CAVITATION EROSION IN METALLIC MATERIALS USING THE ROTATING DISK DEVICE

Gil Bazanini
Universidade do Estado de Santa Catarina – UDESC Joinville.
Campus Universitário. Departamento de Engenharia Mecânica. Bairro Bom Retiro, Joinville-SC. CEP: 89223-100.
dem2gb@joinville.udesc.br

José Divo Bressan
Universidade do Estado de Santa Catarina – UDESC Joinville.
Campus Universitário. Departamento de Engenharia Mecânica. Bairro Bom Retiro, Joinville-SC. CEP: 89223-100.
dem2jdb@joinville.udesc.br

Abstract. *In the rotating disk device, a steel disk with cavitation inducers and specimens fixed on it rotates inside a water chamber to provide the cavitating flow and erosion. In this work, a new concept of the horizontal axis rotating disk device is presented and discussed as well as some preliminary results obtained from its operation. The purpose of the device is to generate the bubbles that will erode the specimens fastened in the disk surface and close to the bubbles inducers. To prevent vibration problems, each pair of holes and specimens are diametrically opposite.*

When bubbles collapse near solid surfaces, damage may occur. Two are the already known damage mechanisms: liquid micro-jets impingement and shock waves. The micro-jets are caused by the bubble splitting in two parts near the solid surface (influenced by the surface proximity) in the final stages of the collapse and the shock waves are caused by instant variable pressure fields (the time necessary for the collapse is about few milliseconds). These micro-jets and shock waves are responsible for loss of material from the surface, basically by wear failure.

After several hours of device operation in cavitating conditions, the specimens are weighted to obtain the mass loss by erosion, comparing it to the initial weight. Pitting formation resulting from the erosion process can also be seen with the aid of a scanning electronic microscope. Working with different metallic materials, the relative resistance to erosion by cavitation can be evaluated and comparison with existing results is made. In the present work, erosion and pitting formation in aluminum and brass specimens as well as mass loss due to erosion by the cavitation phenomena was observed and measured.

Key-words: *erosion, rotating disk, cavitation.*

1. INTRODUCTION

The cavitation phenomenon, that is, the formation, growth and collapse of air and vapor bubbles in liquids is, as well known, responsible for damage in metallic and non-metallic solid structures in liquid mediums, remarkably in water. Such bubbles, or liquid cavities, nucleate from micro-bubbles of air present in the liquid. This bubble formation phenomenon is named “cavitation inception” (see Hammitt(1)). As it growths, the bubble is filled by liquid vapor present when the mixture pressure and temperature are close to the vapor pressure and the temperature of the surrounding liquid, up to reaching an bubble equilibrium radius as can be seen in the work by Young(2). After that, the bubble or bubbles begin their collapse and may disappear or initiate a new cycle; that may then be repeated for several times until the bubbles disappear (this can be seen in Young(2)).

When bubbles collapse near solid surfaces, damage may occur. Two are the already known damage mechanisms: liquid micro-jets impingement and shock waves (see Fujikawa et al.(3) and Hammitt(1)). The micro-jets are caused by bubble splitting into two parts near the solid surface (influenced by the surface proximity; a good visualization of the phenomenon can be found in Shervani-Tabar(4)) or by the re-entrant micro-jets from the opposite side of the bubble. These micro-jets are due to asymmetrical bubble collapse at its final stages. Shock waves are caused by instant variable pressure fields (collapse duration is of about a few milliseconds; pressure fields can be seen in Bazanini(5)). These micro-jets and shock waves are responsible for the loss of material from the surface, basically by fatigue failure.

With the aim to study the effects of cavitation on solid surfaces, several devices have been developed during the last decades. The most important are the jet-impact damage device (as described by Janakiram(6)) that consists of water liquid jets impinging in specimens fixed on rotating disks, the vibratory apparatus (Kapp et al.(7)) where the specimens are set to vibrate in the test liquid, the rotating disk with vertical axis, used by Wood et al.(8) where a disk with the specimens fixed on it is rotating in water to provide cavitating flow, and finally, the rotating disk with horizontal axis that can be seen in the works by Rao et al.(9) and Vivekananda(10). Here, a new concept of the rotating disk device with horizontal axis is presented and discussed.

