

## CAVITATION RESISTANCE OF TURBINE RUNNER BLADES AT THE HYDROPOWER PLANT 'DJERDAP'

### OTPORNOST PREMA KAVITACIJI LOPATICA RADNOG KOLA TURBINE U HIDROELEKTRANI "DJERDAP"

Originalni naučni rad / Original scientific paper

UDK /UDC: 620.193.16:621.224

620.179.16

Rad primljen / Paper received: 6.04.2017

Adresa autora / Author's address:

<sup>1)</sup> University of Belgrade, Faculty of Technology and Metallurgy, Serbia, email: [rina@tmf.bg.ac.rs](mailto:rina@tmf.bg.ac.rs)

<sup>2)</sup> Institute for Materials Testing, Belgrade, Serbia

<sup>3)</sup> University of Belgrade, Faculty of Mech. Engineering, Serbia

<sup>4)</sup> ISIM, Timisoara, Romania

<sup>5)</sup> High Technical School of Professional Studies, Arandelovac, Serbia

#### Keywords

- turbine
- runner blade
- cavitation damage
- cavitation rate
- incubation period

#### Abstract

*Hydropower plants need to develop means of protection of turbine and hydromechanical equipment from undesirable occurrences, such as degradation of parent material and/or weld metal of parts and structures caused by stresses and unpredictable influence of vibrations, fatigue, corrosion, erosion and cavitation. Results of tests that refer to the cavitation resistance of turbine runner blades made of cast steel 08X15H4ДМЛ, in accordance with GOST standard are presented in this paper. For the testing of cavitation resistance, the ultrasonic vibration test method is used (with the stationary sample), for which it is necessary to measure the mass loss during specified time intervals, while the cavitation resistance of the material is being defined, taking into account the incubation period and cavitation rate. Scanning electron microscope analysis is carried out to study the morphology of sample damage due to cavitation. The obtained results show that the tested steel has a good cavitation resistance and that fatigue is the main failure mechanism.*

#### INTRODUCTION

Vertical Kaplan turbines, manufactured in Russia, with nominal power of 200 MW, have been installed in 6 hydroelectric generating units at 'Djerdap 1', /1/, Fig. 1. Various non-destructive and destructive tests were performed on the parent material and welded joints for state analysis and assessment of the level of damage and degradation, as well as for the determination of causes for damage occurrence during the refurbishment of hydroelectric generating sets A4, A5, A6 and A1.

Cavitation is one of liquid erosion mechanisms that comprises creation and implosion of bubbles within the fluid /2, 3/. The shock waves and microjets emitted during

#### Ključne reči

- turbina
- lopatica radnog kola
- kavitaciona oštećenja
- brzina kavitacije
- period inkubacije

#### Izvod

*U hidroelektranama postoji potreba za zaštitom delova turbina i hidromehaničke opreme od neželjenih pojava, kao što su degradacija osnovnog materijala i/ili metala šava kod delova i konstrukcija, koje izazivaju naponi i nepredvidljiv uticaj vibracija, zamora, korozije, erozije i kavitacije. Predstavljani su rezultati ispitivanja otpornosti prema kavitaciji lopatica radnog kola turbine izrađenih od livenog čelika 08X15H4ДМЛ, prema standardu GOST. Za ispitivanje otpornosti prema kavitaciji, korišćena je metoda ispitivanja vibracija ultrazvukom (sa stacionarnim uzorkom), kod koje je potrebno izmeriti gubitak mase tokom zadatih vremenskih intervala, gde se istovremeno definiše otpornost materijala prema kavitaciji, uzimanjem u obzir inkubacioni period i brzinu kavitacije. Skening elektronska mikroskopija je izvedena radi proučavanja morfologije oštećenja uzorka usled kavitacije. Dobijeni rezultati pokazuju da ispitivani čelik poseduje dobru otpornost prema kavitaciji, dok je zapravo zamor glavni mehanizam loma.*

the collapsing of bubbles interact with neighbouring solid surfaces may cause material damage, /4, 5/. The process of elimination of material from the surface is called cavitation erosion, while the resulting damage is called cavitation damage. Degraded surfaces of parts of hydraulic equipment subject to cavitation can become rather large during short periods of time, while cavities can be up to 100 mm deep.

