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The SEM study of cavitation damage of as-cast ductile iron

O. Eric Cekic[1], M. Dojcinovic[2], S. Balos[3], D. Rajnovic[3], L. Sidjanin[3]

[1]Innovation Centre, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia
[2]Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia
[3]Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia

olivera66eric@gmail.com
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Cavitation is material damage caused by the formation and collapse of bubbles, in a liquid. The shock waves and microjets emitted during the collapses of vapor structures interact with neighboring solid surfaces and may cause the material damage [1-3]. During cavitation, the implosion of the bubbles formed in the liquid on the component surface erodes the surface. The cavitation is a source of concern in machine parts that are subject to vibratory forces while in contact with a liquid. Different materials offer different levels of resistance to cavitation. Cast iron is a material known to have relatively low resistance to cavitation. Examples of cast iron machine components that are susceptible to cavitation include, among others, housings of pumps and liners of engine cylinders. The cavitation erosion resistance of a material is commonly determined by mass loss measurements in the laboratory using an ultrasonic vibratory apparatus and the resistance is reported in term cavitation rate. Methods alternative to mass loss-time measurements to quantify erosion damage represent evaluation of surface roughness parameters which provide more detailed information in addition to erosion loss [4, 5]. Different types of cast iron are subject to cavitation due to the presence of graphite and relatively weak metal matrix. A significant number of studies have been carried out on the grey and austempered ductile iron, but only few on nodular cast iron with ferrite matrix may be found [6]. A small number of studies have been performed on the effect of microstructure with a wide variety of ferrite/pearlite ratios on cavitation resistance behavior of ductile cast iron [7]. In this paper, a detailed study of unalloyed ductile cast iron was subjected to intensive cavitation in water, by the application of ultrasonic equipment. The frequency of vibration and the peak-to-peak displacement amplitude of the horn were 20±0.5 kHz and 50 µm, respectively, with separation of 0.5 mm between the specimens and the horn tip. The liquid test was done in water at 25±0.5 °C. The microstructure of ductile iron consisted of spheroidal graphite in a predominantly ferrite matrix with 10% pearlite. The morphology of graphite was fully spherical with average graphite volume fraction of 10.9%, nodule size of 25 to 30 µm and nodule count of 150 to 200 per mm^2. The cavitation damage was assessed by a common mass loss technique, as well as metallographic examination of eroded surfaces by means of scanning electron microscope (SEM) JEOL JSM 6460LV, operated at 20kV. The SEM micrographs were taken after 30; 60, 120 and 240 minutes of cavitation process, while light microscope (LM) examinations were done before and after cavitation, to find eventual metal matrix modifications as a result of cavitation shock waves. At the beginning of cavitation testing the erosion and separation of graphite nodules from ferrite matrix occurs, Figure 1. With increase of testing time cavitation caused the separation of graphite nodules from ferrite matrix leaving pits, Figure 2. It was shown, that the portion remaining after the nodules removal has the form of pits with notchs which have high stress concentration and represent favorable locations for cavitation erosion. In the initial periods of cavitation, ferrite matrix was slightly attacked. With increase of cavitation time, ferrite matrix also becomes subjected to attack and undulations are formed on grain boundaries and slip bands. Increase of undulations appears with longer time of testing. It was found that with increasing time of testing the attacked area of the specimen became larger with more pits, micropits and surface deformation, Figure 3. Ductile deformation can also spread to the matrix away from the pits that formed as a result of the removal of graphite nodules. The ductile removal of the material in the matrix by coalescence of these pits with formation of deep craters was observed in Figure 4. In the last stage, after 240 min of cavitation testing, numerous craters and grooves with intense plastic deformation can be observed on the damaged surface, Figure 5. The SEM results were correlated to the results obtained by mass loss analysis, performing a linear dependence between mass loss and cavitation duration. It can be concluded that cavitation erosion of ductile cast iron begins by removal of graphite nodules and afterwards by ductile removal of material in the ferrite matrix. The cavitation rate of ductile cast iron was 1.85 higher compared with that of carbon steel with similar hardness, since graphite nodule removal produces high stress concentration in cast iron.

