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CAVITATION DAMAGES MORPHOLOGY OF HIGH-STRENGTH LOW-ALLOY STEEL

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This paper presents the research into behaviour of HSLA steel affected by cavitation. The parent material (PM) and simulated heat-affected zone (SHAZ) were studied. Ultrasonic vibratory cavitation test was performed in laboratory conditions (by stationary specimen method). Scanning electron microscopy (SEM) was used to observe the variations in the surface morphology that occurred within different time intervals.

Key words: HSLA steel, cavitation damage, SHAZ, surface, time of testing

INTRODUCTION

Cavitation is a phenomenon that comprises formation, growth and implosion (collapse) of bubbles in a liquid flow. During cavitation, when the bubbles collapse, high temperatures and pressures develop locally in a very short time interval, [1, 2]. Implosion of bubbles creates impact-shock waves and micro jets, which energy dissipates within the liquid or becomes absorbed by a solid surface, which the liquid is in contact with, [3]. The energy of imploded bubbles absorbed by the material induces the elastic or plastic deformation or failure, thus representing the destruction affected by cavitation. Previous studies showed that cavitation resistance of materials commonly used for manufacturing of hydraulic elements depends on the mechanical properties and microstructure, [4 - 6]. Low-alloy steels are alloyed with one or more elements wherein total content of all alloying elements does not exceed 5 %. Such steels are classified according to the level of achieved strength, i.e. yield limit. The benefits of high-strength steels in relation to other structural steels are the following: reduced structure weight, increased carrying capacity, increased service life and lower costs of manufacture, [7, 8]. HSLA steels are, among others, used in shipbuilding. Due to cavitation occurring in exploitation of hydraulic machinery, HSLA steel NIONIKRAL 70 (NN70) was selected for testing of its resistance to the effects of cavitation. The aim of the presented research was to demonstrate surface damage morphology of HSLA steel affected by cavitation.

EXPERIMENTS

Material

Within this research, there were two types of specimens tested: (1) one specimen made of NIONIKRAL 70 PM specimen and (2) one specimen taken from the simulated HAZ of the same steel-SHAZ specimen. Chemical composition of tested material is presented in the Table 1. Table 2 overviews the tensile properties of tested material. Microstructure of the parent material (PM) comprises tempered martensite and bainite (Figure 1a).

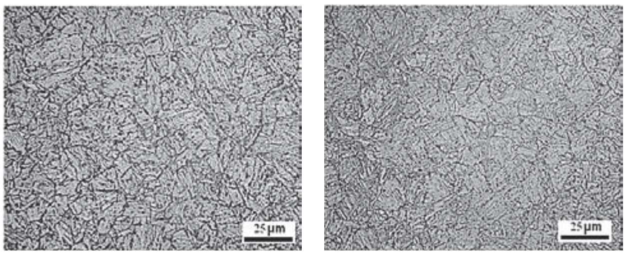
Table 1 **Composition of NN 70 / wt. %**

C	Si	Mn	P	S	Cr	Ni	Mo
0,1	0,21	0,22	0,01	0,02	1,3	2,4	0,3

Table 2 **Tensile properties of NN 70**

Specimen	$R_{p0,2}$ / MPa	R_m / MPa
PM	780	820
HAZ	750	800

In addition to the above specified micro constituents, the microstructure of SHAZ includes a small quantity of ferrite with carbides (Figure 1b). It was de-



(a) (b)

Figure 1 Microstructure of a) parent material PM (microstructure of tempered martensite and bainite with carbides), b) simulated heat affected zone

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termined that the material was characterized by a high level of porosity. Value of measured PM hardness was 269 HV1 and the value of measured SHAZ hardness was 276 HV1.

Test methods

Ultrasonic vibratory cavitation test was carried out in laboratory conditions to test the resistance of material to cavitation (by stationary specimen method), [9,10]. Testing was performed within the recommended standard values of the following parameters [11]:

- The frequency of mechanical vibrations: 20 ± 0,2 kHz;
- The amplitude of vibrations at the top of the transformer: 50 µm;
- Gap between the test specimen and the transformer: 0,5 mm;
- Water flow rate of 5 - 10 ml/s;
- The water temperature in the bath: 25 ± 1 °C.

Morphology of damaged surfaces of the specimens was analyzed by scanning electron microscopy (SEM).

RESULTS AND DISCUSSION

PM specimen

In the initial stages of exposing the specimen to cavitation, there were undulations appearing on the surface, which indicated that there was a strain hardening of the surface. There were also determined pits of local character, which were formed either as a result of separating inclusions from the matrix, or as a result of porosity present in the steel (Figure 2).