Cavitation damage on turbine and hydromechanical equipment originates as a result of degradation of surfaces on which the implosion of cavitation bubbles occurs, created when the critical speed is exceeded, which mostly depends on the overall pressure. Process of degradation is in a direct connection with the conditions of exploitation. Cavitation damage is especially detectable on locations

where the direction of streamlines and speed of liquid abruptly change.

Cavitation has not been investigated enough yet, but it is known that one of the causes for its origin are high speeds at which the drops of liquid hit the surface of the metal. The conditions for the occurrence of critical speeds are avoided through structural solutions. Vibrations and noises mostly reveal the occurrence of a cavitation damage at parts of the

turbine and hydromechanical equipment. At locations where cavitation occurs, the local pressure can reach 20 MPa, which leads to mechanical degradation of material (creation of cavities and wear, in general). Cavitation reduces the positive effect of turbine operation due to the fact that a substantial part of the energy transforms into heat.

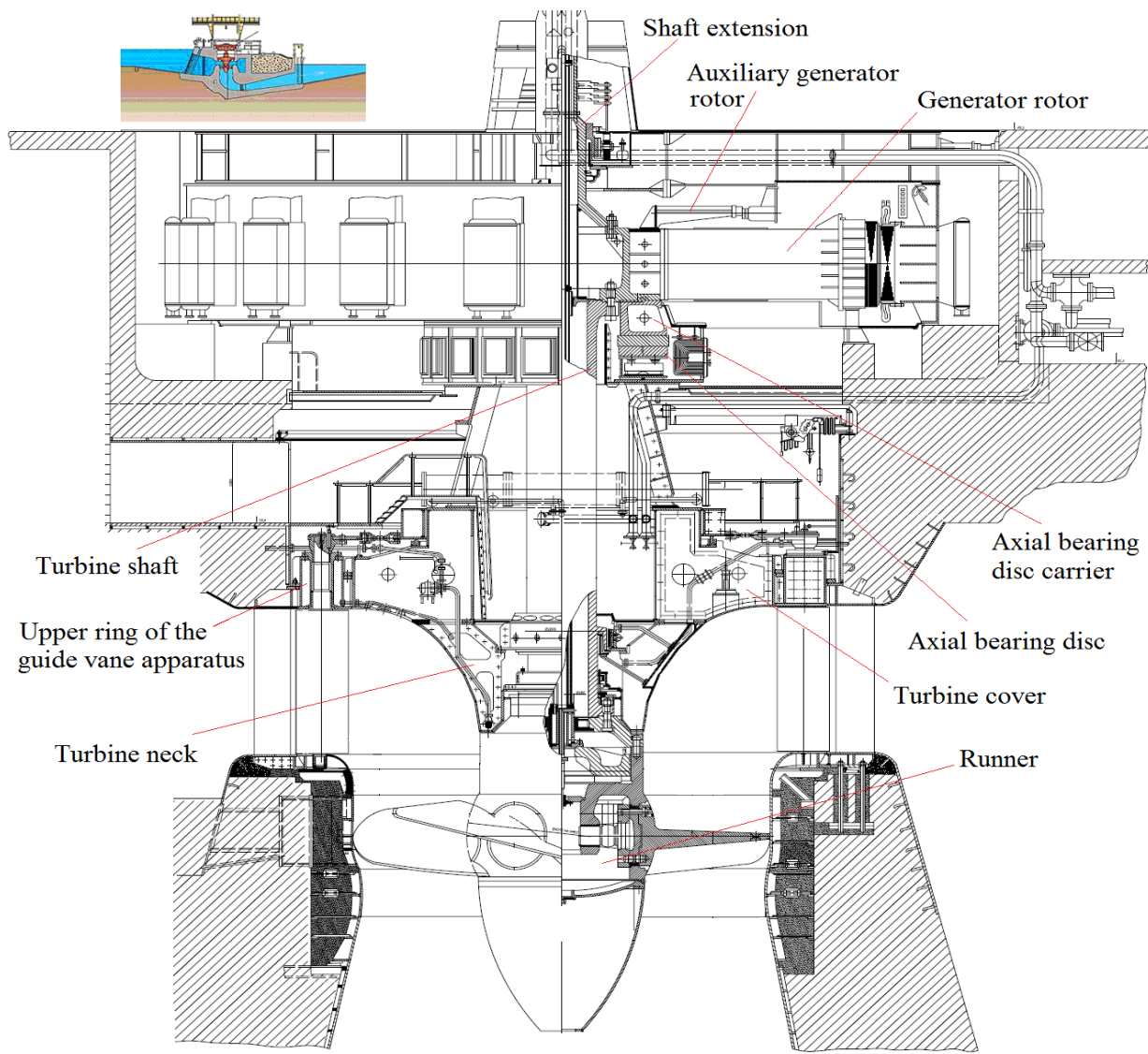


Figure 1. The vertical Kaplan turbine, nominal power 200 MW.

EXPERIMENTS

