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CAVITATION EROSION MICRO-JETS STUDIES OF ALUMINUM SPECIMENS WITH THE AID OF THE COMPACT ROTATING DISK DEVICE

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ABSTRACT

The shape of micro-jets created in the final stages of cavities collapses are studied here with the goal to explain the shape of the pits, formed on the surface of commercial aluminum specimens.
These marks on the specimen surfaces are obtained experimentally with the aid of the compact rotating disk device and a scanning electronic microscope. Some explain is attempt, based on the theories of the potential flow and forms.

Keywords: cavitation; potential flow; micro-jets

NOMENCLATURE

ε	eccentricity of the hyperbola
w	complex potential
Φ	velocity potential
Φ_{pit}	pit diameter
ψ	stream function
c	real constant

INTRODUCTION

The study of forms started in the decade of 1960 with the meteorologist Edward Lorentz (Riccieri, 1990; Petiot, http://hal.archives-ouvertes.fr/hal-1265180v2, 2017), when performing simulations trying to predict whether conditions.

In the images from the literature available (Brennen**,** 1995) it is not possible to distinguish the shape of the micro-jets between the cavity and the solid surface. So, a theoretical analysis of the shape is intended here using the potential flow (since the viscosity of water is relatively low), for comparison purposes with the pits of cavitation observed experimentally in this work. The velocity of these micro-jets is of about 100 m/s (Frank and Michel, 2005).

Visualization of flows may be possible by the use of the potential flow theory, where the stream functions ψ represents the flow itself.

From the complex numbers theory:

$$z = x + i\,y \tag{1}$$

The complex potential w is given by Chorlton (2004):

$$w = \phi + i\psi \tag{2}$$

Where Φ is the velocity potential.

Since the viscosity of the water is relativity low, it justifies the use of the potential flow here.

To create experimentally the erosion due to the micro-jets, it will be used the rotating disk device (Bazanini et al., 2010; Bazanini and Bressan, 2017), that can be seen in Fig. 1, associated to observations with a scanning electronic microscope.

EXPERIMENTAL SET UP AND APPARATUS. PROCEDURE

The test rig proposed by Bazanini et al., (2010**)** consists of a water chamber inside which a metallic disk rotates. On the disk surface there are cavity inducers (through-holes) fixed close to the specimens. The disk is fixed on the rotating shaft and can be removed to attach the specimens. A glass cover is mounted on the chamber to visualize the flow and the cavities formation inside it.

The purpose of the rig is to create the cavitation bubbles. These cavities, by collapsing on the surface of the specimens, will be responsible for the cavitation erosion of the surface of the specimens fixed on the disk surface.

Although some sizes of cavities are expected, a reasonable average initial radius is 1 mm, resulting in an initial micro-jet diameter of about 0.1 mm (10 % of the cavity initial radius), according to Frank and Michel, (2005). In fact, numerical simulations of the collapse of a cavity of 1 mm of initial radius was already performed by Bazanini (2003).

Figure 1. The rotating disk device.

In the final stages of a cavity collapsing close to a solid wall, the cavity takes a toroidal form, from where the micro-jet emerges toward the wall (Bazanini et al., 2017), impinging its surface.

An analogy is made between the jet through the toroidal cavity and the flow through an aperture in a partition. In this case, the function is (Chorlton, 2004):

$$z = c\, conh\, w \tag{3}$$

Where c is a real constant.

Substituting Equations (1) and (2) in Eq. (3) and solving for x and y:

$$x = c \cosh \phi \cos \psi \tag{4}$$

And

$$y = c\, senh\phi\, sen\psi \tag{5}$$

Solving Equations (4) and (5) for constant stream functions ψ, results:

$$\frac{x^2}{c^2 \cos^2 \psi} - \frac{y^2}{c^2\, sen^2\psi} = 1 \tag{6}$$

Since that is the equation of a conic (a hyperbola, in fact), the jets passing through the toroidal cavity shall have a hyperbolic shape. c is the foci of the hyperbola (Venturi, 2003), that will be taken here in the internal surface of the toroidal cavity:

$$c^2 = a^2 + b^2 \tag{7}$$

And the eccentricity of the hyperbola is defined as:

$$\varepsilon = \frac{c}{a} \tag{8}$$

So, the shape of the stream function lines as well as the dimensions used in the calculations can be seen in Fig. 2.

