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Character of the cavitation erosion on selected metallic materials

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Abstract. It's well known, that the imploding cavitation bubbles causes the damage on the solid surfaces. This process is then dangerous for the mechanical parts of the hydraulic machines. Proposed article dealing with the analysis of the type of the damage caused by the cavitation erosion according to the selected metallic material of the specimen. As is shown in the article, the type of the damage has a realtion to the hydraulic parameters of the flow (velocity, cavitation number). The optical and weight measerument methods will be used for the anlysis.

1 Introduction

The cavitation erosion is object of the scientific research since the 1895, when Parsons has built his first experimental device, designed for experimental research of the cavitation in the blades of the propellers of the steamships. When the original research was oriented on the identification and elimination of the erosion effects of the cavitation, further research is oriented more on the utilization of these effects. In this field, many authors have published their works. For purposes of this paper, the works published by Summers [1], [2] are very important. His research is oriented on the drilling applications of the cavitating jet instead of the water jet or mechanical driller. Important outputs of this research are measured dependency curves of the geometrical parameters of his experiments and the erosion effects, measured by the total mass loss of the eroded material. Interesting device for pavement cutting was introduced by Conn [3]. For applications in the field of mechanical engineering, more important are informations about the cavitation erosion on the metallic materials. On these materials, cavitation erosion evolves in stages. During the first stage, no material is removed from the specimen. Only the plastic deformation and creation of small pits can be observed on the metallic surface. Also the local hardening of the material can be observed. As surface become harder and fragile, the material removal can be observed, as the second stage of the cavitation erosion starts. Response of the material on the cavitation is the topic of the work [4]. The hardening of the surface layer of the material is described in the work of Soyama [5]. Also many the methods for examining and describing of the cavitation erosion were developed. Very interesting method, based on observing of the particles removed from the solid surface, was presented by Hattori [6].

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Our research team deals with cavitation research for long time and has published many works in this field ([7], [8]). Our research is oriented not only on the cavitation erosion, but on the usage of the cavitation effects in general, for example in biology, chemistry and environment protection. This article is oriented mainly on the qualitative description and the comparison of the cavitation damage created on different metallic materials.

2 Experiment

The cavitation is generated by the flow of the water though the orifice of the diameter 0.2mm to 0.5mm. In the defined distance from the orifice end is placed metallic specimen. This configuration can be seen on the Figure 1.

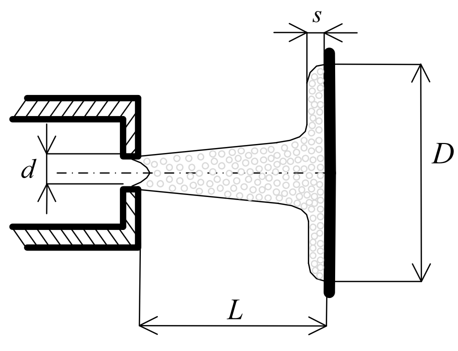


Figure 1. Geometry of the cavitation cloud.

Schematic configuration of the experimental device can be seen on the Figure 2. The experimental rig consists of the five main subsystems: hydraulic circuit, the cell where the cavitation is generated (Lichtarowicz cell), DAQ system, system for visualization, pneumatic system used for control of the pressure in the lichtarovicz cell. Hydraulic system consists of the gear pump (pos. 9), which drives the fluid to the Lichtarowicz cell, where the nozzle is placed. Used fuid then moves to the waste reservoir (pos. 15). A secondary pump (pos. 16) is used to move the fluid from the waste reservoir back to the main reservoir (pos. 8). Because, the gear pump produces the pressure and flow pulsations, the accumulator (pos. 12) is connected parallel to the hydraulic circuit to dump these pulsations. Some fluid can also get to the vacuum recipient (pos. 18) during the process of the gas removal from the Lichtarovicz cell. This fluid is also pumped back to the main reservoir.

The Lichtarowicz cell [9], consists from the frame with the removable, transparent side walls. The specimen is placed on the holder, which can be removed without need to disassemble some other parts of the cell. Construction of the cell allows measure the inlet pressure, the pressure inside the cell and the temperature of the fluid at the inlet. These parameters are very important for further analysis and quantitative description of the flow and the cavitation erosion.

