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Observations of cavitation erosion pit formation

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ABSTRACT

Previous investigations showed that a single cavitation bubble collapse can cause more than one erosion pit (Philipp & Lauterborn [1]). But our preliminary study showed just the opposite – that in some cases a single cavitation pit can result from more than one cavitation event. The present study shows deeper investigation of this phenomenon. An investigation of the erosion effects of ultrasonic cavitation on a thin aluminum foil was made. In the study we observed the formation of individual pits by means of high speed cameras (>1000 fps) and quantitatively evaluated the series of images by stereoscopy and the shape from shading method. This enabled the reconstruction of the time evolution of the pit shape. Results show how the foil is deformed several times before a hole is finally punctured. It was determined that larger single pits result from several impacts of shock waves on the same area, which means that they are merely special cases of pit clusters (pit clusters where pits overlap perfectly). Finally it was shown that a thin foil, which is subjected to cavitation, behaves as a membrane. It was concluded that the physics behind erosion depends significantly on the means of generating cavitation (acoustic, hydrodynamic, laser light) and the specimen characteristics (thin foil, massive specimen), which makes comparison of results of materials resistance to cavitation from different experimental set-ups questionable.

Further development of the shape from shading method in the scope of cavitation erosion testing will enable better evaluation of cavitation erosion models.

1. Introduction

Cavitation describes the formation and the consequent collapse of bubbles in a liquid. It occurs when a liquid is subjected to rapid changes of pressure. In most cases it is undesired as it is accompanied by effects like noise, vibration, drop in efficiency of turbine machines and also by erosion of the solid surfaces of the flow tract.

We can distinguish two main periods in the cavitation erosion process. The incubation period where only small plastic deformations (pits) can be seen, which is followed by the second period during which the material separates from the surface, first at an exponential and later at a linear rate (Franc & Michel [2]).

The damage within incubation period is usually evaluated visually according to the number, and the size of the pits (Dular et al. [3]), later on, during the mass loss period the damage can only be evaluated by weighting or by profilomerty (Bachert et al. [4]).

Many authors (Zeqiri et al. [5], Laborde et al. [6], Krefting et al. [7], Dular & Osterman [8]) used thin metal foil to estimate the erosion, but these studies all lack in detailed and qualitative evaluation of the damage.

Previous investigations showed that a single cavitation bubble collapse can cause more than one erosion pit (Philipp & Lauterborn [1]). But our preliminary study showed just the opposite – that in some cases a single cavitation pit can result from more than one cavitation cloud collapse. We observed the aluminum foil from both sides at a frame rate of 4000 fps. Cavitation structures formed only on the front side, hence we could observe pit formation from the back side of the foil. Fig. 1 shows a sequence of bubble cloud growth, collapse and two rebounds – three collapses of cavitation cloud occur at the same position shortly one after another.

Fig. 2 shows the deformation of the foil that was recorded simultaneously with the images in Fig. 1. The quality of the images was too poor for advanced evaluation; hence the data can only be used for qualitative explanation of the phenomenon.

One can see that the pit grows when the cavitation cloud on the other side of the foil is most active (shortly before it collapses to its minimum volume). This occurs three times in the present case, hence showing that more than one collapse can be involved in a single pit formation.

The present study shows deeper investigation of this new phenomenon. Cavitation was generated by means of ultrasound in a small cylindrical vessel. A thin aluminum foil was used as a sensor for cavitation erosion. We used two high resolution high speed cameras to observe pit formation.

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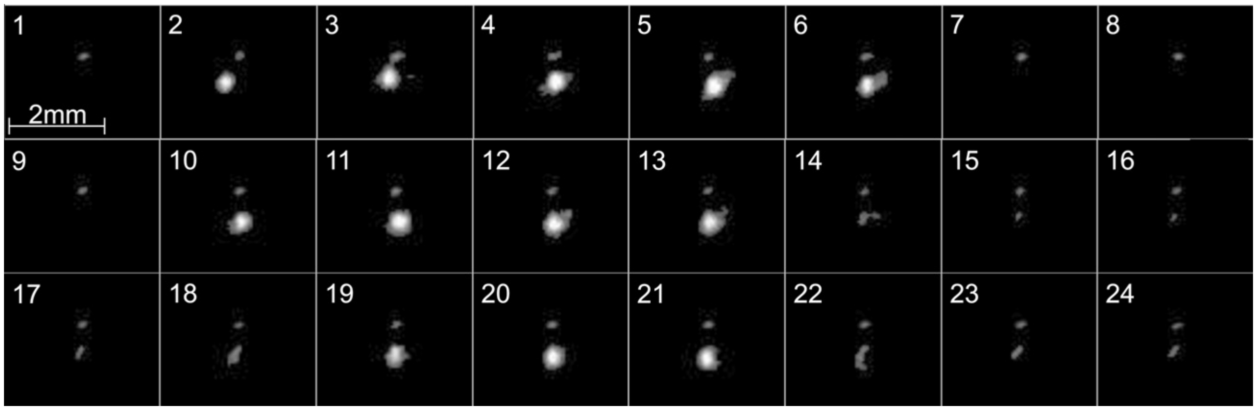

Fig. 1. Growth and collapse and two rebounds of a bubble cloud.

