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The Study of Acoustic Cavitation and Cavitation Erosion of Materials and Coatings

The Study of Acoustic Cavitation and Cavitation Erosion of Materials and Coatings

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Abstract. The article describes a study of cavitation in the border areas of the vibrational tools and static solid of ultrasonic field. A high-speed camera Fastcam SA-X2 version 1000K which is able to shoot up to 1 million frames per second with electronic shutter 283 ns was used for a more practical covering of the processes occurring in the cavitation bubble at collapse near a solid surface, as well as on the possibility of fixing the cumulative impact of a collapsed bubble to the surface. The studies of cavitation resistance materials peening methods, failure of which could be due to the cumulative effect or cavitation bubbles collapse in the immediate vicinity of the sample can be used to optimize the choice of emitter material operating in corrosive liquid environments.

1. Introduction

Reynolds is considered to be the first to predict the phenomenon of cavitation that in 1893[1] during the tests of the British navy torpedo boat destroyer “Daring” [2]. 25 years later in 1917 Relay theoretically described [3] the aggressive action of collapsing cavitation bubbles [4].

Since then the scientists carry out the research on detecting cavitation effects and searching for the evidence of theoretical knowledge. The main problem in the study of cavitation is the fact that we do not know where a cavitation bubble will occur in an acoustic field or turbulent motion. Therefore, researchers tried to solve this issue in different ways.

In the scientific work [5] the authors used a reinforced plastic box section of 235 mm filled with water, the remaining air was pumped to 0.04 atm. The experiment took place in 1966 at the University of Cambridge. The water was degassed before the experiment. During the experiment the cavitation bubble “grew” from a small “nucleus” (embryo) consisting of hydrogen obtained by electrolysis on the surface of the platinum electrode at the bottom of the box. Thus, the authors managed to make the bubble size reach 20 mm in diameter and make it appear at a certain place. The life cycle of the bubble was 17.8 ms under these conditions. They also managed to capture the cumulative jet that was observed in the last millisecond of collapse.

In 1944 article [6] the authors of the Leningrad Physicotechnical Institute were one of the first to attempt to capture the cavitation effect [7-10]. They assembled a special installation which main principle was the survey of cavitation bubbles coaxially with the action of a magnetostrictive transducer (7.5 kHz). Thus, the main direction of the research was to study the radial and surface vibrations of the vapor-gas bubble. The authors described the theory of an unstable bubble destructive effect, consisting in the action of water flows on a solid surface from the disintegration of a bubble into several parts. This theory is schematically illustrated in Figure 1. These illustrations can serve as a proof of this theory.

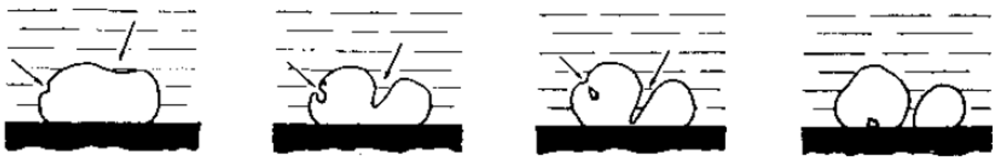

Figure 1. Scheme of a bubble decay effect.

In paper [11] the authors studied the effect of different modes of acoustic cavitation excitation and finding the optimal modes for surfaces cleaning without detail damage. They used high-speed shooting of cavitation (up to 60 000 fps), excited by the emitter with a frequency of 22 kHz. Pulsations were presented and described as individual bubbles and clusters (combination of multiple bubbles). But the equipment used by the authors did not allow shooting the life cycle of the bubble in detail.

In other works, which are devoted to the study of the cavitation bubble behavior, laser technologies were used to obtain locally a separate bubble [12-14].

Earlier, we have investigated the cavitation resistance of two methods of materials surface hardening [15], the destruction of which could be associated with the cumulative effect or cavitation bubble collapse in close proximity to the sample [16-19].

2. Experimental part

The aim of this work is to study cavitation in an ultrasonic field in the immediate vicinity of a static solid surface. A high-speed camera Fastcam SA-X2 version 1000K which is able to shoot up to 1 million frames per second with electronic shutter 283 ns was used for a more practical covering of the processes occurring in the cavitation bubble at collapse near a solid surface, as well as on the possibility of fixing the cumulative impact of a collapsed bubble to the surface.

