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# Cavitation Erosion of Nodular Cast Iron – Microstructural Effects

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## Abstract

The paper deals with susceptibility of nodular cast iron with ferritic-pearlitic matrix on cavitation erosion. Cavitation tests were carried out with the use of a cavitation erosion vibratory apparatus employing a vibration exciter operated at frequency of 20 kHz. The study allowed to determine the sequence of subsequent stages in which microstructure of cast iron in superficial regions is subject to degradation. The first features to be damaged are graphite precipitates. The ferritic matrix of the alloy turned out to be definitely less resistant to cavitation erosion compared to the pearlitic matrix component.

**Keywords:** Wear resistant alloys, Nodular cast iron, Cavitation erosion, Distilled water

## 1. Introduction

With increasing flow rates and pressures, criteria concerning selection of materials for components of water supply systems become more and more demanding. Among limitations to be taken into account when implementing new solutions is susceptibility to cavitation erosion observed in the materials used to date by the industry [1].

As it follows from the current state of knowledge, resistance of structural materials to cavitation can be linked to their hardness, tensile strength, or yield point only to a limited degree. However, it is a well-known fact that some materials are characterized with higher resistance to cavitation erosion than other [2]. Correct selection of material solutions for such components requires research effort aimed at acquisition of new knowledge on the subject.

The direct cause of cavitation erosion occurring in liquid-carrying systems are turbulent flows with local abrupt increases of fluid flow speed. Such unstable flows occur mainly in ports of valves, constrictions and throats of conduits, or in pipe fittings diverting direction of liquid flows.

If an abrupt increase of liquid speed occurs locally in a hydraulic system, then, according to the Bernoulli's principle, value of static pressure of the liquid must decrease. In view of the fact that the boiling point of liquid decreases with decreasing pressure, the liquid starts boiling when local pressure reaches a critical value resulting in development of gas bubbles, the effect being known as cavitation [3]. According to [4], pressure of saturated water vapor at temperature 20°C is 2.337 kPa. If, with increasing water flow speed, pressure drops locally below this value, volume fraction of cavitation bubbles increases together with the size of the fluid zone in which cavitation occurs. With local pressure increasing above the critical value, cavitation bubbles are subject to sudden disappearance which in fact is an implosion resulting in occurrence of a shock wave caused by sudden increase of pressure in micro-areas of the liquid [2, 5].

The problem of cavitation erosion is a complex issue as the related phenomena are affected by numerous factors. To assess their contribution to the overall effect, numerous experimental set-ups were developed [6, 7]. The standard test method for cavitation erosion using vibratory apparatus is described in ASTM G 32-10 [8]. Differences in designs of different test set-ups used by various researchers affect the obtained results and make inter-

laboratory comparisons difficult. It is a commonly accepted fact that microstructure of subsurface layer and strong development of surface resulting from cavitation erosion increases susceptibility of the material to electrochemical corrosion. Properties of water (e.g. tap water instead of demineralized one) have also an effect on cavitation erosion of involved materials [9]. It has been found that contaminated and gassed liquids are more susceptible to occurrence of cavitation bubbles which nucleate easier on suspended particles and discontinuities of the liquid. Temperature of liquid has also an effect on its susceptibility to formation of cavitation bubbles. When tests are carried out on set-ups with vibration exciting devices, an increase of temperature during the test must be taken into account. According to [10], for the ratio of the vibration exciter power to the vessel volume of  $1 \text{ W/cm}^3$ , temperature of water may increase at a rate as high as  $20^\circ\text{C}$  per hour.

Susceptibility of cast iron used for cast components of valves and pumps to cavitation erosion is a very important issue in view of high costs of system shut-downs. The issue, on an example of refineries and petrochemical plants in Kuwait, was signaled in [11]. The same problem was further investigated by authors of [12] who have undertaken an attempt to determine the mechanism of cavitation erosion occurring in nodular cast iron with ferritic matrix, using vibratory-induced cavitation apparatus with parameters similar to those characterizing the experimental set-up used in the present study. The authors have found that the paths of facilitating the cavitation erosion were graphite-ferritic matrix interfaces. Graphite was then subject to fragmentation and ultimately removed. In further stages, cavities in the matrix developed and subsequently increased in size.

