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Ultrasonic cavitation erosion of nodular cast iron with ferrite–pearlite microstructure

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ABSTRACT

The cavitation erosion of ductile cast iron with ferrite–pearlite microstructure was analyzed based on ultrasonic experiments performed according to ASTM G32-2010 and the resistance was compared to the C45 steel with similar hardness. The microstructural observation of the surface for different exposure times to the ultrasonic cavitation reveals the fact that the process initiates at the nodular graphite–ferrite interface and is controlled by micro-galvanic activities and mechanical factors. The cavitation erosion resistance was evaluated based on the evolution of the mean depth erosion and the mean depth erosion rate as a function of the cavitation time. The cavitation erosion rate of the cast iron is up to 1.32 times higher than the one of the C 45 steel with similar hardness. This is explained by the occurrence of stress concentrators due to the expulsion of the graphite from the metallic matrix.

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1. Introduction

Cavitation erosion is a process that affects a significant number of components used in hydraulic equipments, like pumps, ship propellers or turbines for hydroelectric power plants [1]. When subjected to cavitation erosion, materials behave differently, depending on their composition, structure, surface treatments etc [2]. During the cavitation erosion of metals and alloys, the work-hardening process due to the bubble collapse in the superficial layer is associated with a surface hardness increase [3]. For ductile materials it was also observed that the erosion rate is scaled by the ratio of the thickness of the hardened layers to the covering time, but also depending on the flow aggressiveness [4]. Franc and Michel [1] also pointed out that fatigue mechanisms have to be expected due to the repetitive nature of the process, involving high strain rates and short impact duration.

In order to asses one material's resistance to such conditions, specific tests are standardized, aiming to simulate the cavitation erosion process in accelerated conditions performed in a laboratory. However, there is significant difference compared to real cavitation phenomena that occur in components of hydraulic machines and there are concerns on accepting the accelerated erosion tests versus the full scale erosion. Choi et al. [5] studied the influence of different erosion intensities and testing methods and concluded that the relative ranking of erosion resistance of some materials depends on the cavitation intensity. According to Chahine et al. [6], the ultrasonic method leads to the formation of a cavitation bubble cloud, always at the same location, with bubbles of nearly uniform size and form obtained at a fixed frequency, compared to the real cases where a distribution of nuclei size exists as well as various exciting frequencies. They also emphasized that the standardized test does not allow a full characterization of the behavior in real conditions due to the absence of a real liquid flow or the interaction of bubble nuclei with turbulent vortex filaments.

Compared to real cavitation erosion that occurs after a long duration of exposure, the standardized accelerated tests provide however relevant laboratory results that can be used to compare materials tested under similar conditions. The equipment for this purpose leads an intensive erosion process in a controllable and reproducible manner, by generating bubbles clouds that erode the surface of a sample made out of the tested material. Such equipments can be used to assess the resistance to cavitation erosion of a material in terms of the erosion rate, thus allowing materials to be classified based on this property. Ultrasonic equipments have been developed for the purpose of evaluating the cavitation erosion process, according to ASTM G32-09 standards [7,8]. They have the advantage of using simple equipments, with easily controllable parameters, that generate longitudinal vibrations, amplified and transmitted into the liquid as ultrasonic waves. The bubbles that

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form during these vibrations implode at the surface of the samples leading to a cumulative effect that has a destructive effect on the surface with an energy that depends on the parameters used in the process and the characteristics of the ultrasonic probe. The cavitation erosion pits depend on the material's particularities with the predominant failure related to the fatigue process [9]. Although the ultrasonic cavitation erosion experiments can be performed in various fluids more intense cavitation occurs for higher surface tension of the fluid. The increase of the viscosity is expected to lead to a reduced erosion of the surface due to the decrease in the rate of growth and collapse of the bubbles [10].

Nodular cast irons are a class of materials with the microstructure that depends on the chemical composition and the cooling rate during the casting process. A common characteristic of all nodular cast irons is the almost spherical shape of the graphite nodule, that leads to an increased ductility and affect less the metallic matrix compared to the lamellar graphite. An improved erosion resistance was reported after laser treatment due to the very fine structure, high micro hardness and the dissolution of the graphite nodules [11]. The microstructure of the metallic matrix of the nodular cast iron is influencing in a large degree the mechanical characteristics and the cavitation erosion resistance. Work has been done so far on the analysis of the relationship between the cavitation erosion resistance of a variety of lamellar and nodular cast iron with ferrite or bainite matrix. It thus becomes important to further expand the limits of knowledge to ductile cast irons with the ferrite–pearlite matrix. Hattory and Kitagawa analyzed the cavitation erosion behavior of cast iron and compared the results with carbon steel data, observing that the erosion resistance was 1/3 to 1/5 lower for gray cast iron and 2/3 to 1/3 lower for ductile cast iron compared with that of carbon steel with the same hardness [12]. Dojčinović et al. studied the morphology of the surface damaged by cavitation for ductile cast iron with ferrite matrix and observed that the cavitation rate was 1.85 higher for ductile iron compared with that of carbon steel with similar hardness [13].

