Hereby, a assessment method for the structural degradation of alloyed heat resistant steels was proposed. This method results from the "A" parameter method, but it refers only to the microstructural degradation due to the carbides distribution, as well as to the granulation grow and precipitated carbides sheroidization. The method consists in the determination of a structural parameter by stereometric measurements, using the metallographical replicas. On the basis of this parameter the structural degradation state of the analysed steel is evaluated.

The P parameter is defined as the ratio of the (damaged) grain boundaries with carbides (N_C) to the total number of damaged and undamaged grain boundaries ($N_C + N_N$). The parameter is calculated with the relation:

$$P = \frac{N_C}{N_C + N_N}. \qquad (1)$$

The value of the P parameter varies between 0.0 and 1.0. As the value shifts to the upper limit, the level of the structural degradation increases.

2. Experimental program

The paper analyses the structural degradation of a pipe made out of 12CrMoV3 weldable heat resistant steel, with the dimensions ∅273x38 mm, which worked at the temperature of 540^{0}C and the pressure of 140 bar for 44,827 hours.
Within the experimental program the following problems were analysed:

- determination of the chemical composition of the pipe material;

- experimental researches with metallographical replicas on the external surface and the internal surface of the pipe;
- hardness determination on the surfaces examined by the metallographical replica method.

Two specimens, designated "D" and "S", sampled from the same thermal circuit, but from different batches, were analysed.

3. Experimental research results

3.1. Determination of the chemical composition

The values of the chemical composition for the two specimens sampled from the ∅273x38 mm pipe made out of 12CrMoV3 steel, as well as the values stipulated in STAS 8184-87 are presented in table 1.

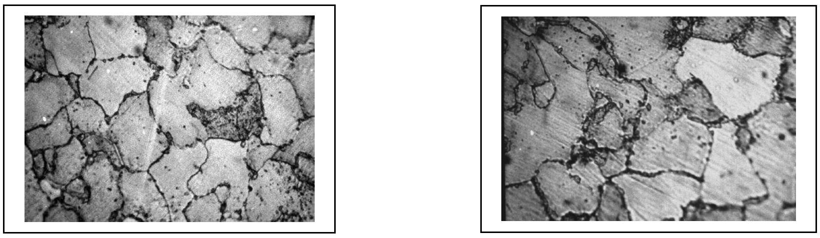
Table 1.

Steel grade	Chemical composition [%]											
	C	**Mn**	**Si**	**Cr**	**Mo**	**P max**	**S max.**	**Al**	**Ni**	**Cu**	**W**	**V**
12VCrMo10 (12CrMoV3) **STAS 8184-87**	0,08-0,15	0,40-0,70	0,17-0,37	0,90-1,20	0,25-0,35	0,030	0,025	0,015-0,045	-	-	-	0,15-0,30
S specimen	0,11	0,53	0,32	0,94	0,29	< 0,030	0,030	0,024	0,059	0,23	0,023	0,21
D specimen	0,13	0,61	0,31	0,96	0,29	< 0,027	0,038	0,023	0,053	0,28	0,018	0,19

Comparing the obtained values with the ones stipulated in STAS 8184-87, it can be observed that the values for sulphur are exceeded for both specimens. These deviations are not situated within the deviations permitted in the standard.

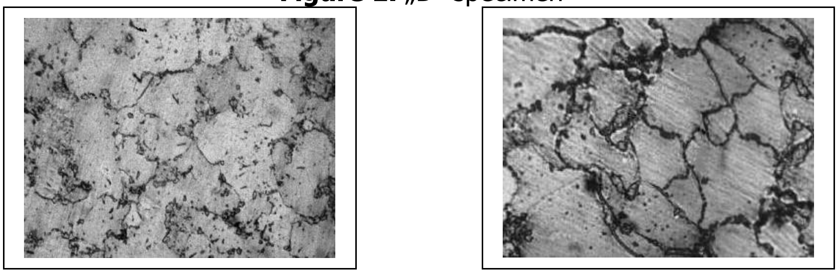
3.2. Experimental researches with metallographical replicas

The microstructures, determined using the metallographical replicas, of the "D" and "S" specimens consist in ferrite, with small areas of spheroid pearlite and fine Cr, Mo and V carbides placed intra- and inter-granular (figures 1 and 2, Nital etched 2% , 500x).



a) external surface b) internal surface

Figure 1. „D" specimen



a) external surface b) internal surface

Figure 2. „S" specimen

Figure 3 illustrates the average values of the P parameter for the two specimens, established on the external and internal surfaces of the pipe.