2. EXPERIMENTS WITH THE ROTATING DISK

2.1. Objectives and Review

Some preview versions of the rotating disk with vertical axis have appeared in the last years such as presented by Ramamurthy and Bhaskaran(11)., Rao et al.(9) and Zhiye(12). The device consists of a water chamber inside which a metallic disk rotates. On the disk surface are located the cavity inducers that can be holes or protruding pins, and the specimens also. The disk is fastened on a shaft and can be detached to weight or change the specimens. A glass cover is mounted on the chamber to visualize the flow and the formation of the bubbles inside it.

The purpose of the device is to generate the bubbles that will be responsible for the erosion of the specimens fixed on the disk surface, close to the bubble inducers. To prevent vibration problems, each pair of holes and specimens in the disk are diametrically opposite.

Some authors (Rao et al.(9) and Vivekananda(10)) used a chamber made by cast iron and protruding pins mounted on the disk as cavitation inducers. In this work, we are now using holes in the disk as inducers in a rotating disk with a horizontal axis. The disk and the chamber were fabricated in stainless steel, more resistant to cavitation erosion. Several materials have been studied to see their relative resistance to cavitation erosion, remarkably metallic materials.

2.2. Test Apparatus

It was used a compact version of the rotating disk device with horizontal axis, now with a more compact chamber and a smaller disk (diameter of 250 mm). By employing an “intermediary casing”, commonly used to connect rotor pumps to electric motors, it was possible to avoid the use of bearing and the coupling, resulting in a shorter shaft. It has also the function to prevent water leakage by providing a sealing ring between itself and the chamber. That is, the chamber now replaces the pump. This reduces loss transmissions as well as alignment problems. A glass cover is mounted on the chamber to visualize the flow and the bubble formation inside it. Vibration absorbers were also used at the equipment foundations and the disk with the test specimens was balanced before the tests were performed. Eight baffles equally spaced were welded in the chamber, at a distance of 18 mm from the rotating disk to minimize half-body rotation of the test fluid. Although the baffles are welded, the distance of 18 mm can be reduced by using another set of **mobile** baffles mounted over the welded ones. But, in these preliminary experiments, that distance was kept constant at 18 mm. The test chamber can be seen in Fig. 1 below.

Figure 1. Cavitation test chamber

The cavitation test chamber shown in Fig.1, and the disk in Fig. 2 were fabricated in stainless steel which is more resistant to cavitation erosion. Details of the rotating disk, including the cavity inducer holes and some test specimens can be seen in Fig. 2 .

Figure 2. Rotating disk and the test specimens.

Connections for inlet and outlet of cooling water, temperature and pressure visualizations, water drain and air outlet are also provided. The baffles welded inside the chamber (seen in Fig. 1) also have the function to minimize half-body rotation of the test fluid and generate the desired cavitation formations at the inducer holes, thus, leading most of the bubbles to be confined in the region situated between the baffles and the disk, and to collapse over the disk surface.. A frequency inverter was used to control the motor and, thus, the disk rotation. For cooling purposes, a water reservoir was used to circulate the water inside the chamber. Inlet and outlet piping are provided by control valves and a filter to protect the pump from small particles resulting from the erosion process.

2.3. Materials and Method

The inlet and outlet valves are used to regulate the temperature and pressure inside the chamber which is connected to an overhead water reservoir. Temperature and pressure in the chamber were monitored by a thermometer and a manometer with scales 0 -100 °C and 0 - 3 bar respectively. A frequency inverter was used to control the rotation of the electric motor (and the total power consumption) and thus, the disk rotation and the water flow velocity over the test specimens. After 15 hours working on cavitating conditions, the specimens were weighted in a digital balance accurate to 0,1 mg to obtain the mass loss in the process by comparing to its initial weight. Images of the specimens eroded surface were also obtained using a scanning electronic microscope, SEM.

2.4. Results and Discussion

In this preliminary experience, commercial aluminum and common brass of 2.54 centimeters in diameter each were tested as specimens fastened in the disk. The operation conditions recorded for the electric motor is shown in table 1 below. The equipment was first tested at 3600 rpm. After that, it was operated at 4400 rpm (resulting in a flow velocity at the specimen surface of 47.9 m/s) during 15 hours to obtain the results presented here. This experiment was performed at atmospheric pressure and the temperature was kept constant at 37 ^{o}C by fresh water flow circulation.