The current paper aims to investigate the cavitation erosion behavior of nodular cast iron with a matrix composed of ferrite and pearlite in almost the same amount and to compare the resistance to the one of a carbon unalloyed steel with similar hardness. This work is important in order to expand the limits of knowledge for the adequate selection of materials for hydraulic components, given the better damping response and lower specific weight of the ductile iron compared to steels.

2. Experimental procedure

The cavitation experiments were performed using a piezoceramic crystals vibrating system, according to ASTM G32-09 shown in Fig. 1.The direct method was used, with the specimen attached to the ultrasonic vibrating horn. This set up allows a reliable a reproducible control of the experimental parameters, thus permiotting the comparison of the cavitation erosion behavior for different materials tested under the same conditions. During the experiments, the frequency, the amplitude and the temperature of the fluid are controlled.

Fig. 2a shows the typical sample dimensions for the cavitation test used in the experiments, while the typical image of the cavitated cast iron sample after 165 min is presented in Fig. 2b.

The samples with a polished surface are firmly attached to the end of the vibrating horn and submerged in distilled water. The bubbles growth and collapse near the front of the sample lead to surface damage due to the cavitation erosion. The following functional parameters were used for the experiments: 500 W power, 20 kHz vibration frequency, 50 μm vibration amplitude, for a sample with 15.8 mm diameter. The tests were performed at constant temperature for the of 22 ± 1 °C.

A nodular cast iron (EN-GJS-400-15, according to EuroNorm standards) was selected for the experiments, with the microstructure and composition analyzed using optical (OM) as well as scanning electron microscopy (SEM). The typical graphite distribution and the matrix were observed in an Olympus Bx50 microscope, while the effects of the cavitation were studied in a TESCAN Vega 3LM electron microscope, equipped with a Bruker Quantax 200 Energy Dispersive X-ray Spectroscopy (EDX) system with Peltier-cooled XFlash 410 M silicon drift detector. The EDX composition determined for the nodular cast iron is shown in Table 1.

The mass of the samples subjected to the cavitation erosion tests were periodically weighted to determine the mass loss and the effect on the surface was investigated by OM and SEM. The mass loss curves for the casted iron were compared with the ones recorded under the same conditions for a C45 steel with the same hardness.

The cavitation erosion test were performed on three sets of samples with a total duration of the cavitation exposure of 165 min divided in 12 periods (i) of 5, 10, 10 and the rest 15 min intervals. The average mass loss Δm_i for each of the three sets samples was based on three measurements of each samples. The total mean cumulative mass loss for up to the total duration of the process was determined by,

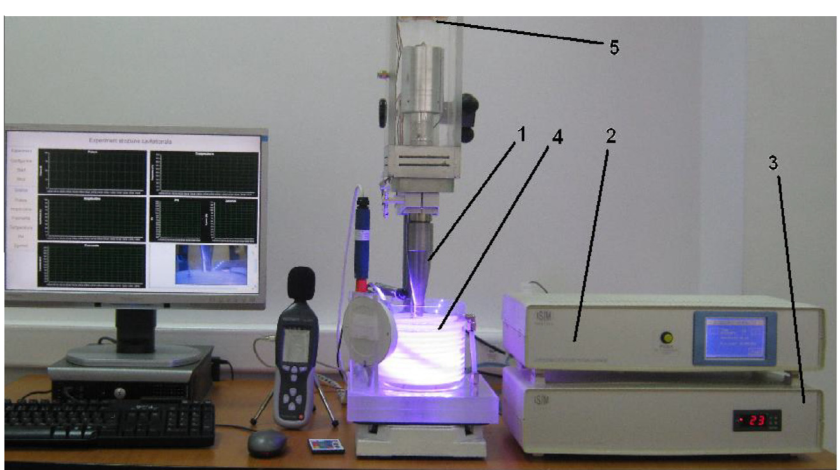

Fig. 1. Details about the ultrasonic cavitation erosion equipment used in the experiments (1 – sonotrode; 2 – electronic generator; 3 – cooling controller; 4 – water recipient; 5 – cooling fan).

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