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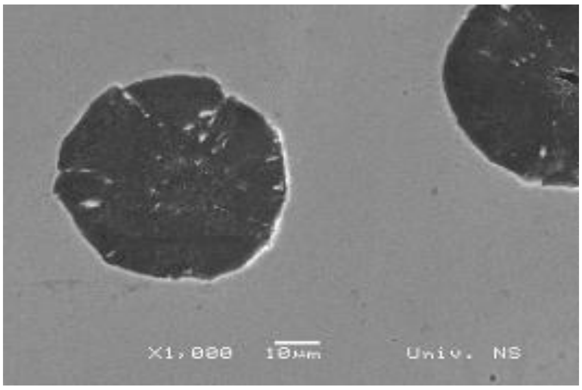

Figure 1. Erosion of graphite nodules

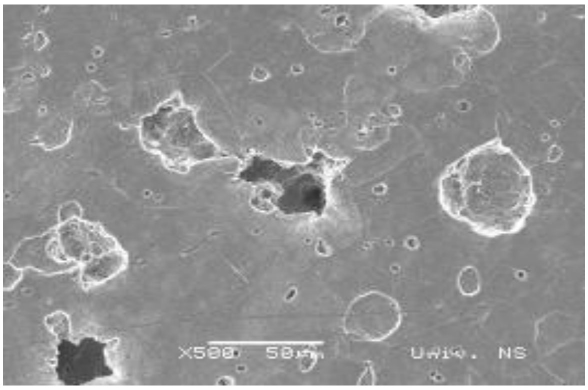

Figure 2. Pits produced by graphite nodule removal 30 min cavitation time

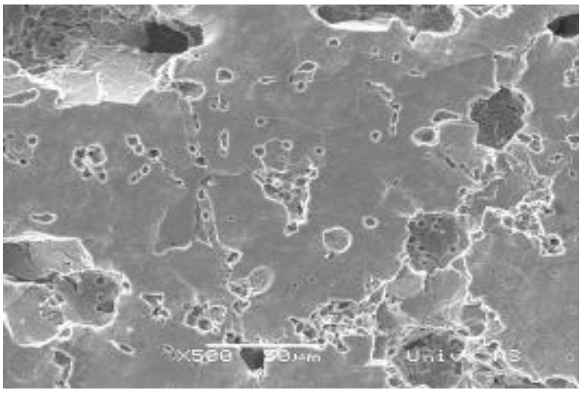

Figure 3. Formation of microcracks by coalescence of pits, 60 min cavitation time

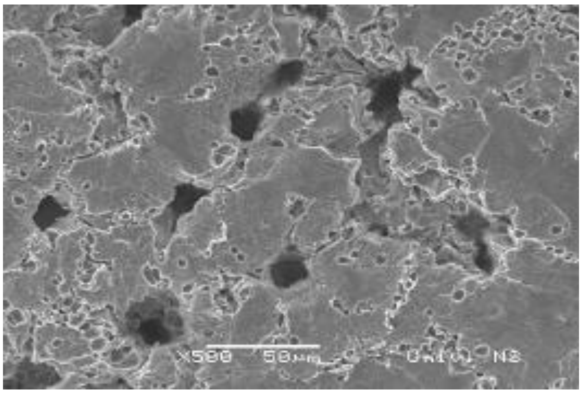

Figure 4. Groves and microvoids forming along the phase boundaries, 120 min cavitation time

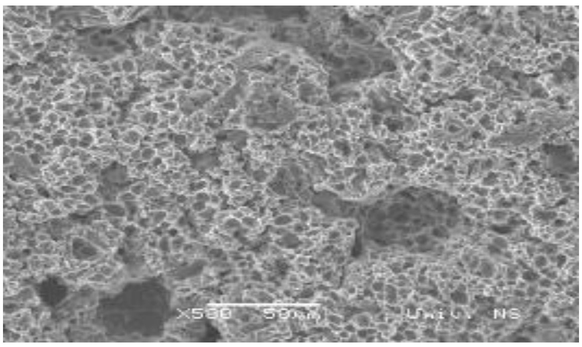

Figure 5. The eroded surface 240 min cavitation time