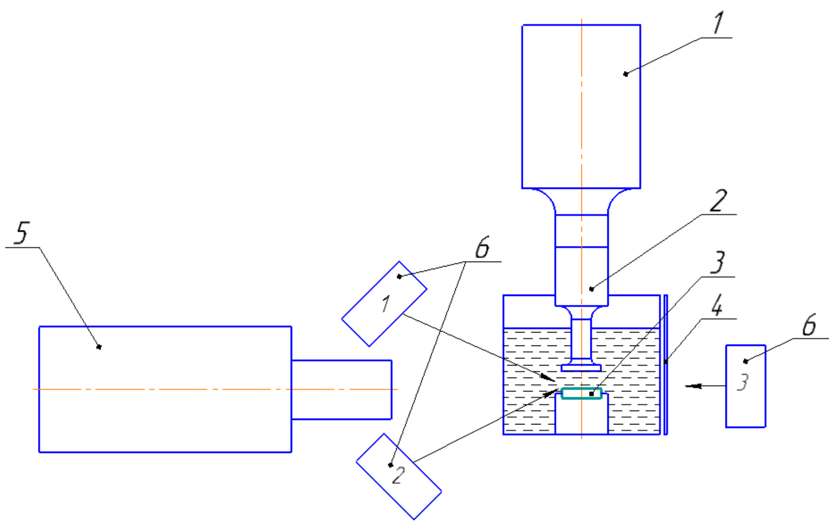

Figure 2. Installation Diagram.

The installation diagram is shown in Figure 2. It consists of an ultrasonic transducer 1, a stepped waveguide 2 immersed into distilled water, a solid object (anvil) 3 coaxially located under the waveguide, reflecting surface 4 (paper or foil), a high-speed camera 5 located either at the same level with the anvil or at a small angle to the anvil surface and three flashes 6. We used a camera, which was equipped with a macro lens AF-SVR MicroNikkor 105mm f/2.8G together with the macro rings AF Meike 36 mm to obtain the maximum approximation level.

We shooted only in fully-developed mode. The duration of shooting took no more than 1 second (depending on the frame resolution settings). During the experiment, different variants of illumination of three flashes were tried. The reflecting surface (aluminum foil) or the scattering surface (sheet of paper) was placed on the back of the water vessel during the operation of flashes 1 and 2. Surface 4 was removed at shooting with flash 3. The flashes were synchronized with the recording start time. In our case, during shooting, the part of the recording, which captures the process of cavitation, is limited within the flash operation time, which was about 4 ms.

3. Results and discussion

Video of the cavitation process was carried out as a result of the experiment. You may notice that cavitation bubbles behave differently on the surface of a solid. We consider several options for their behavior below.

The most common way is the separation of a bubble into two or more bubbles of a smaller size. As can be seen from the shoots in Figure 3, the bubble is divided into two only after the process of complete compression, which is inconsistent with the theory described in paper [6]. The following shooting mode was selected: 295,890 fps with an exposure - 1.5 μs, the time between two frames was about 5 μs.

In Figure 4, we observe the formation of a cavitation bubble above the surface of an anvil.
It can be seen that the bubble has a non-spherical shape and a "tail" above the surface, over which it collapses. Such actions over the solid material surface create a rarefication zone, which in turn can also affect the surface wear. The life cycle of the cavitation bubble was 45 μs with a shooting mode - 200,000 fps and exposure - 1.57 μs.

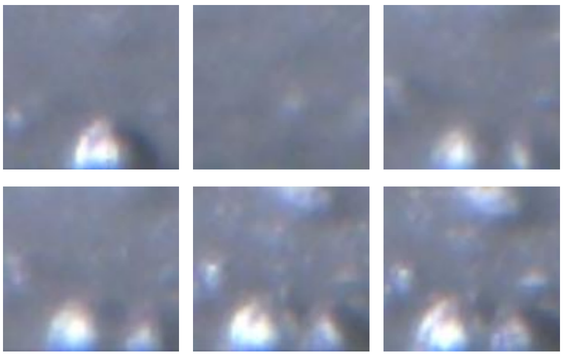

Figure 3. Decomposition of the cavitation bubble into two parts.

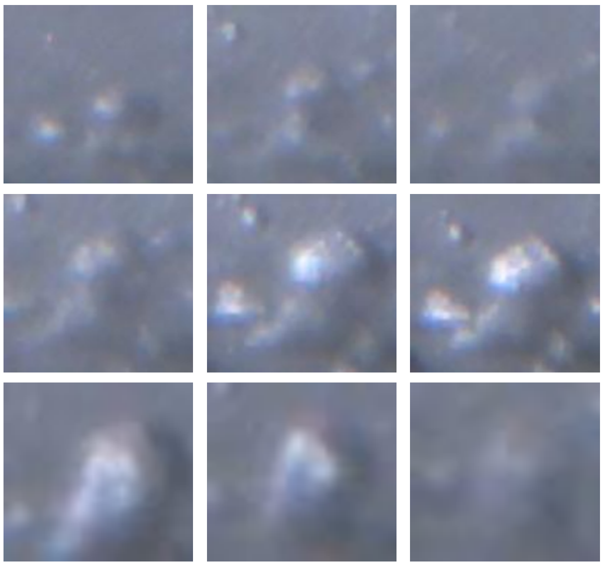

Figure 4. Life cycle of the cavitation bubble.

Figure 5 shows the process of bubble collapse with the formation of a jet directed to the surface. It is difficult to say whether it is a cumulative jet or some other process, since during the shooting process that was not seen what occurs inside the bubble. The shooting speed was 200,000 fps with an exposure - 4.21 μs, the time between two frames was about 5 μs.