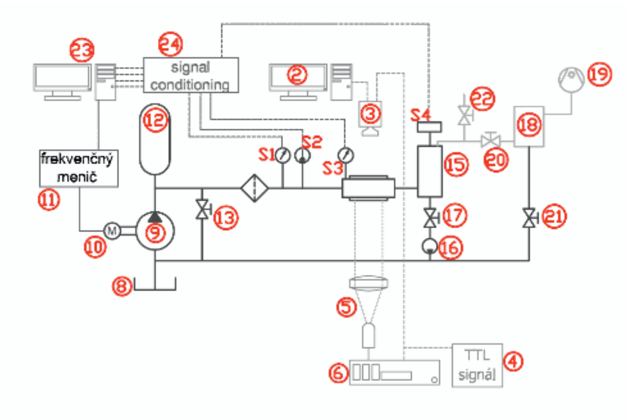


Figure 2. Experimental rig.

The pneumatic vacuum system consists of the vacuum recipient (pos. 18) and attached vacuum pump (pos. 19). The vacuum recipient is connected to the waste reservoir (pos. 15). Any change of the pressure in the waste reservoir causes the change of the pressure in the Lichtarowicz cell. This is one of the ways how the hydraulic parameters can be set to desired value. If the connection of the Lichtarowicz cell and the atmosphere is required, the valve V3 must be opened.

The nozzles (Figure 3) are made from two parts. The frame is made of brass. On the end of this part is attached the orifice plate. This can be made from different materials, in our case from brass, carbon material, saphire. Depending on the selected material, different manufacturing technology i sused for creating the orifice:

- Drilling for brass
- Electrospark manufacturing for carbon
- Laser drilling for saphire

Also the geometry of the orifice changes depending on material or the manufacturing technology. The thickness of the plate is the same for all of the materials (0.5 mm). The diameter can change from the 0.5 – 0.3 m (brass, carbon) up to 0.05mm (sapphire).

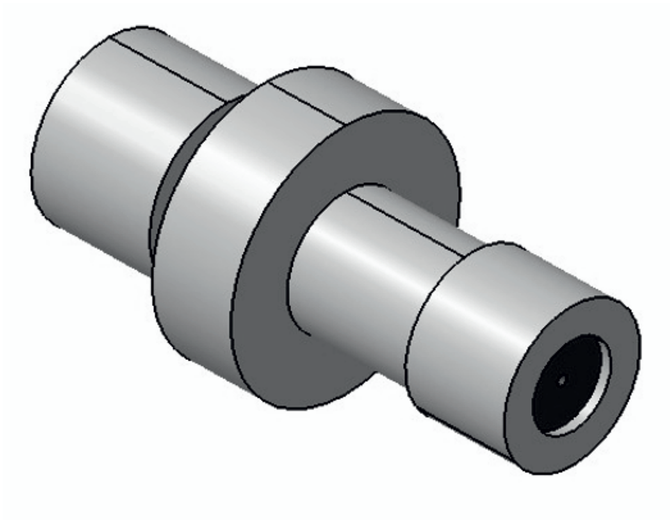


Figure 3. Construction of the nozzle

3 Measured parameters and processing of the results

As a result of the cavitation, eroded area on the specimen surface is created. The morfology and properties of the eroded area are different from the original surface. The first phase of the evolution of the cavitation erosion is typical by the plastic deformation of the surface. After longer exposition to the cavitation, the material begins to remove and the cavity is created (Figure 4). For purposes of this article, some of the geometric parameters of the cavity must be defined (Figure 4):

- Area influenced by the cavitation A_s / h
- Depth of the cavity h
- Mass of the removed metallis material M

Because the erosion is dependent on the hydraulic parameters and material properties of the surface, it's necessary to observe also the parameters of the flow and geometrical parameters of the experiment, not only the material response of the metallic material. Using all of the measured data, we are able to find non-dimensional criterions which can be used for description of the cavitation damage.