Kaplan turbine runner blades are produced 40 years ago of cast steel 08X15H4ДМЖІ, in accordance with the GOST standard, /6/. Chemical composition and mechanical properties are shown in Tables 1 and 2. The photo of the runner

blade with areas where cavitation damages occur the most, is shown in Fig. 2. Figure 3 shows the area where cavitation damage has occurred before and after repair welding. The microstructure of the sample taken from one of the blades is presented in Fig. 4.

Table 1. Chemical composition, according to GOST standard.

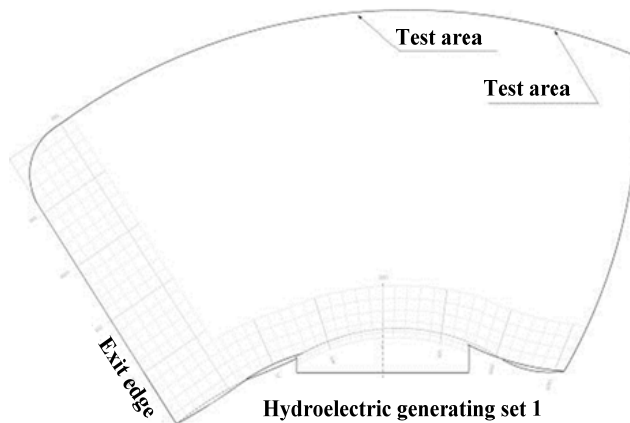
Cast steel designation	Chemical composition in mass percentage (%)								
	C	Si	Mn	Cr	Ni	Cu	S	P	Mo
08X15H4ДМЖІ	max		1.00-1.50	14.00-16.00	3.50-3.90	1.00-1.40	max		0.3-0.45
	0.08	0.40					0.025	0.025	

Table 2. Mechanical properties, according to GOST standard (min. values).

Cast steel designation	T = +20°				T = -10°	Hardness HB
	Yield strength YS <sub>0.2</sub> [N/mm <sup>2</sup> ]	Tensile strength TS [N/mm <sup>2</sup> ]	Elongation A, %	Contraction Z, %	Impact energy KV <sup>-10</sup> , [J/cm <sup>2</sup> ]	
08X15H4ДМЛ	590	740	17	45	40	220-290



a) turbine runner blade

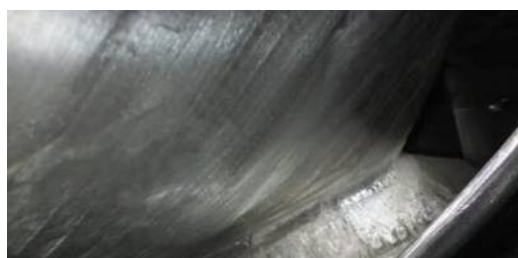


b) areas of the blade where damages occur the most

Figure 2. A turbine runner blade and areas where cavitation damages occur the most.



a) cavitation damage on a runner blade



b) runner blade area after repair

Figure 3. The area where cavitation damage has occurred before and after the repair.