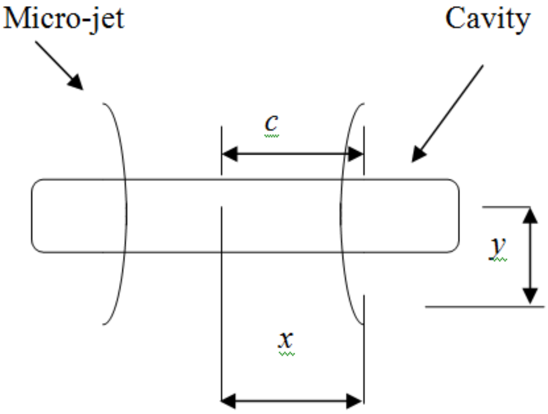

Figure 2. Toriodal cavity and hyperbolic micro-jets.

Table 1. Chemical Composition.

Chemical Element	Weight (%)
Pb	0.01
Zn	0.02
Al	98.24
Fe	0.22
Si	0.45
Cu	0.16
Mn	0.22
Mg	0.68

Assuming that the pit is made by the micro-jet, x will be taken as the half value of the cavity pit diameter $Ø_{pit}$, and y will be the distance from the cavity to the surface of the specimen.

In fact, the hyperbolic shape of fuel jets in combustion engines was predicted theoretically by Riccieri (1990) and numerically by Nicoud (http://math.univ-montp2.fr/~nicoud/, 2017).

In the experimental part, the specimens, made by commercial aluminum, of 2.54 cm in diameter, were removed after 5 hours operating in cavitating conditions in the equipment, cleaned by ultrasound and dried. Images of their surface were also obtained using a scanning electronic microscopy, SEM (Fig. 3).

Before the experiments, it was taken the chemical composition (seen in Table 1 above) of the specimens, and the Vickers micro-hardness was measured.

For the Vickers micro-hardness (HV300gf), it was obtained the value of 99.70. The experiments were performed at the sea level ambient pressure, and a temperature of 37° C was measured.

Figure 3. Scanning electronic microscope (SEM).

RESULTS AND DISCUSSION

Every stream function line shall have a different value for ψ, corresponding to a hyperbola with its own eccentricity ε.

The shape of the three selected hyperbolic lines, using the potential flow through an aperture, appears in a qualitative form in Cole (1962). Here, it was calculated the stream functions ψ as well as the eccentricity ε for those lines, showed in Fig. 4 and named as 1, 2 and 3, respectively, to present them in a quantitative form. These calculated values are shown in Tab. 2.

Table 2. Calculated values of stream function and eccentricity for the hyperbolic micro-jets of Fig. 4.

Line	Stream function ψ	Eccentricity ε
1	0.45	1.1
2	1.05	2.0
3	1.47	10.0

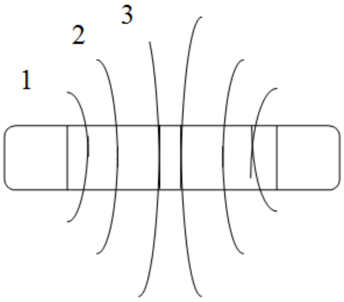

Figure 4. Selected lines for stream function and eccentricity calculations for the hyperbolic micro-jets.

The images of the pits after the experiments in cavitating conditions for the specimens in commercial aluminium are shown in Figures 5 to 7. They were used for measures and calculations here.

