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The relation between the high speed submerged cavitating jet behaviour and the cavitation erosion process

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ABSTRACT

In order to accurately and reliably evaluate the cavitation erosion resistance of materials using a cavitating jet generator, the effects of the hydrodynamic parameters and the nozzle geometry on the erosion process were investigated. Since the behaviour of a high speed submerged cavitating jet is also depending on the working conditions; their influence is also discussed based on the evaluation of cavitation erosion process. The erosion rate was used as an indicator for cavitating jet behaviour. Specimens of commercial-purity copper were subjected to high speed submerged cavitating jets under different initial conditions, for certain time periods. The force generated by jet cavitation is employed to initiate the erosion in surface. The tested specimens were investigated with a digital optical microscope and a profilometer. It was found that erosion becomes more pronounced with decreasing cavitation numbers, as well as with increasing exit jet velocities. The nozzle configuration and hydrodynamic parameters have strong influences on the erosion rate, eroded area and depth of erosion. A comparison between the obtained results explains some of the mechanisms involved in cavitation and erosion processes and their relation to the tested parameters. Mathematical expressions which combine these parameters with the erosion rate are obtained. These parameters are very important in order to control the cavitation as a phenomenon and also to control the performance of the cavitating jet generator.

Introduction

Cavitation causes many adverse effects that are to be avoided or at least controlled in any hydraulic facility. On the other hand, cavitation is used in many diverse scientific and industrial applications (jet cutting, under water cleaning, etc.) via cavitation clouds produced by cavitating jet generators. The impingement of a cavitating jet leads to serious erosion in valves and hydraulic equipment. In order to reduce cavitation erosion in valves and oil hydraulic equipment or to improve the performance of jet cutting or under water cleaning, etc., it is necessary to have an adequate knowledge about the mechanism of erosion due to the impingement of a cavitating jet (Choi et al., 2012; Field et al., 2012; Hutli et al., 2008; Soyama, 2011a; Soyama et al., 2009; Yamaguchi and Shimizu, 1987). The great advantage of testing erosion by the use of cavitating jet is that the cavitating jet apparatus can simulate different cavitating conditions. If a relationship between the cavitation intensity in a cavitating jet and the erosion rate of a material were investigated precisely, the key parameter to predict the cavitation erosion rate could be clarified and the performance of the cavitation generator could be increased as well (Hutli et al., 2010; Minguan et al., 2013; Soyama et al., 2012). The collapses of the cavities are the origin of high pressure spikes on the target surface. The amplitude of the collapse stress pulses is varying and random, but it can reach up to 1500 MPa, which is a level of stress high enough to deform or to rupture the surface of most industrial alloys (Karimi, 1986). In addition, the collapse of cavitation bubbles produces not only mechanical impact, which normally results in cavitation erosion in fluid machinery, but also high temperature spots which have a significant thermal effect.

Frequently cited studies found that a converging shock wave reflects at the bubble centre, generating peak pressures and temperatures above 10 Mbar and 10^7 K in a small central region of the bubble (Wu and Roberts, 1993; Moss et al., 1994; Bass et al., 2008). Therefore it should be noted that, in the investigation of the

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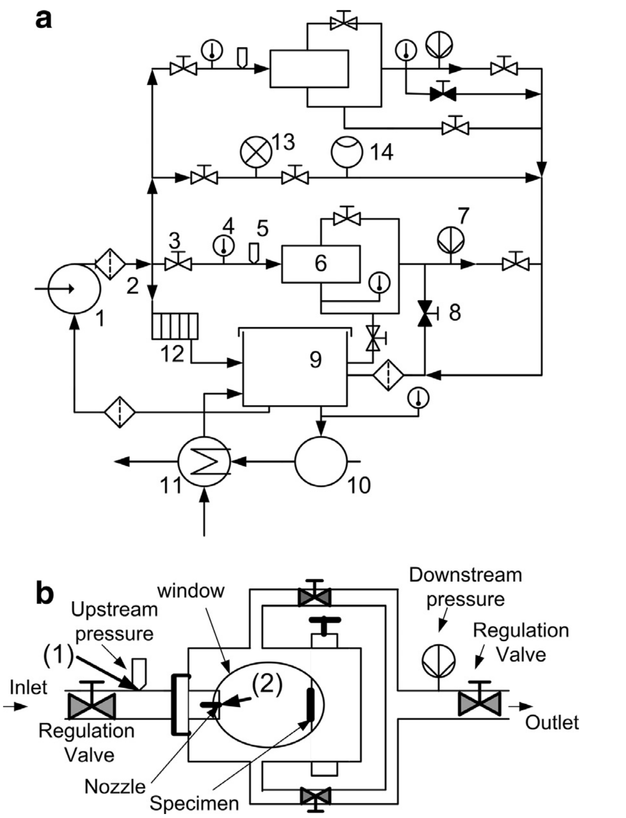

Fig. 1. (a) Schematic diagram of the cavitating jet machine. (1 – plunger pump, 2 – filter, 3 – regulation valve, 4 – temperature sensor, 5 – high-pressure transducer, 6 – test chamber, 7 – low-pressure transducer, 8 – safety valve, 9 – tank, 10 – circulation pump, 11 – heat exchanger, 12 – distracter energy, 13 – pressure gauge, and 14 – flow indicator). (b) Schematic diagram of the test chamber.

cavitation damage, the possible influence of the generated temperature on the target surface should be considered.