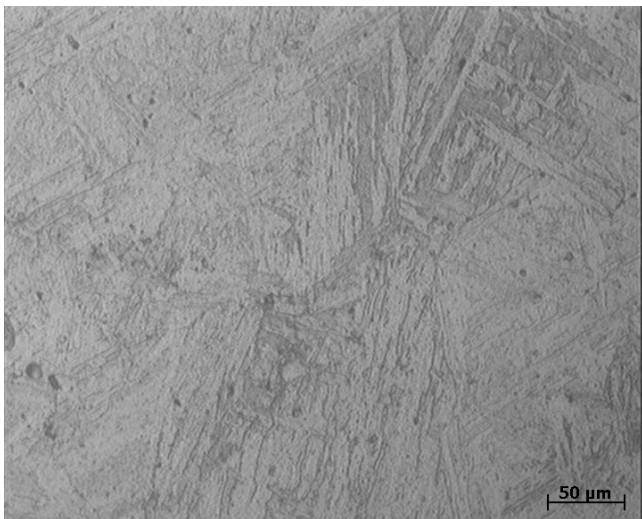
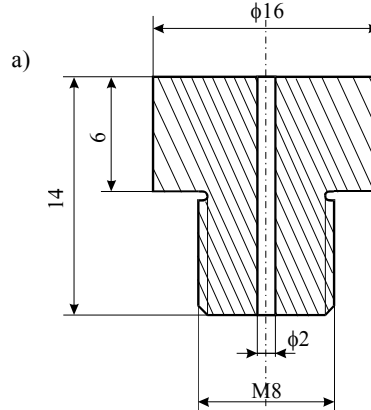


Figure 4. Microstructure of a sample taken from a blade, (martensite ferrite microstructure).

The ultrasonic vibration test method is used for testing the resistance to cavitation of the cast steel sample, taken from a runner blade. In Fig. 5, a test sample with basic dimensions is shown, while Fig. 6 shows a device on which the tests were performed, /7/.



a)



b)

Figure 5. The test sample: a) basic dimension; b) photo, /7/.



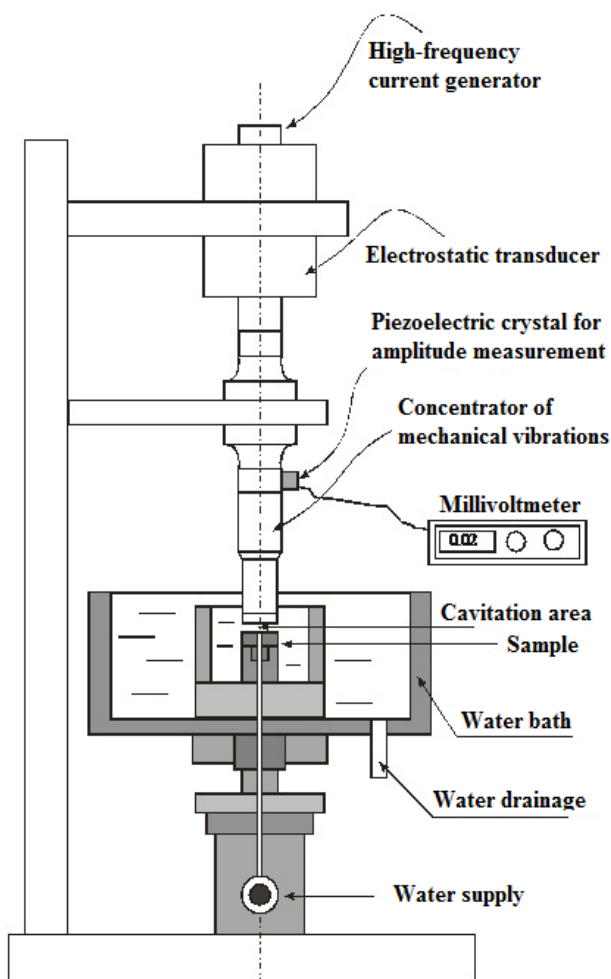


Figure 6. Schematic overview of cavitation test setup, /7/.

