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Cavitation damage of the medium carbon steel: Implementation of image analysis

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Abstract

Cavitation damage of the medium carbon steel was performed using the modified vibratory cavitation test set up. Erosion rates were measured by analytical method. The morphology of damage under cavitation action was determined by optical microscopy techniques. Image analysis was used for determination change of the ratio of ferritic phase in the heat treated medium carbon steel during cavitation action. Implementation of image analysis was done by Image Pro Plus Program.
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Keywords: Cavitation; Medium carbon steel; Optical microscopy; Ferritic phase; Image analysis

1. Introduction

Cavitation, one of the mechanisms of liquid erosion, characterized by the generation and the collapse of vapor structure in liquid, occurs frequently in hydraulic machinery such as pumps, turbine and propellers [1,2,3]. The pressure waves emitted during the collapses of vapor structures interact with neighboring solid surfaces, leading to material damage [4,5,6]. The purpose of most laboratory tests on cavitation erosion is to predict the material performance under cavitation attack in a full-scale hydraulic machine or structure. As the course of erosion is generally known to depend essentially on cavitation impacts distribution, reproduction of this distribution in laboratory may be considered a condition of reliable quantitative assessments.

In order to obtain realistic cavitation erosion predictions in hydraulic machines, the vibratory device was used in this investigation. The cavitation cloud is generated here by a horn vibrating with high frequency in water. The obvious advantages of the method include: high erosion rate (test duration from 4 to 6 h is often sufficient), small size of the device and low energy consumption. Vibratory method was standardised by the ASTM Committee on Wear and Erosion in an interlaboratory test carried out in 1969.

Image Pro Plus is a software package used for image acquisition, enhancement and analysis. The software has the ability to read and generate image data in many formats, including TFF, LPEG, BMP and TGA. Image data can be enhanced using a large variety of color and contrast filters. Program enables users to trace and count objects manually or automatically. Object attributes such as area, length, and diameter can be measured, and the image can be calibrated to the desired unit of measure [7]. In the framework of this research, Image Pro Plus Program was used for image analysis of microstructure of samples before and after cavitation. Change of the ratio of ferritic phase in the medium carbon steel as a result of mass loss from surface layer of samples during cavitation action was determined. Determination of relation of testing time and the ratio of ferritic phase was the goal of the paper.

2. Experimental

2.1. Materials

In this paper, a medium carbon steel was chosen for examination. The heat treatment of steel was performed by normalizing (heating at 860 °C and air cooling). Chemical compositions and mechanical properties of the medium carbon

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Table 1
Chemical composition (wt %) and mechanical properties of the tested steel

Chemical composition					Mechanical properties			
C	Si	Mn	P	S	Vickers hardness	Yield stress	Tensile strength	Elongation
%	%	%	%	%	HV_{30}	N/mm^2	N/mm^2	%
0.36	0.32	0.65	0.019	0.028	187	270	520	19

steel — 1.1181 (standard EN 10027-2) are listed in Table 1. Chemical compositions and mechanical properties are given by the producer.

The microstructure formed consists of a ferrite phase and a pearlite phase. The microstructure of tested steel is shown in Fig. 1. This steel may be regarded as a coarse-grained material.

2.2. Methods

The test set up for conducting the laboratory testing of the cavitation resistance by using the Modified Vibratory Cavitation Test Method is shown in Fig. 2 [8].

The set up consists of: a high frequency generator of 360W, an electro-strictive transducer, a transformer for mechanical vibrations and a water bath containing the test specimen.

Cavitation erosion testing was accomplished utilizing the recommended standard values:

- Frequency of vibration: 20±0.2 kHz
- Amplitude of vibrations at the top of the transformer: 50± 2 μm
- Gap between the test specimen and the transformer: 0.5 mm
- Temperature of water in the bath: 25±1 °C
- Ordinary water flow: from 5 to 10 ml/s

These parameters were controlled throughout the testing process [9].