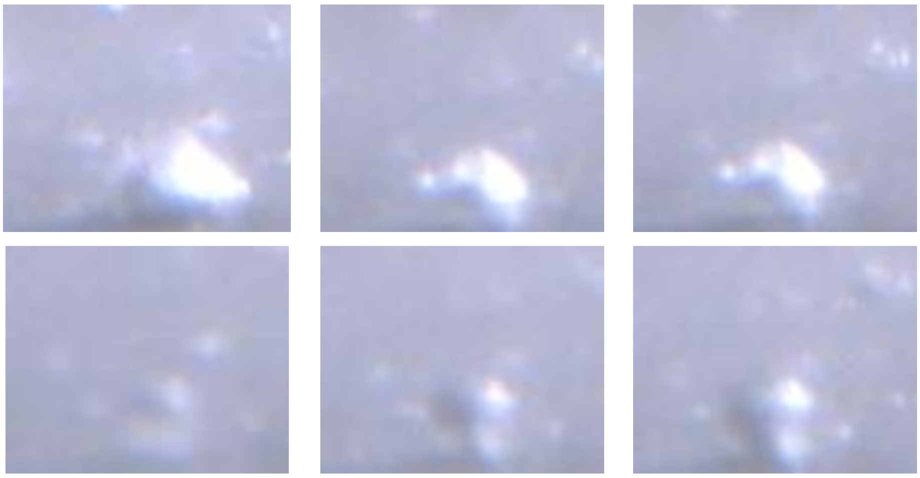

Figure 5. The process of a cavitation bubble collapse.

Figure 6 shows the "normal" life cycle of a cavitation bubble, here we can observe a process of compressing a bubble on the solid surface, with its subsequent growth to the original size. The shooting speed was 225,000 fps with an exposure - 2.82 μs, the time between two frames was about 4.4 μs.

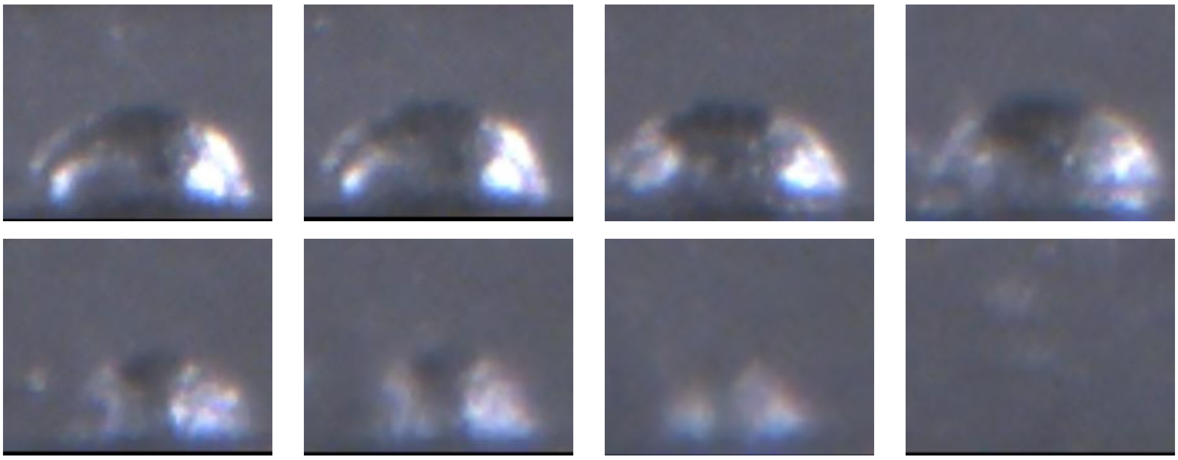

Figure 6. Cavitation bubble collapse process.

Figure 7 shows a photograph of the sample surface under the cavitation. It is clearly seen that the cavity has a round shape with a diameter of about 100 μm and there is an extruded material at its edges.

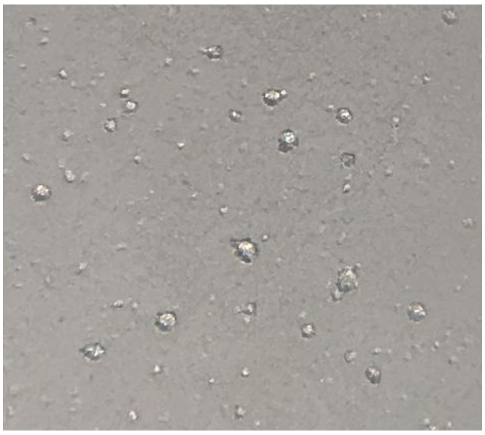

Figure 7. Morphology of cavitation wear.

4. Conclusion

No formation of cumulative streams was observed experimentally. However, the analysis of the development phases of the cavitation bubble shows an effect similar to the formation of the cumulative explosively formed nucleus [21]. In addition, the surface destruction nature indicates the presence of such a phenomenon as the cumulative core. Craters with a diameter of one-third of the bubble characteristic size were observed on the surface of the sample. Due to the influence of a localized strike, there is a displaced material on the crater edges.

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