Bearing in mind significance of the issue of extending service life of cast-iron components of water supply systems, the present authors have undertaken a study on resistance of the nodular cast iron to degradation caused by the cavitation process, considering results published in [12] as a reference material.

## 2. The material and methodology

The material used for the study were plates ( $255 \text{ mm} \times 55 \text{ mm} \times 10 \text{ mm}$ ) cast of nodular cast iron with the following chemical composition: 3.4% C, 2.7% Si, 0.09% Mn, 0.025% P, 0.010% S, 0.02% Ni, 0.01% Cu, 0.003% Ti, 0.051% Mg, 0.02% Al, 0.01% Zn, and Fe to balance. Plate casings were cast into bentonite clay moulds.

The castings were used to prepare specimens for cavitation erosion resistance tests in the form of plates with dimensions  $20 \text{ mm} \times 10 \text{ mm} \times 10 \text{ mm}$  mounted in Bakelite. Specimen surfaces were prepared by grinding and then polishing on a polishing wheel with diamond suspension. The value of the profile height parameter  $R_t$  defined as the distance between the peaks line and the valleys line was  $0.5 \mu\text{m}$ .

The cavitation erosion resistance tests were carried out with the use of Vibra-Cell ultrasonic liquid processor (SONICS) equipped with a probe with piezoelectric transducer. The adopted vibration frequency was 20 kHz. In the course of tests, specimens were immersed in distilled water. The distance between face of

the ultrasonic probe and the specimen surface was 0.5 mm. The cavitation effect was induced for 30 minutes and 120 minutes.

A view of the cavitation mist area developed over the specimen surface in the course of cavitation erosion tests is shown in Figure 1.

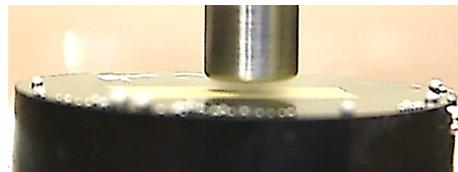


Fig. 1. A view of the cavitation mist area developed over the specimen surface in the course of cavitation erosion test

After completion of the cavitation erosion resistance tests, specimen surfaces were examined with the use of VEGA3 scanning electron microscope (TESCAN). Values of the height parameter  $R_t$  characterizing geometrical structure of specimen surfaces was determined with the use of T8000 roughness measurement system (HOMMEL-ETAMIC).

## 3. Research results and analysis

Microstructure of the nodular cast iron used for the purpose of the present study is shown in Figure 2.

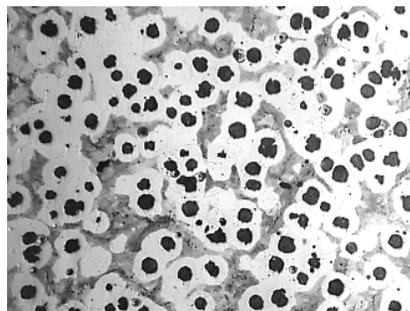


Fig. 2. Microstructure of the nodular cast iron used in the present study. Ferrite, pearlite, graphite. Magnification  $100\times$ . Section etched with 4%  $\text{HNO}_3$

Example 2D profilograms of specimen surfaces in the cavitation activity region after 30-min and 120-min test are shown in Figure 3.

Values of the parameter  $R_t$  characterizing geometrical structure of specimen surface after cavitation erosion resistance test in central portion of the cavitation interaction area are summarized in Table 1.

The obtained results indicate that with the increase of cavitation interaction time from 30 min to 120 min, value of parameter  $R_t$  increase more than fivefold.

An example view of specimen surfaces after the cavitation erosion resistance test lasting 120 minutes is shown in Figure 4. To reveal microstructure of matrix, specimens were etched with 4%  $\text{HNO}_3$ .