The understanding of these mechanical and thermal effects and their application may be employed to improve the corrosion resistance of a material (Soyama and Asahara, 1999). The flow across the holes of a nozzle can be controlled by different factors, which may be classified under three categories: operation conditions, orifice geometry and flow properties. The importance of these parameters may be understood from the results of many authors who have investigated the performance of jets (e.g. Okada et al., 1995; Soyama et al., 1998a; Sun et al., 2005; Vijay et al., 1991; Zhou and Hammitt, 1983).

The aim of this study was to examine the influence of hydrodynamic conditions, such as cavitation number, exit jet velocity, and the nozzle configuration (convergent or divergent) on the behaviour of the created cavitating jet, where the cavitation erosion of commercial copper is used as an indicator of the cavitation behaviour. In this way the performance of the cavitating jet generator can be analysed.

Experimental set-up and measurement procedure

The experimental set-up for the investigation of the cavitating jet performance was the closed hydraulic loop shown in Fig. 1(a). A high speed submerged cavitating jet was produced in the test chamber by the adjustment of the appropriate hydrodynamic conditions and the final outflow to the test chamber through the nozzle. The specimens were mounted in the chamber co-axially with the nozzle, the chamber was filled with water and then the water was pressurized by a plunger pump. Only one chamber was functional, while the other one was in reserve. A shortcut line with a pressure gauge functioned as a pressure regulator in the system. The regulation of the water temperature to ±1 °C during the erosion tests was achieved by a cooling circuit with a heat exchanger. The details of the chamber are shown in Fig. 1(b).

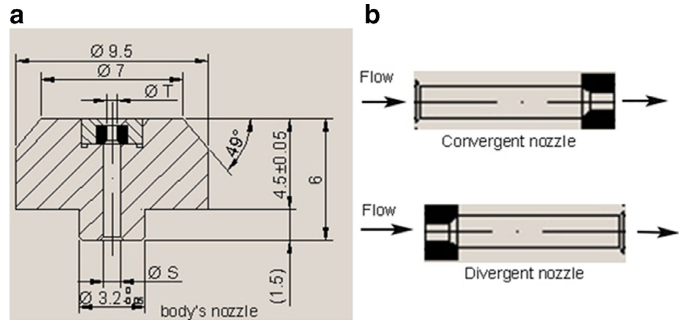

Fig. 2. (a) Geometrical parameters of the nozzle. (b) Ways of nozzle installation (dimensions in mm).

The hydrodynamic conditions were the following: nozzles with different diameters were used (0.4, 0.45, 0.55, 0.6,1, 1.1 and 2 mm); the top speed of the jet was more than 250 m/s for an upstream pressure set to 450 bar (with nozzle diameter of 0.45 mm); the downstream pressure could be adjusted from atmospheric pressure up to 6 bar. The volume of the test chamber was 0.87 l

A rotating holder was employed to attach up to 6 specimens at a distance of $x = 25.67$ mm away from the nozzle (on the opposite side of the chamber – Fig. 1(b)), with the aim to allow switching from one sample to another during the test. It also allows a quick start and/or stop of the exposure to cavitation without the necessity for turning on/off the test rig. The software used for data acquisition and to control the machine was LABVIEW 7.1.

Usually the non-dimensional standoff distance ($\frac{x}{d}$) where d is the outlet nozzle diameter is used instead of standoff distance (x(mm)).

Before the tests, the specimens were prepared by metallographic polishing in order to provide a perfectly smooth surface appropriate to be examined for any damage imposed by the cavitation jet.

The specimens were first weighed and then mounted in the holder. The hydrodynamic conditions were selected to produce a suitable cavitating jet. The cavitating jet then impinged on the specimen at 90° to its surface. The facility was turned off, the chamber evacuated and then the specimen was removed. The specimens were dried and weighed and then the procedure was repeated with other specimens. The intensity of the cavitating jet was controlled via the upstream and downstream pressures, which were measured precisely by transducers and controlled using the needle valves (regulation valves). Filters were employed to remove impurities from the circulating water. A temperature regulator and temperature sensors were used to control the water temperature. Fig. 2 shows the geometrical properties of the nozzle mounting. The nozzle could be mounted in the holder in two ways with respect to the inlet and outlet diameters: divergent and/or convergent conical nozzle.

Cavitation erosion parameters and erosion quantification

The cavitation number σ was calculated as $\sigma = (p_{ref.} - p_v)/(0.5\rho V_{ref.}^2)$. It represents a measure of resistance of the flow to the incidence of cavitation, since the lower it is, the more intensive the cavitation will be. The value of this parameter was obtained by measuring the upstream and downstream pressures, and by calculating the reference velocity from the measured flow-rate. p_{ref} is the reference pressure (p_2), p_v is the