The test specimen was placed under the transformer with a gap of 0.5 mm. The evaluation of the mass losses of the test specimens was done on an analytical balance with an accuracy of ±0.1 mg. Before being weighted, the test specimens were washed in alcohol and dried in hot air. The measurements were performed after each test specimen had been subjected to cavitation for a duration of 1 h. Obtained results calculated for the coordinate system: mass loss (ordinate) and exposure time (abscissa). The diagram shows relation between mass loss and testing time, where the lines were drawn by least-square method and data can be expressed by a straight line [10]. The slope of the straight line represents the cavitation rate. The point where the straight line intercepts the abscissa, indicates the incubation period, i.e. time elapsed before the destruction of material commences.

Three test specimens were used for each test and as a result average value of measurements was taken. The duration of the tests was 4 h.

Optical microscopy technique was performed to analyze the effect of the erosion and to interpret the results of the cavitation tests.

After cavitation tests, cross sections of the test specimens were prepared. They were chemically plated with a layer of

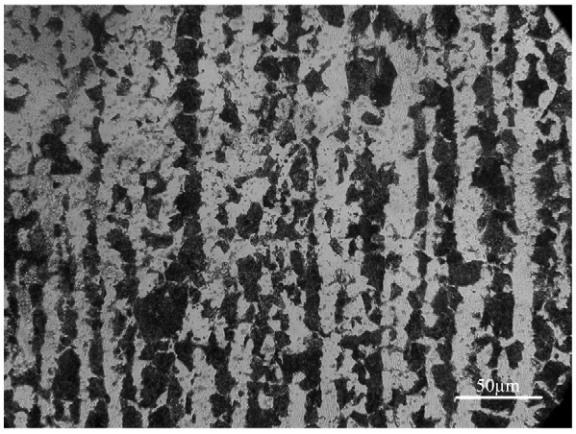

Fig. 1. Microstructure of the medium carbon steel (light particles represent ferrite and dark particles represent pearlite). Magnification 500×.

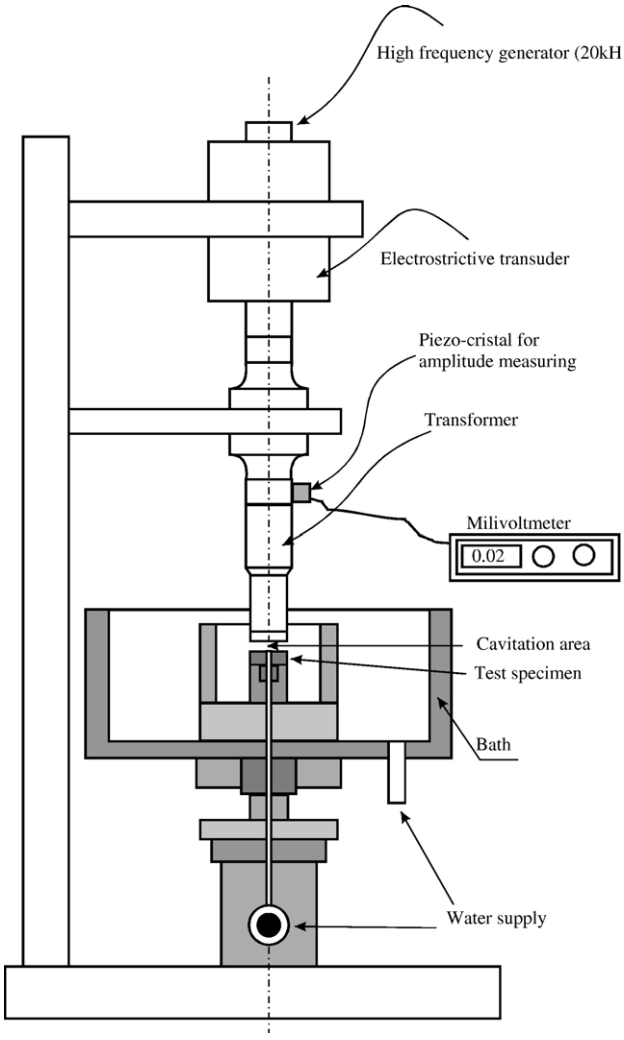

Fig. 2. Schematic overview of cavitation test set up.

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