CAVITATION EROSION STUDY FOR DUCTILE MATERIALS

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Abstract: The paper outlines the cavitation erosion of ductile materials. Cavitation erosion studies on aluminum in ordinary tap water and degassed water are presented. The mean depth of erosion (MDE) in degassed water was higher that in tap water. The mean depth of erosion in degassed water presents a peak and than decreased continuously with time, but the maximum erosion rate in tap water in first stage of the process remained approximately constant and than starts increase. It is highlighted the tempering of the superficial layer and cavitations effects are presented as well as the appreciation parameters of cavitation destruction.

Keywords: cavitation erosion, ductile materials, mean depth of erosion (MDE), degassed water, tap water

1. INTRODUCTION

To develop a cavitation event we must transmit a high intensity pressure wave from the transducer into a liquid with enough amplitude so as to tear the liquid apart in the rarefaction half cycle and drop the pressure within the liquid below its point of vaporization. When this has been achieved we will develop millions of minute vacuum bubbles called cavitation events. Every half cycle we develop these vacuum bubbles which store their developing energy and then collapse or implode in the compression half cycle releasing their energy. This causes the shear forces they release to break the bonds holding a particle to the item being cleaned. At 40 kHz this cleaning cycle will repeat itself 40,000 times a second.

Cavitation development and amount of energy released relies on a number of factors such as: ultrasonic power, density, vapor pressure, temperature and condition of the liquid.

The imploding cavitation bubble conducts the majority of the mass loss by the development of shearing forces but is aided by what is known as micro streaming within the liquid the maximum size of the cavitation bubble is proportional to the applied frequency. As we lower the frequency the larger the imploding bubble will grow. The larger the imploding bubble the greater the implosion force. As we lower the frequency we also lower the number of cavitation events. As we increase the frequency we decrease the size of the cavitation bubble and weaken or soften the implosion force. As we increase the frequency we also increase the number the number of cavitation events.

The most promising methodologies to predict cavitation erosion of materials in hydraulic machines are based on the measurement of cavitation induced vibrations [1,2]. Although satisfactory results have been recently obtained with these methods, they are incomplete because the material characteristics are not taken into account and the transmissibility characteristics between the source of excitation and the measuring position are not well known. Actually, no absolute method to quantify cavitation erosiveness has been fully validated from a practical point of view so that it can be successfully applied to hydraulic machines or systems. One of the lacking points is that the specific resistance of the material forming the solid surface that receives the impact forces is not taken into account. Therefore, it would be convenient to consider the intrinsic material resistance to the cavitation attack since materials of different nature might have significantly different responses when submitted to the same level of cavitation aggressiveness.

Cavitation erosion studies in ultrasonic vibratory cavitation test on aluminum in ordinary tap water and degassed water are presented. There were made many researches for establishing the dependency between the resistance to cavitation erosion and the mechanical characteristics of the metals (hardening, traction limit, toughness manner). It was used, as working liquid, the distilled water at a temperature of 27 ºC. The results do not show a direct connection between the indicator to cavitational erosion and the different mechanical characteristics.

Vyas and Preece [3] have studied the cavitation erosion to cubic structure metals with centred faces on a model vibration cavitation system. The best behavior is noticed for Ni 99.9%, Cu 99.9% and the weak behavior has Al 99.9%. The destructions are noticed under irregular crater forms. Hobbs [4] has studied the behavior of Al 99.99% to cavitation destruction comparing the obtained results in many world laboratories on models hydrodynamic cavitation systems and vibration cavitation systems. Similar tests are made by Erdman – Jestitzer [5] and Hirth [6] who studied the destruction map of Al 99.9% for different temperatures (25 ºC, 55 ºC and 80 ºC) and different vibration frequencies. Tomlinson and Matthews [7] are studied the cavitation erosion on cast aluminum-silicon, cast aluminum- zinc and mechanichanical alloyed aluminum alloys using a 20 kHz ultrasonic vibratory device. The cast Al-Si alloys had the poorest resistance to erosion.

2. EXPERIMENTAL EQUIPMENT

The experiments were carried out in an ultrasonic magnetostrictive oscillator operating at 20.338 kHz frequency. A sonic horn probe with a power supply was used to generate ultrasound in experimental cell. The ultrasonic power entering the cell was calibrated calorimetrically according to the procedure of Mason et al [8].

The material for the test specimens was commercially pure aluminum rod, 10 mm in diameter. The functional surface of the specimens was thoroughly polished (electrically). The test liquids were ordinary tap water and degassed water. The test specimen was subjected to cavitation, and weight loss measurements were taken at 15 min intervals.

The erosion rate of the material is determined by periodically stopping the test and drying and weighing the sample. An electronic balance with a weighing accuracy of ±0.1 mg was employed for the determination of mass loss of specimens in cavitation erosion tests.

3. RESULTS AND DISCUSSION

Mass loss is minimum if the impact falls on a virgin surface and maximum if hardening is completed. During the acceleration period, the fraction of the surface which is fully hardened progressively increases. When the whole exposed area is hardened, the erosion rate becomes constant: it is the steady state period.

During the incubation period, the pit depth results only of plastic deformation. Once the rupture strain is reached on the surface, mass loss occurs. The characteristic of a ductile material exposed to cavitation is to be progressively hardened by the successive collapses. The impact duration of the cavitation is a few micro-seconds and it occurs sporadically.

The specimens showed low cavitation resistance because of the high value of the cavitation erosion rate 0.0932 mg/min in tap water and 0.2046 mg/min in degassed water. Such a behavior can be explained by the coarse grain size of aluminum which can be coupled to the low values of hardness, tensile strength and tensile stress.