Observed parameters of the flow are:

- Mass flow-rate of the fluid
- Pressure drop on the orifice
- Diameter the orifice
- Distance from the front the nozzle to the specimen
- Temperature of the fluid

The ambition of the data processing is to find the correlation between the erosion and the hydraulic parameters of the flow.

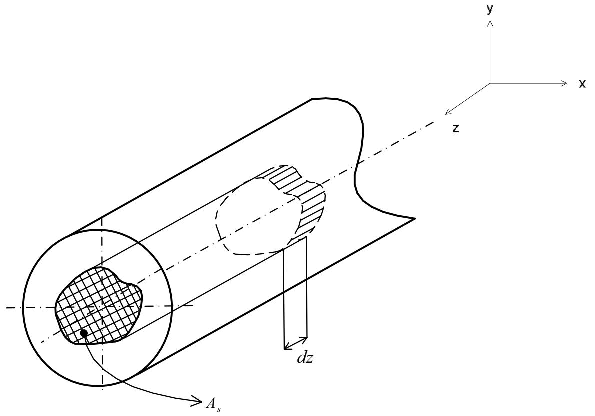


Figure 4. Definition of the geometry of the cavitation damage on the solid surface

It can be expected, that the level of damage is dependent on the combination of hydraulic, geometric and material parameters of the experiment, so is reasonable to use non-dimensional parameters for description of selected relationships. Well known and widely used criterion in the cavitation research is the cavitation number (1).

$$\sigma = \frac{p_2 - p_v}{\rho \cdot \frac{v_2^2}{2}} \tag{1}$$

It can be observed the relation between the cavitation number and the structure of the cavitation cloud generated by the nozzle ([7], [8], [9]), (Figure 5).

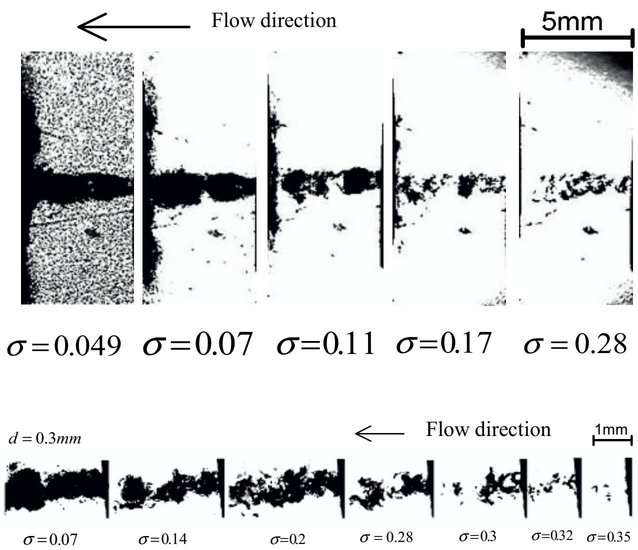
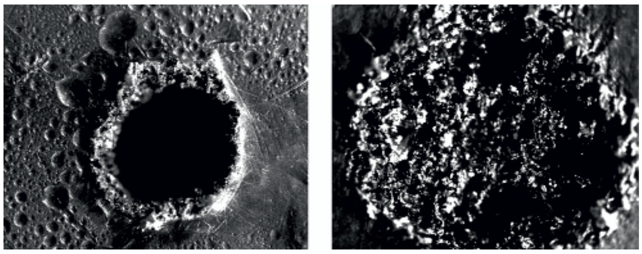


Figure 5. Dependency of the structure of the cavitation cloud on the cavitation number

Although is the cavitation number helpful in many applications, it describes only the hydraulic parameters of the flow. As can be seen in our previous works ([7], [8]), is the damage dependent also on the geometrical parameters. Then is reasonable to find another criterion, which describes both, the hydraulic and also the geometrical parameters of the flow. In [10], is showed the relation between these parameters using the comparison of the theoretical time of the bubble collapse (τ) and the transition time of the bubble between the nozzle and the specimen (t).