Table 1.Electric motor operation conditions.

Motor speed (rpm)	Power consumption (kw)	Electric current (A)
3600	10.2	21.0
4400	14.6	25.1

After 15 hours of operation, it was observed a mass loss of 17,2 mg for brass and 1 mg for aluminum. The mass loss of brass is very close to the one obtained by Vivekananda$^{(10)}$ who worked with a rotating disk of 335 mm in diameter, using protruding pins as cavitation inducers. It was expected a greater mass loss for aluminum, in relation to brass, as can be seen in the previous works on cavitation erosion such as in the recent work by Soyama et al$^{(13)}$. The mass losses for 15 hours of operation can be seen in table 2 below.

Table2. Mass loss of tested specimens after 15 hours.

Material	Mass loss (mg)
Aluminum	1.0
Brass (present work)	17.2
Brass (Vivekananda, 1983)	~ 18.0

Images of the specimens were also obtained using a scanning electronic microscope. These images are shown in Figs. 3 to 6 for aluminum and brass tested in the present work.

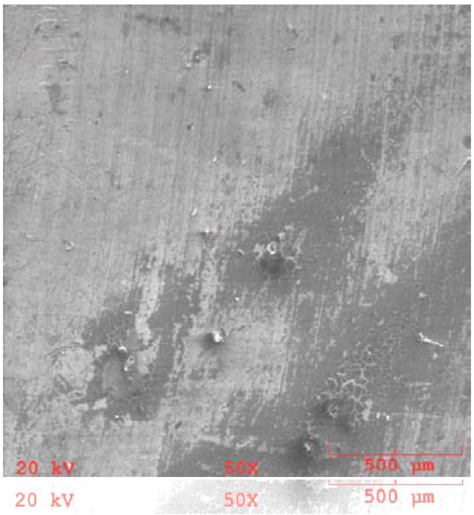

Figure 3. Aluminum, magnification: 50 x.

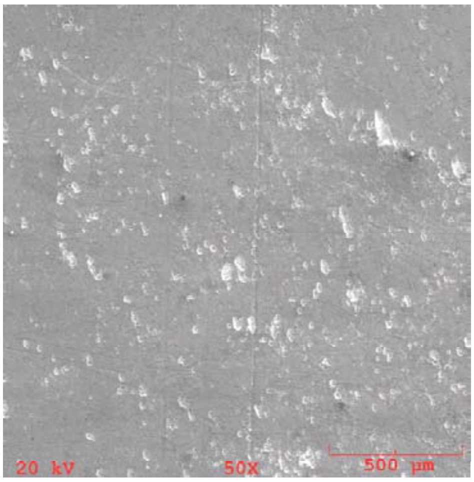

Figure 4. Brass, magnification: 50 x.

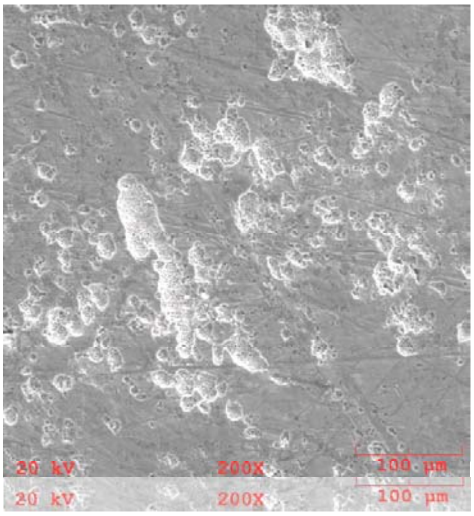

Figure 5. Brass, magnification: 200 x

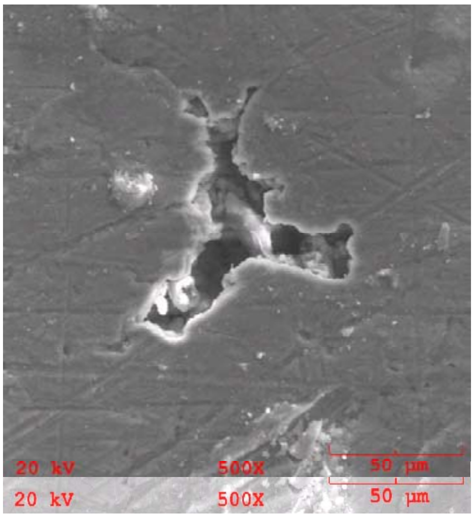

Figure 6. Aluminum, magnification: 500 x

In Figs. 3 and 4 it is possible to see the pittings resulting from the erosion process, as well as the damages in the aluminum and brass specimens surfaces. Figures 5 and 6 show eroded portions or craters in these specimens. These damages are caused by liquid impingiments due to cavitation phenomena as mentioned above (Fujikawa; Akamatsu(3)).