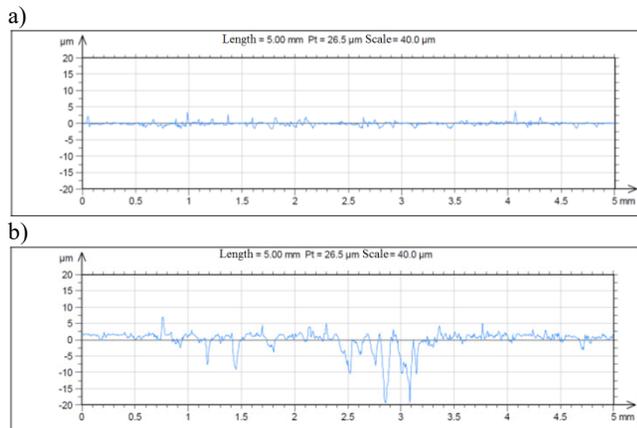


Fig. 3. Example profilograms of nodular cast iron specimen surfaces subject to cavitation erosion test for: (a) 30 minutes, (b) 120 minutes

Table 1.

Values of the height parameter  $R_t$  characterizing geometrical structure of the nodular cast iron specimen surface in central portion of cavitation interaction spot

Cavitation test duration	$R_t$ parameter value, $\mu\text{m}$
30 min	4.20
120 min	22.70

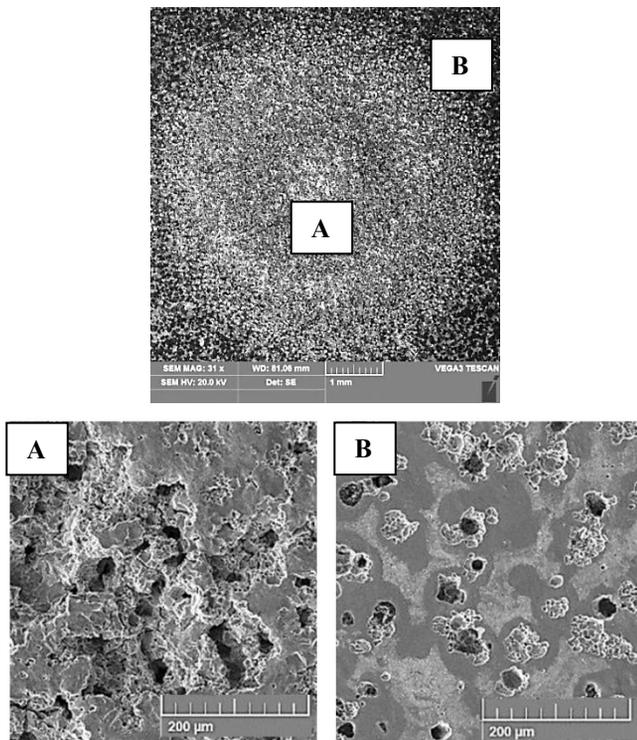


Fig. 4. Example views of specimen surface after 120 minutes of cavitation erosion resistance testing; A — central and B — outermost area of cavitation interaction spot

Figures 5–8 illustrate characteristic changes in microstructure of areas subject to cavitation interaction.

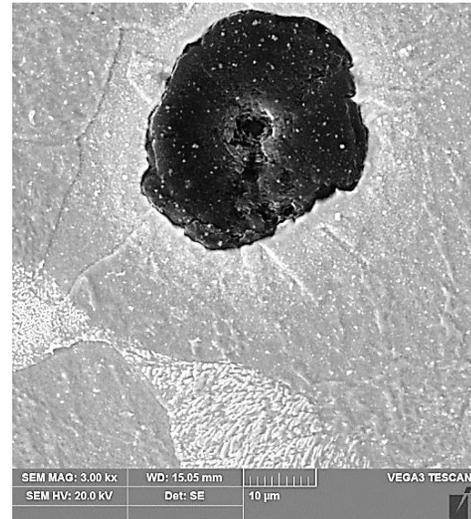


Fig. 5. The first stage of cast iron microstructure degradation. Outermost portion of cavitation interaction spot. Destruction of graphite precipitates in ferritic matrix progressing from center towards graphite-matrix interface