In order to describe the geometry of the damaged area is usefull to use the equivalent area A_e instead of the original damaged area A_s . For these areas is valid that $A_e = A_s$. Because the A_e has circular shape, it's possible to describe it only using its diameter D_e . Type of the damage can be then characterized by the ratio $\frac{D_e}{h}$. In the case of $\frac{D_e}{h} >> 1$ can be the damage characterized as the surface damage. In opposite case can be the damage characterized as the deep damage (Figure 6a).



a **b**

Figure 6. Observed types of the cavitation damage on lead specimens

(a- Deep damage, b- surface damage)

In this paper, the values of the parameters are scaled into values (0,1>. The scale is done using the set of the measured values of the variable *A*. This set consists of the measured values of the variable for the same hydraulic parameters ($A_1 = \{A_{1_1}, A_{1_2}, ..., A_{1_n}\}$). Every value in this set is then divided by the maximal value $\max(A_1)$. By this way we obtain the set of normalized values of the selected parameter:

$$A_{n1} = \{\frac{A_{1_1}}{\max(A_1)}, \frac{A_{1_2}}{\max(A_1)}, ..., \frac{A_{1_n}}{\max(A_1)}\} \tag{2}$$

The set of normalized values A_{n1} now consists of the values in the range (0,1>. This operation is done in order to compare data obtained from differet measurements with different paraeters of the experiment in one chart.

4 General quantitative analysis of the cavitation damage

Processed experimental data alows us to analyze the cavitation damage. As can be seen, the amount of removed material is directly dependent on the distance between the nozzle and the specimen. (Figure 7, Figure 8). According to the removed mass, also the type of the damage changes. After comparison of the (Figure 7) and the (Figure 8) can be observed that the position, where the maximum mass loss occurs, is dependent on the hydraulic (flowrate, pressure drop) and also on the geometrical (diameter of the orifice) parameters [10]. Although these figures can provide some information about cavitation damage for some specified cases, more general description of the cavitation damage is needed. For this purpose is needed to use the non-dimensional criterion which involves both, the hydraulic and geometrical parameters of the experiment.

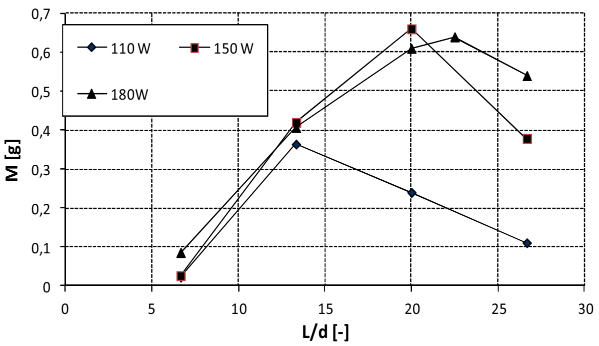


Figure 7. Mass loss with orfice d=0.3mm for different hydraulic regimes

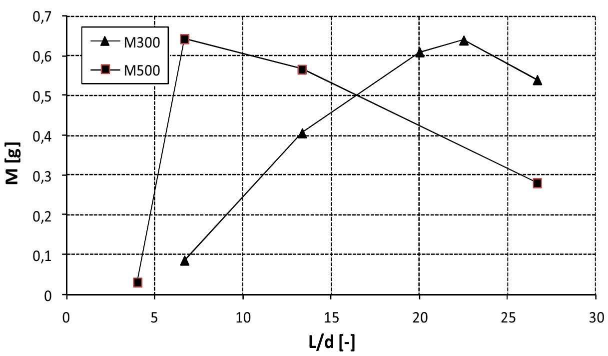


Figure 8. Mass loss for constant hydraulic regime and different orifices (diameters 0.3 and 0.5 mm)

Results processed using this criterion can be seen on the (Figure 9). Although the shape of the curve is similar to the previous figures, the points according to the similar regimes are more unified. It can be observed, that the maximum mass loss occurs by the value $t/\tau = 1$. Also, the area of the damaged surface changes according to t/τ. As the t/τ recedes from the value of 1, the mass loss decreases and the damaged area increases. So by the regime, where the mass loss is maximal, the deep damage can be observed and by the regimes, where the mass loss decreases, the damage changes into surface damage.