Test conditions and procedure, sample preparation and interpretation of results are defined in accordance with the standard ASTM G32, /8/. Application of the ultrasonic vibration test method enabled the measurement of sample mass loss in specific time intervals, while the resistance of the sample material to cavitation is defined by the incubation period and cavitation rate.

The vibration frequency and peak-to-peak displacement amplitude of the horn are  $20 \pm 0.5$  kHz and  $50 \mu\text{m}$ , in respect, with separation of 0.5 mm between the sample and horn tip. The cavitation area is formed below the frontal area of the horn and sample. The test is carried out in water at  $25 \pm 0.5$  °C. The water is brought to the water bath through an opening in the sample by means of a pump, and it cools the sample. At the same time, the water with its constant flow creates a pressure field which instigates the implosion of cavitation bubbles at the surface of sample.

The sample is 16 mm diameter, 6 mm thick with an aperture at the centre of 2 mm diameter, and is coupled to the test rig by a screwed spigot 8 mm long. After machining, the test specimens are rubbed down on successively finer grades of emery paper, until 2400 grit is applied. Then, the specimens are polished with 6, 3, and  $1 \mu\text{m}$  diamond paste, to remove any work hardened layer formed during the manufacture of specimens. Mass loss of test specimens is measured with an analytical balance, accuracy of 0.1 mg,

after rinsing in alcohol and drying in hot air. Measurements are taken after each test interval (60 min.) in order to obtain the erosion curve. The duration of the test was 240 min.

The Tescan FESEM Mira X3m scanning electron microscope (SEM) is used for monitoring the surface degradation level of the sample after each test interval.

## RESULTS AND DISCUSSION

Results of mass loss measurement during the test period are shown in Fig. 7. The diagram shows the relation between mass loss and testing time. The curve is drawn by least-square method and data can be represented with straight lines. The slope of the line represents the cavitation rate. The intersection point of that direction and the abscissa defines the incubation period, the period of time during which no mass loss or destruction of material occurs due to cavitation, but only due to deformation (deformation strengthening). Figure 7 shows that the incubation period of the sample is about 40 min. as well as a significant mass loss starts to occur after 180 min. of cavitation action. The calculated value of cavitation rate of the sample is 0.025 mg/min. The value of cavitation rate and incubation period of the cast steel 08X15H4DMJI sample indicates a high resistance of the tested sample to cavitation.

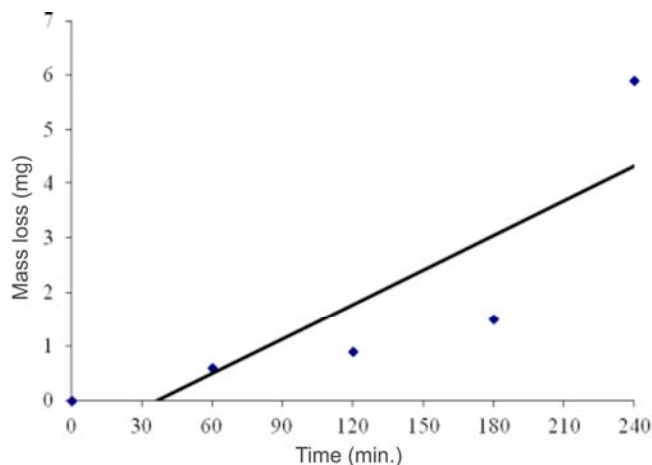


Figure 7. Mass loss of sample during testing time.

Figures 8 and 9 show the morphology of the damaged surface of the test sample after each test interval.

Microscopic analysis of the surface of cast steel 08X15 H4DMJI sample after 60 minutes of cavitation action at SEM (Fig. 8a) shows that the surface layer starts to deform due to cavitation. Surface undulations of the sample show that plastic deformation of the surface layer occurs due to dislocation movement (incubation period lasts around 40 min., Fig. 8). Nevertheless, inclusions at grain boundaries block further dislocation movement, and therefore, cavitation action causes the weakening of bonds between the metal grains and the occurrence of initial pits along the grain boundaries. These pits in the surface layer cause the focusing of shock wave energy that occurs due to implosion of cavitation bubbles which intensifies the effect of cavitation action. At this stadium of testing, mass loss is initiated and localized only at specific locations of sample surface.