After 120 minutes of testing, higher level of strain hardening occurred due to more pronounced undulations on the material surface layer, Figure 3. Furthermore, an increase occurred in the size of pits that were in some places connected to each other. Those pits in the surface layer induced focus of energy of the impact waves created by the implosion of cavitation bubbles, which intensified the cavitation effects.

After 180 minutes of exposure to cavitation effects, it was observed that the surface layer of the PM specimen developed two zones with different morphology of damage (zones A and B, Fig. 4). Changes in morphology created in the zone A did not differ from those created in the previous test intervals. It can be concluded that the zone A did not exhibit changes in the morphology of the surface even after an additional 60 minutes of exposure to cavitation effects, Figure 4a. In the zone B, there were groups of pits formed as a result of material porosity. The degree of damage in this interval was more pronounced than in the previous one, as the surface had cracks probably initiated because of an increase of pits and their interconnecting, Figure 4b. After 240 minutes of exposing the PM specimen surface to the cavitation effects, there were numerous pits developed, which was most probably caused by the porosity of the initial PM. Both the number and size of pits were increased. Morphology of the entire specimen surface after testing indicated porosity of the material (Figure 5).

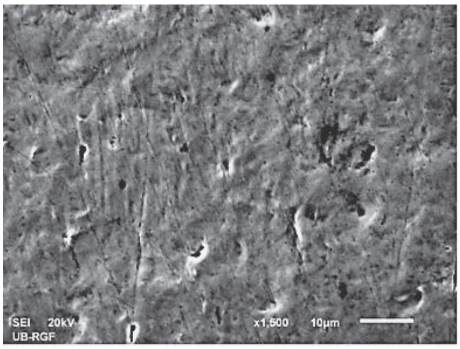


Figure 2 Morphology of the PM specimen surface test time 90 minutes

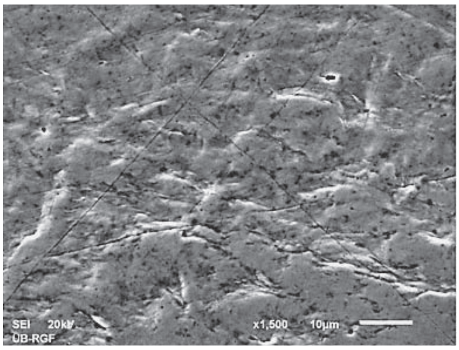
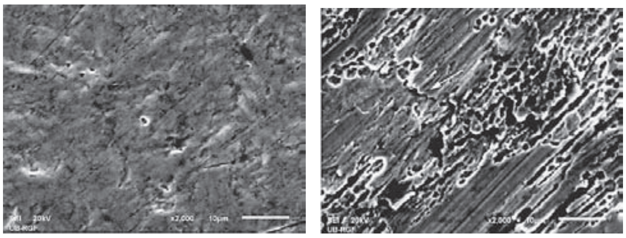


Figure 3 Morphology of the PM specimen surface test time 120 minutes

SHAZ Specimen

After 90 minutes of exposing the SHAZ specimen to cavitation effects, there were initial grooves appearing,



(a) (b)

Figure 4 Different morphology a) zone A and b) zone B of the same PM specimen after 180 minutes of testing.

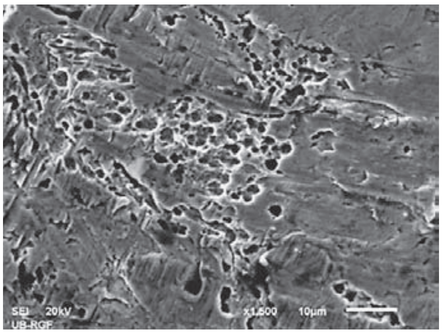


Figure 5 The morphology of the PM specimen test time 240 minutes

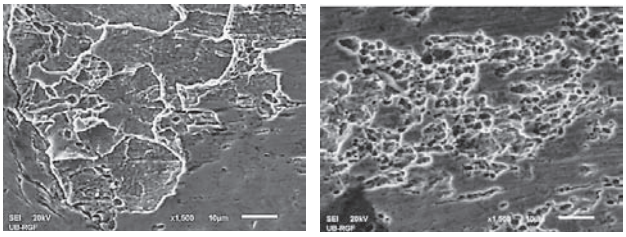

(a) (b)

Figure 6 The morphology of the SHAZ specimen test time 90 minutes

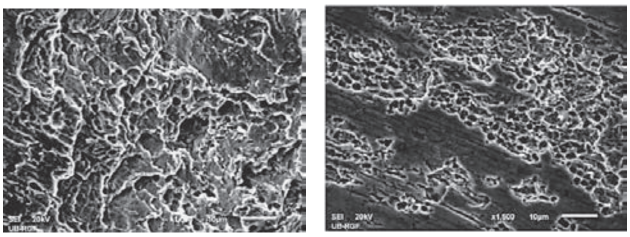

(a) (b)

Figure 7 Morphology of the SHAZ specimen test time 180 minutes

around which the material deformed, Figure 6a. Such morphology is characteristic to tempered martensite. The Figure 6b shows the defect caused by the porosity of material.