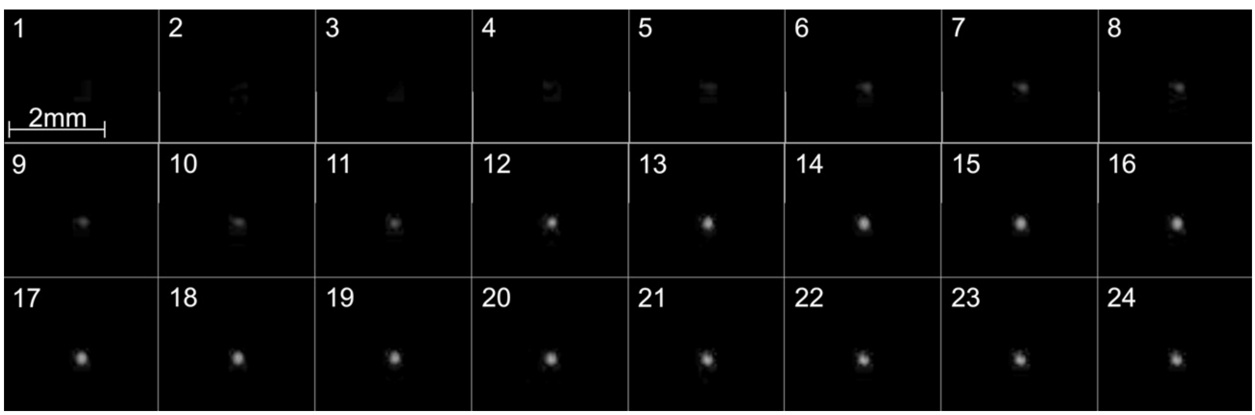

Fig. 2. Formation of a single cavitation pit.

To evaluate the damage caused by cavitation we used stereoscopic imaging and the shape from shading method. This way the damage could be quantitatively evaluated at a very high frequency (1000 Hz or more in the present case). This is a breakthrough compared to the methods employed previously, which allowed only very limited insight into the evolution of the damage as detailed evaluation could only be performed when the cavitation process was stopped (every several minutes for example – Osterman et al. [9]).

2. Experiment

2.1. Set-up

Fig. 3 shows the experimental set-up. On the left picture the set-up (without holders for the cylinder) and on the right one the position of the cameras are presented.

A small, 140 mm high and 72 mm in diameter, cylindrical vessel made out of stainless steel, was used for the experiments. A 50 W, 40 kHz piezo actuator was used to generate cavitation. The ultrasound frequency was carried by low frequency of electrical network (50 Hz), hence cavitation was only triggered for a short period of time every 1/50th of a second.

The cameras were positioned at a distance of 500 mm from the surface of the aluminum foil. The angles α, β and γ were set in a way that enabled surface shape reconstruction. The values were: $\alpha = 65°$, $\beta = 65°$ and $\gamma = 65°$.

MotionBLITZ EoSens mini1 high speed CCD cameras were used to capture the images of the foils surface. The region of interest varied – the resolution was 30 μm/pixel. A continuous light source VEGA VELUM150DR (lamp: EKE 21 V 150 W) was used for illumination.

A 10 μm thick aluminum foil was used as erosion "detector". It was mounted on a cylinder with an inner diameter of 40 mm and submerged into the vessel. The water level inside the cylinder was the same as the level in the vessel. The foil was positioned in the center of the vessel 112 mm (3 wave lengths) from the bottom. The level of water was always 10 mm above the position of the foil.

Unprepared water was used for the experiments which were performed under constant atmospheric pressure of 985 mbar and at a constant temperature of 25 °C.

2.2. Evaluation

Different methods for reconstruction of objects shape from its image or images exist. In addition to binocular disparity, shading, texture, and focus all play a role in how we perceive shape. The study of how shape can be inferred from such cues is called shape from "*x*", since the individual instances are called shape from shading, shape from texture, and shape from focus (Szeliski [10]). Each method comes with its own limitations, advantages and costs.

In the present study the shape in question is constantly changing but the texture remains unchanged. Improving the shape from shading algorithm by application of light from different directions (photometric stereo) is not possible due to the unsteady nature of the case. Finally shape from shading algorithm was used to reconstruct the shape from each of the two images taken from different perspectives which is a method similar to the photometric stereo addition by Zhang et al. [11].