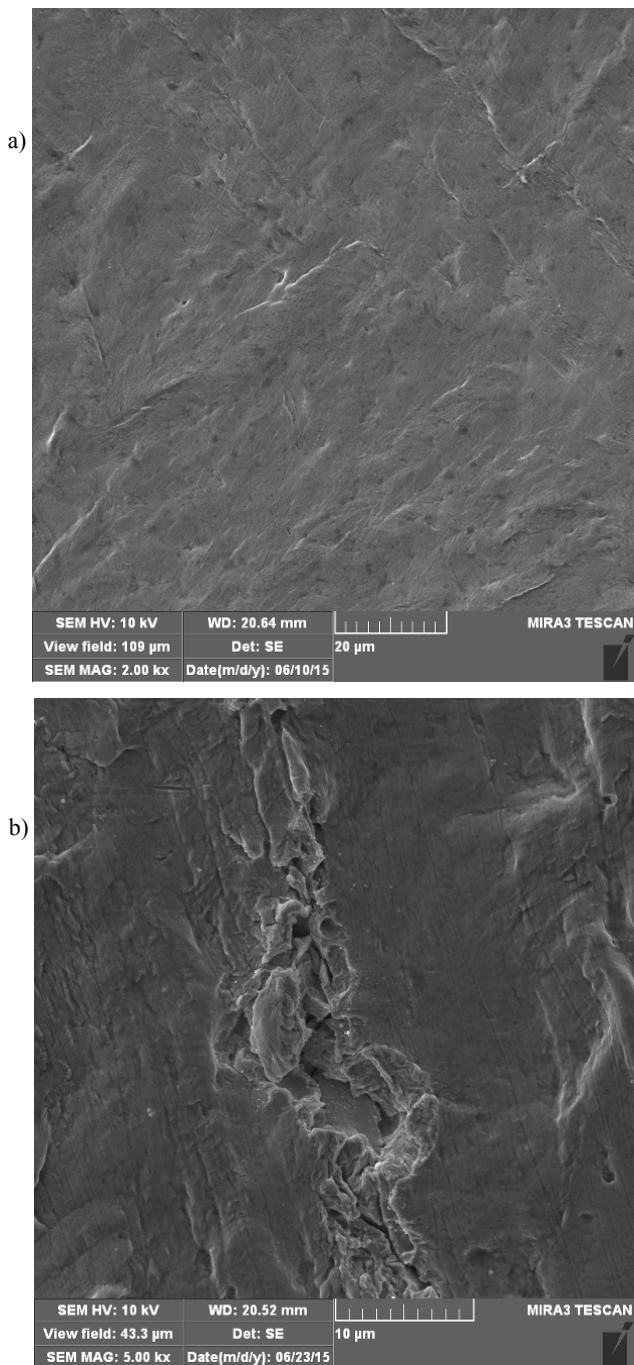


Figure 8. SEM micrographs of sample surface after: a) 60 min., and b) 120 min. of cavitation action.

After 120 min. of testing, the surface morphology is characterized by distinctive plastic deformation (Fig. 8b). Also, at specific surface locations, the damaging of ferrite due to the initiation of microcracks occurs. In steels of martensite-ferrite microstructure, cracks mostly occur in the ferrite phase which is soft, while hard martensite phase acts as a barrier to crack propagation. The efficiency of this barrier depends on the volumetric share of martensite and the geometric distribution of phases. The morphology of the sample surface after 180 min. of cavitation action (Fig. 9a) shows that during this period the surface roughness increases, or in other words, the damaging of the marten-

sitic phase has started as well. The removal of material starts at boundary surfaces of martensite slats, in a form of small pits. At the damaged surface of the sample, a net of microcracks forms, as well as local micro pits. When shock waves and micro jets, that occur due to the implosion of cavitation bubbles, continue to act on the surface during further action of cavitation, the degradation rate of the material increases. The morphology of the surface after 240 min. of testing proves that fatigue is the main degradation mechanism (Fig. 9b), because there are many pits and grooves with distinctive plastic deformation at the damaged surface of the sample.