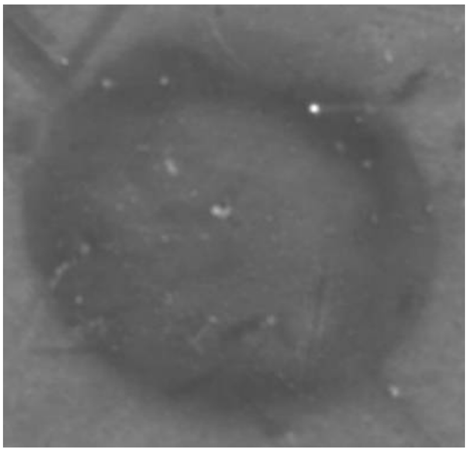

Figure 5. Aluminum after 5 hs in cavitating conditions, 100x. Pit 1.

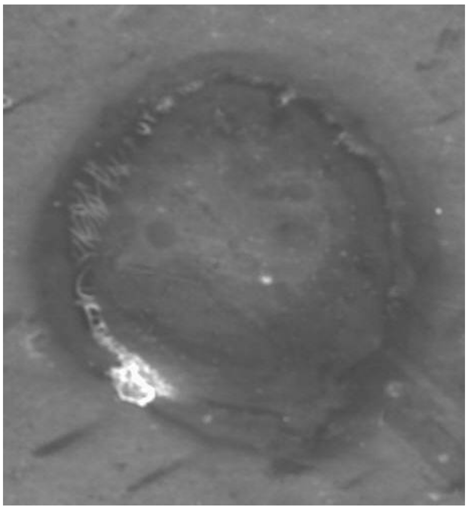

Figure 6. Aluminum after 5 hs in cavitating conditions. 100x, Pit 2.

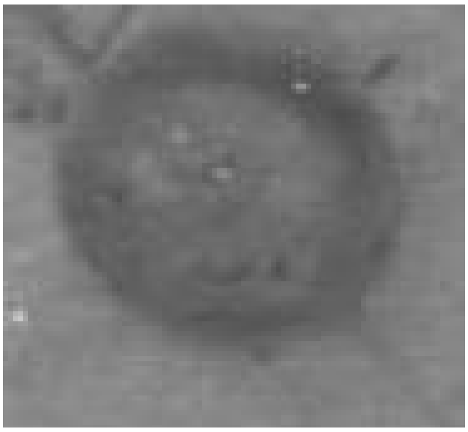

Figure 7. Aluminum after 5 hs in cavitating conditions, 100x, Pit 3.

Table 3. Measured and calculated values for the pits.

Pit	1	2	3
$Ø_{pit}$ (measured), μm	250	282	220
x (calculated), μm	125	141	110
y (calculated), μm, line 2	212	240	186
Δt (calculated), μs	2.12	2.40	1.86

The values calculated and measured for an average value for the stream function of 1.05 is shown in Table 3, where Δt is the time required for the micro-jet to reach the surface of the solid surface, in this case, the specimen, considering a jet velocity of 100 m/s.

In the images from Brennen (2005), although it is no possible to identify the shape of the micro-jet, it is possible to observe a distance y of about 170 μm, for a period of time Δt of about 2 to 4 μs.

CONCLUSIONS

First of all, it was possible to see the damages on the surface of the specimens after 5 hours in cavitating conditions, using a scanning electronic microscope. The rig worked quite well by making the damages by cavitation on the surface of the specimens.

Although it is not possible to see the shape of the micro-jets in the literature, the results of distances and times obtained here are close to the ones available in the bibliography, resulting in a good approximation for the micro-jets phenomena.

Although the potential flow is used for bi-dimensional flows, the micro-jet was considered symmetric in each direction. The potential flow also gave good results because the viscosity of the water is relatively low, and the compressibility of the liquid water is negligible, since it must appear only in the final stage of the cavity collapse, that is already a very fast process, of about ms.

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