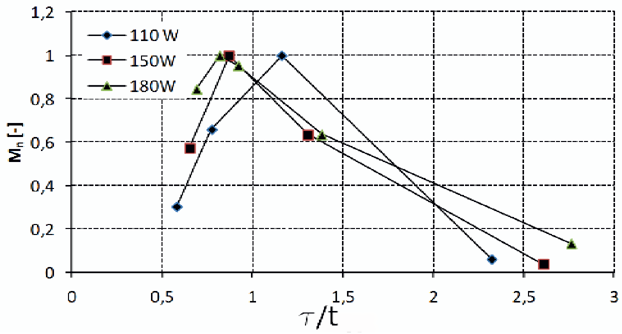


Figure 9. Mass loss for different orifices and hydraulic regimes compared using non-dimensional criterions

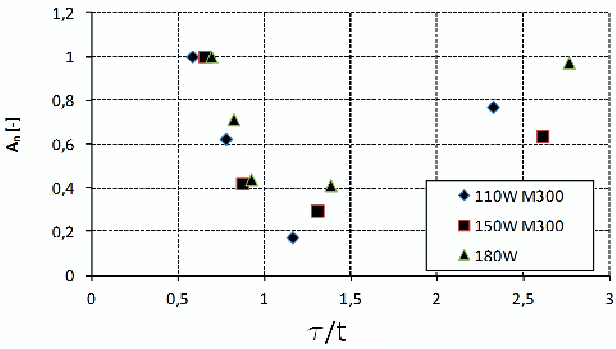


Figure 10. Size of the eroded specimen surface for different orifices and hydraulic regimes compared using non-dimensional criterions

5 Qualitative comparison of the damaged area on the different materials

In this section, the damage observed on the brass, dural and stainless steel (A321.) is compared. Generaly can be the evolution of the cavitation erosion divided to the phase of the plastic surface damage and the phase, when the material is removed. The duration of the single phases is influenced by the material properties of the surface. As expected, the weakest influence of the cavitation is observed on the steel specimens. The dural and brass specimens are more susceptible to the cavitation damage (Figure 13). Although the size of the damaged area has similar size in both cases, there can be observed that the structure and morphology of the damaged area changes for each material. Even at the early stages of the evolotuion of the cavitation damage (Figure 11) can be observed significant difference in the morphology of the influenced surface for each compared material. The erosion on the brass material is almost continual on whole influenced area, except the small areas, “islands” of original, not eroded surface. The dural material is covered by the small flakes, which are progressively removed from the surface. There can be still observed the original texture (scratches…) of the surface. The depth of the created cavities is not uniform. The erosion on steel material is scattered on the surface. Most of the area is still not influenced. In the further stages of the erosion evolution can be observed also several differences in the morphology of the eroded surface (Figure 12). There can be observed, that previously eroded areas on the brass surface deepens, but still can be found the areas, where the original surface remains. The morphology of the dural surface changed rapidly since previous stage. The original flakes has been removed and now has the surface structure similar to sponge with no sharp edges. The damage on the steel surface is strictly bounded and there is no significant deep damage. From the observations of the time evolution of the cavitation damage (Figure 14, Figure 15, Figure 16) can be stated that in the case of the brass and dural, the size of eroded area increases evenly during the experiments. The steel resist in the early stages. The massive increase of the influenced area shows after longer exposition to the cavitation.

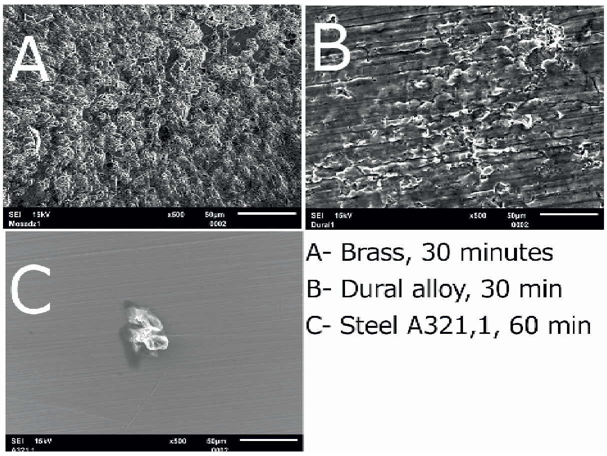


Figure 11. Damaged surface in the earlier stages of the cavitation erosion, $t_s / \tau = 1$