The wear is mainly located in an elliptical area. Cavitation erosion is strongly concentrated in the center of the region and diminishes gradually towards the border. Few isolated impacts of big sizes are also observed widely scattered. Observing in detail the attacked area on the specimens, a narrow region is observed where most of the collapses concentrate which in turn is surrounded by a larger zone presenting a less intense attack. If no distinction is done between these two regions with different concentration of impingements, it is used in analysis the the maximum rate of erosion. If this distinction is done it is used **mean depth of erosion MDE**.

The primary result of an erosion test is the cumulative erosion-time curve. Although the raw data will be in terms of the mass loss versus time, for analysis and reporting purposes this should be converted to a **mean depth of erosion (MDE) versus time curve**, since a volumetric loss is more significant than a mass loss when materials of different densities are compared. The MDE is calculated by dividing the mass loss measured by the density of the material and the affected cavitation area. For comparisons, the cavitated area is considered to be the horn tip area and for this setup is 0.502cm^2. Thus MDE is given by equation.

$$MDE = \frac{\Delta m}{\rho\, A(\mathrm{aria})}\ [\mathrm{m}]$$

A typical MDE curve from a metallic sample is shown in Figure 1. Given the shape of the cumulative erosion-time curve, it is not meaningful to compare the absolute MDE for different materials after the same exposure time. The reason is that a selected time may still be within the incubation or acceleration stage for a very resistant material, whereas for a weak material the same time may be within the maximum rate or deceleration stage.

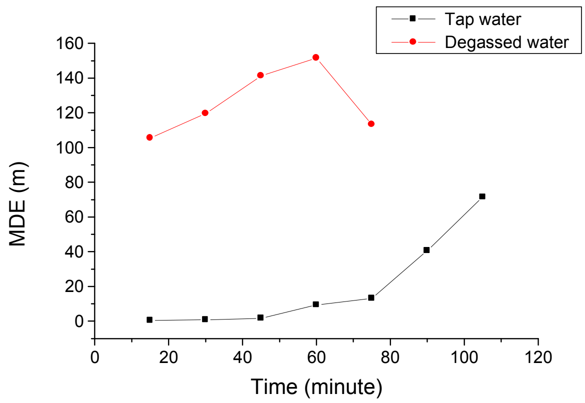

Fig. 1. Mean depth of erosion (MDE) of aluminum as a function of test time.

The most common single-number for comparison of different materials is **the maximum rate of erosion**. This can be defined as the slope of the straight line that best approximates the linear (or nearly linear) steepest portion of the MDE curve and is expressed in micrometers per hour.

For a certain sonic frequency, there is an optimum vapor pressure where the impulse pressure and temperature obtained due to collapse of a cavity are maximal. This is expected to be due to the matching of the vibration frequency of the horn and oscillation frequency of the cavity of a particular radius. When the vapor pressure is increased beyond this critical value, the impulse pressure intensity and the number of cavities decreases steadily with a subsequent increase in the diameter of the cavity. If the vapor pressure is increased beyond the optimum value, large cavities are formed and, instead of collapsing violently, they disintegrate into small cavities or simply dissolve into the water.

The losses of mass Δm the mass losses differences $\delta\,\Delta m$ and the wear speed $(\delta\Delta m/\Delta t)$ are presented in tables 1.

The losses of mass Δm, the mass losses differences $\delta\Delta m$ and the wear speed $(\delta\Delta m/\Delta t)$ for aluminum. Table 1.

t (min)	Δm (mg)		$\delta\Delta m$ (mg)		$(\delta\Delta m/\Delta t)$ (mg/min)	
	Tap water	Degassed water	Tap water	Degassed water	Tap water	Degassed water
15	0.0603	14.302	0.0603	14.302	0.00402	0.953
30	0.108	16.212	0.0477	1.91	0.00318	0.127
45	0.222	19.155	0.114	2.943	0.0076	0.1962
60	1.267	20.537	1.045	1.382	0.06966	0.0921
75	1.777	15.365	0.51	-5.175	0.034	-0.345
90	5.5		3.723		0.2482	
105	9.69		4.29		0.286	

Before cavitation can become effective in an ultrasonic bath dissolved gases trapped in the liquid must be removed. If not removed the cavitation vacuum bubbles being formed will fill with this gas cushioning the implosion force. In some cases the cavitation bubble will sequentially grow with each cycle and when large enough float to the liquid surface without performing any mass loss. In the case of degassed water, the size of bubble cavity is smaller as compared with tap water. The presence of dissolved gasses in tap water may act as nuclei for cavity formation. Cavities of large size and number are formed in tap water but the effective effect of the intensity of shock waves is lowered owing to the cushioning effect due to non-condensable gasses in the cavities. In degassed water, the fraction of non-condensable gasses in the cavities is reduced and a very violent cavity collapse is expected. In the absence of these non-condensable gasses the collapse occurs, yielding greater pressure intensities.

4. CONCLUSION

Summing up, the experimental cavitation erosion measurements have been done for aluminium in water. Nevertheless, further investigations are required because only one material in two different fluids has been tested. An extensive set of tests needs to be performed on various materials under different flow conditions in order to clarify the uncertainties that still exist. Cavitation erosion studies on aluminum in water had the following results:

1. The characteristic of a ductile material exposed to cavitation is to be progressively hardened by the successive collapses. The impact duration of the cavitation is a few micro-seconds and it occurs sporadically.
2. Cavitation erosion is strongly concentrated in the center of the region and diminishes gradually towards the border.
3. The maximum weight loss rate, or **mean depth of erosion (MDE)**, in degassed water was greater that in tap water. However, the MDE increased continuously with further test time in tap water and presents a peak in degassed water.

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