These two types of morphology were repeating until the end of experiment, where only the degree of damage differed, as depending on duration of exposure to cavitation effects. Prolonged exposure of 120 and 180 minutes of testing to cavitation effects, affected in the similar manner the increase in number and depth of pits from which the craters were formed and around which the material deformed. Because of similar surface damage mechanism during testing time, in Figure 7 is shown the morphology of the specimen surface after 180 minutes of testing. As shown in the Figure 8a, after 240 minutes of testing, craters with a high degree of plastic deformation were observed. The Figure 8b shows a high degree of damage, which morphology indicates porosity of material.

CONCLUSION

Testing the resistance of low-alloy high-strength steel NIONIKRAL 70 to cavitation effects by the ultrasonic vibration method with stationary specimen in laboratory conditions provided the data used for analysis of morphology of damages, which was performed by the scanning electron microscopy (SEM). As of the obtained experiment results, the following was concluded:

- Morphology of PM surface is characterized by pronounced strain hardening; however, the morphology of damages in the subsequent stages only indicated the PM porosity, which cannot be correlated to the microstructure of PM represented by tempered martensite and bainite.

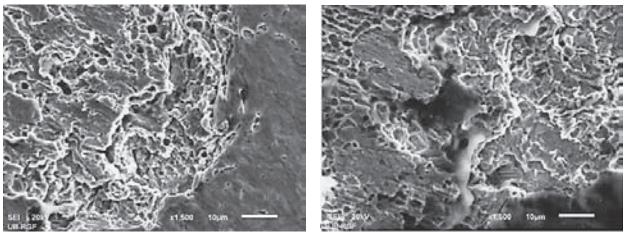

(a) (b)

Figure 8 The morphology of the SHAZ specimen test time 240 minutes

- During testing of SHAZ, two types of morphology were observed: morphology characteristic to tempered martensite and morphology of damage created as a result of material porosity.
- In the case of SHAZ, it was assumed that the presence of bainite led to the reduction of negative effects of ferrite, which has low resistance to cavitation effects.

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REFERENCES

[1] Brennen, C.E.,Cavitation and Bubble Dynamics, University Press, Oxford, 1995.
[2] Ahmed, S.M., K. Hokkirigawa, K., Oba, R., Fatigue failure of SUS 304 caused by vibratory cavitation erosion, Wear. 177 (1994), 129-137.
[3] Hammitt, F.G. Cavitation and Multiphase Flow Phenomena, McGraw-Hill, New York, 1980.
[4] Karimi, A., Martin, J.L., Cavitation erosion of materials, Int. Met. Rev. 31 (1986), 1-26.
[5] Heyman, F.J., Characterization and Determination of Erosion Resistance, ASTM STP474, 1970, pp. 212-222.
[6] Knapp RT, Daily JW, Hammit FG. Cavitation. New York: McGraw-Hill; 1970.
[7] Grabulov V, Blačić I, Radović A, Sedmak S., Toughness and ductility of High Strength Steels Welded Joints, Integritet i vek konstrukcija, 8 (2008) 3, 181-190.
[8] Gubeljak N, Predan J, Rak I, Kozak D., Integrity Assessment of HSLA Steel Welded Joint with Mis-Matched Strength. Integritet i vek konstrukcija, 9 (2009) 3, 157-164.
[9] Dojčinović, M., Volkov-Husović, T., Cavitation damage of the medium carbon steel: Implementation of image analysis, Mat. Lett., 62 (2008), 963-958.
[10] Dojčinović,M., Roughness measurement as an alternative method in evaluation of cavitation resistance of steels, Hem. ind., 67 (2013) 2, 323-330.
[11] Standard Method of Vibratory Cavitation Erosion Test, G32-92. Annual Book of ASTM Standards, Vol. 03.02. Philadelphia: ASTM; 1992.

Note: Responsible person for English translation is prof. Martina Šuto, University of Osijek and prof. Marina Karšić, Croatia