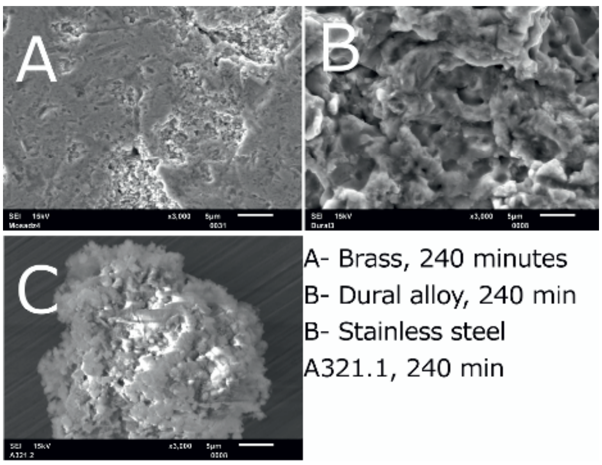


Figure 12. Damaged surface in the further stages of the cavitation erosion , $t_s / \tau = 1$

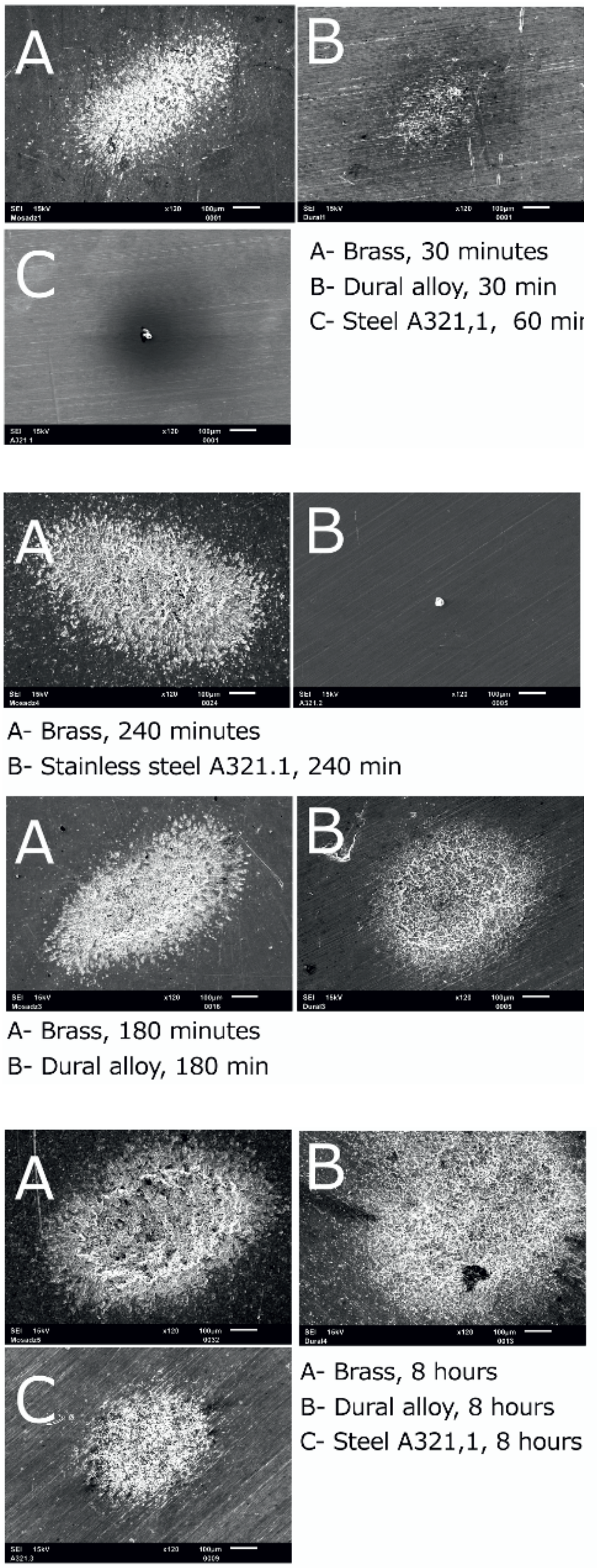


Figure 13. Comparison of cavitation damage of the selected materials, $t_s / \tau = 1$