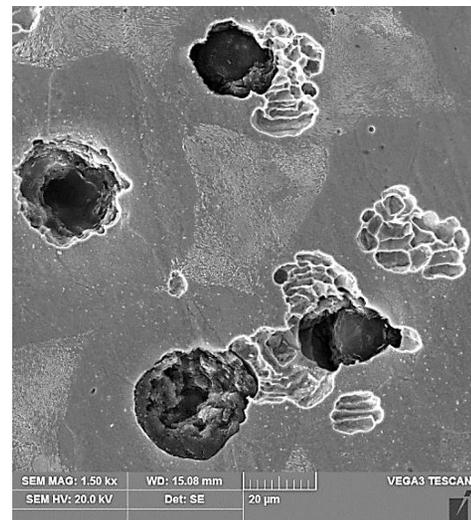


Fig. 6. The second stage of cast iron microstructure degradation. An outermost portion of cavitation interaction spot. Note high degree of graphite precipitate degradations progressing in layers but always from center towards graphite-matrix interface. Partial graphite tear-offs initiate degradation of ferritic matrix

The obtained results allowed to establish the sequence of stages in which microstructure of nodular cast iron with ferritic-pearlitic microstructure is subject to degradation. Destruction starts with graphite precipitate tear-offs occurring in their central portions. The most durable is a thin graphite film in contact with matrix.

In the next stage, degradation spreads onto ferrite precipitates surrounding graphite nodules. Further development of erosion of the ferritic matrix are suppressed by pearlite precipitation areas.

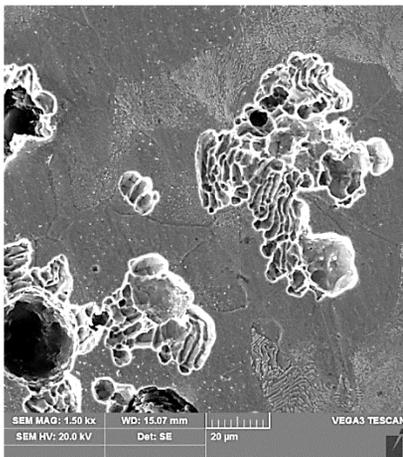


Fig. 7. The second stage of cast iron microstructure degradation. Uttermost region of the cavitation interaction zone. Significant progress in ferritic matrix degradation blocked locally by pearlite precipitation areas

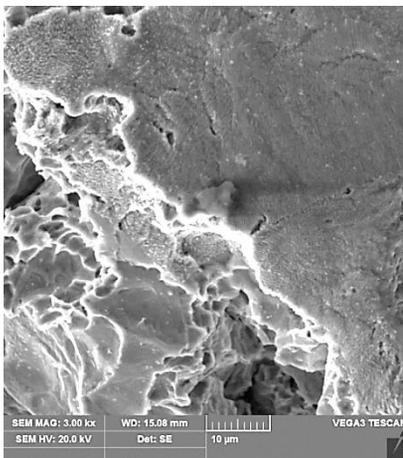


Fig. 8. The second stage of cast iron microstructure degradation. A central portion of the cavitation interaction spot. Deep cavitation-induced cavities in ferritic matrix with visible initial stage of destruction of an exposed, deeply lying graphite precipitate. No visible damages to pearlite precipitates

After the longer test cycle of 120 minutes, no evidence was found of degradation in pearlite precipitates. The obtained results do not confirm any structural response of nodular cast iron microstructure to cavitation interaction in aqueous environment reported by authors of [12]. It seems to be a reasonable assumption that the material examined in the above-quoted study was in after a heat treatment after which the cracks on the graphite-matrix interface occurred as a result of diffusion processes. The cracks could provide easy paths for propagation of cavitation-induced destruction.

## 4. Conclusions

The obtained results indicate that in nodular cast iron, ferritic matrix is more susceptible to cavitation erosion than the pearlitic one. In view of the above, manufacturers should rethink the issue of appropriateness to use cast irons with ferritic matrix for components of water supply system fittings.

It seems to be appropriate to undertake a study on the effect of morphology of precipitates of graphite and of the matrix other than ferritic or ferritic-pearlitic one, on resistance of cast iron to cavitation erosion in the such liquid environments like drinking water, seawater, and contaminated water in general.

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