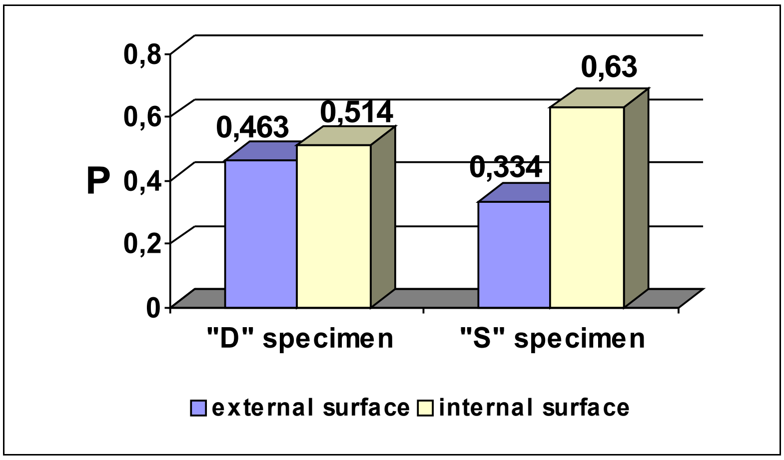


Figure 3. The average values of the P parameter

In order to establish the structural degradation level of the internal surface relative to the structural degradation level of the external surface considered as reference, the relative structural degradation was calculated, and it varies between 11 and 88%.

3.3. Determination of the HV10 hardness

The HV10 hardness test was performed, on the "D" and "S" specimens sampled from the 12CrMoV3 steel pipe, in the material thickness direction, in cross-section, in steps of 2 mm. The obtained values are presented in figure 4.

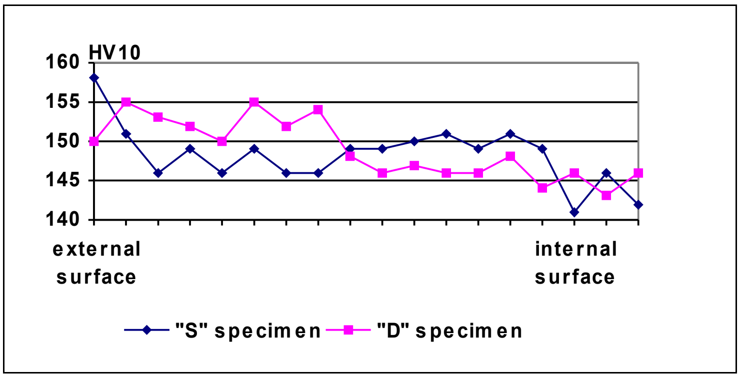


Figure 4. The HV10 hardness values for the "S" and "D" specimens

Analysing the presented values of hardness, it can be observed that the values decrease from the exterior (158 HV10 and 150HV10 respectively) to the interior of the pipe (142 HV10 and 146 HV10 respectively) for both specimens ("S" and "D" respectively).

4. Results analysis

The exceeded value of sulphur in the chemical composition of both specimens, can results in the appearance of the embrittlement susceptibility of the 12CrMoV3 steel, but insignificantly.

The microstructure consists in ferrite, spheroid pearlite and Cr, Mo, V carbides placed inter- and intra-granular, with grains of size 7 – 8, according to SR ISO 643. An agglomeration tendency of the fine carbides along the grain boundaries, toward the exterior of the pipe and as well as toward the interior of the pipe, and both in the longitudinal and transversal direction was observed. This tendency favourites the appearance of the embrittlement susceptibility, too.

The more accentuated degradation was established at the internal surface of the pipe. The structural degradation level of the internal surface is higher with about 11 – 18 % than the structural degradation level of the pipe external surface. This phenomenon is due to the flow within the pipe of a fluid at the temperature of 540^{0}C and the pressure of 140 bar, generating a temperature gradient along the pipe thickness, the temperature in the inner of the pipe being higher.

At the interior of the pipe, this more accentuate structural degradation is correlated to the lower values of the HV10 hardness, which is a measure of the lower mechanical strength characteristics at the interior of the pipe than at the exterior of the pipe.

5. Conclusion

The performed study confirmed that the structural degradation level of the pipe internal surface is higher than the structural degradation level of the pipe external surface. Hence, by applying the metallographical replica method, a certain level of structural degradation of the material external surface is established. This level of degradation is not corresponding to the level determined at the internal surface of the pipe, which can be higher.

Thus, the assessment of the structural degradation at the external surface of the pipe offers insufficient information regarding the real state of the pipe material. The obtained information must be correlate with the information obtained by monitoring the installations from which the pipe was draw out and even with short and long term mechanical testing.

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