3. CONCLUSIONS

From the observed experimental results on cavitation erosion in metals carried out in the laboratory developed equipment, it can be affirmed that this more compact apparatus worked quite well, obtaining bubbles formation (as seen in Fig.1) and erosion by cavitation damage of the test specimens surfaces. The pits resulting from cavitation erosion can be seen in Figs. 3 to 6.

The obtained mass loss by cavitation erosion was the expected one in the brass specimen, but was very small for the aluminum sample. This is not very clear at the present moment, since it was expected a greater mass loss by erosion in the aluminum specimen, although it was observed the pitting formation, as expected. The pitting formation observed in the aluminium specimen is similar to the ones in other specimens. Cavitation damage without significant mass losses has been also predicted in the literature, as can be seen in the ASM handbook(14). Thus, the erosion mechanism in the aluminum was possibly due to water micro-jet impact perpendicular to the specimen surface, producing the erosion crater or pit by breaking the alumina film formation in the surface with very low mass loss. Burned circular craters were also seen, hence, possibly flash temperature has been attained in the aluminum surface. More (and longer) tests have to be made with the device to check out the erosion mechanism in aluminum, as well as in other materials.

For brass, the erosion by cavitation was exactly the expected one, fitting very well to the results presented in the references. The erosion mechanism is possibly due to the weaker beta phase in brass microstructure which is similar to the erosion pits pattern.

4. ACKNOWLEDGEMENTS

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EROSÃO POR CAVITAÇÃO EM MATERIAIS METÁLICOS UTILIZANDO O DISPOSITIVO A DISCO ROTATIVO

Gil Bazanini
Universidade do Estado de Santa Catarina.
R.Tenente Antonio João s/n. Campus Universitário. Departamento de Engenharia Mecânica. Bairro Bom Retiro, Joinville-SC. 89223-100.
dem2gb@joinville.udesc.br

José Divo Bressan
Universidade do Estado de Santa Catarina.
R.Tenente Antonio João s/n. Campus Universitário. Departamento de Engenharia Mecânica. Bairro Bom Retiro, Joinville-SC. 89223-100.
dem2gb@joinville.udesc.br

Resumo. *O colapso de bolhas perto de superfícies sólidas pode causar danos. São conhecidos dois mecanismos de danos: micro-jatos e ondas de choque. Os micro-jatos são causados pela divisão da bolha em duas partes perto da superfície, e as ondas de choque são causadas por variações instantâneas no campo de pressões devido ao colapso das bolhas. Estes dois fenômenos são responsáveis pelo desprendimento de material desta superfície sólida.*

No dispositivo a disco rotativo, um disco contendo indutores de cavitação e os corpos de prova gira em água para provocar o escoamento cavitante. Será apresentada e discutida neste trabalho uma nova concepção do equipamento a disco rotativo com eixo horizontal, bem como os resultados obtidos com sua utilização. A finalidade do dispositivo é criar as bolhas que serão responsáveis pela erosão dos corpos de prova fixos na superfície do disco, próximos aos indutores de cavitação. A fim de se evitar problemas de vibração, os indutores e os corpos de prova estão localizados de forma diametralmente oposta.

Após várias horas de operação em condições de cavitação, os corpos de prova são secados e pesados para se obter a massa perdida no processo. A formação de crateras, ou "pits" resultantes do processo de erosão pode ser vista com a ajuda de um microscópio eletrônico. Trabalhando com diferentes materiais metálicos, pode-se verificar sua resistência relativa à erosão por cavitação. Foram observados a erosão e a formação de "pits" em corpos de prova de alumínio e latão.

Palavras-chave: *erosão, disco rotativo, cavitação.*