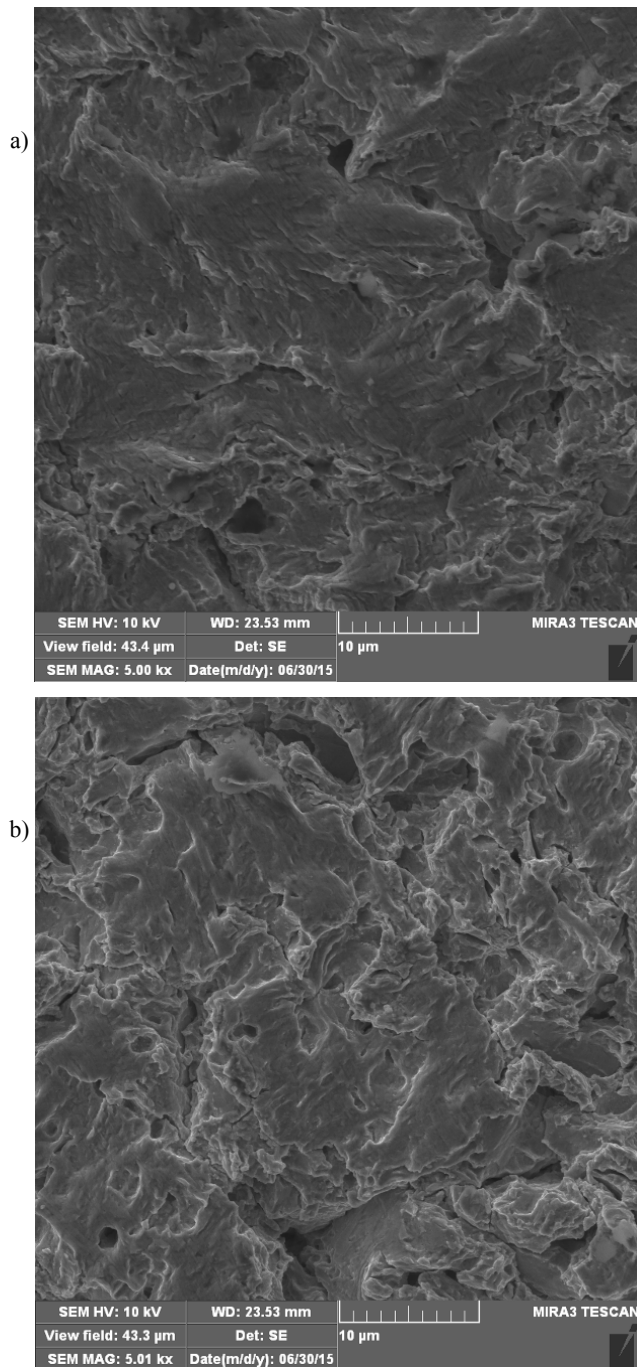


Figure 9. SEM micrographs of sample surface after: a) 180 min., and b) 240 min. of cavitation action.

## CONCLUSION

Test results regarding the mass loss of the cast steel 08X15H4ДМЛ sample indicate high resistance of tested samples to cavitation, because the tested samples had the incubation period of approximately 40 min., while significant mass loss started to occur after 180 min. of constant cavitation action. The morphology of the surface after 240 minutes of testing proves that fatigue is the main degradation mechanism, because there are many pits and grooves with distinctive plastic deformation at the damaged surface of the cast steel 08X15H4ДМЛ sample with a martensite-ferrite microstructure.

## ACKNOWLEDGEMENT

Authors wish to thank the Ministry of Education, Science and Technological Development of the republic of Serbia for the support in the realisation of project TR 35002.

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## Address and contact

Gutshaus Schloßstraße 48 | 12165 Berlin I Germany

Phone: +49 30 8113066 | Fax: +49 30 8119359

[dvm@dvm-berlin.de](mailto:dvm@dvm-berlin.de) | [www.dvm-berlin.de](http://www.dvm-berlin.de)