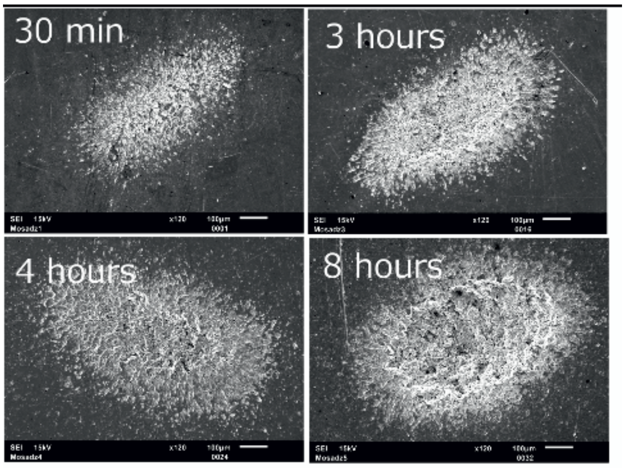


Figure 14. Time evolution of the damaged area on the brass surface, $t_s / \tau = 1$

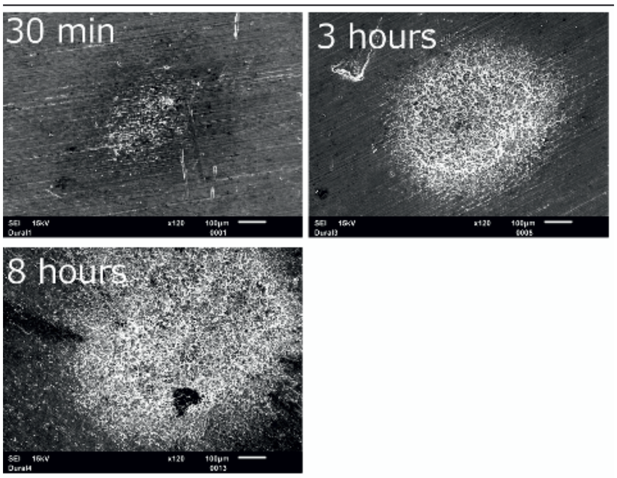


Figure 15. Time evolution of the damaged area on the dural alloy surface, $t_s / \tau = 1$

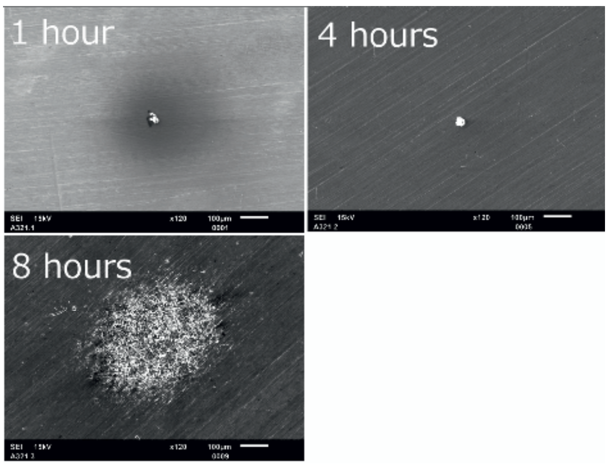


Figure 16. Time evolution of the damaged area on the stainless steel surface, $t_s / \tau = 1$

6 Conclusions

The evolution of the damage caused by the cavitation is a phenomenon, that is influenced by the many parameters. The erosion is caused by the implosion of the cavitation bubble. The implosion is followed by the pressure and temperature shock which affects the solid surface. The next factor which influences the erosion are the material properties of the surface. The cavitation flow can be defined by the parameters like: pressure drop, flow-rate, velocity, fluid temperature, physical properties of the fluid. If the nozzle, or orifice, is used for generation of the cavitation, geometrical parameters also seems to be important in the process of the cavitation erosion. The response of the solid material to the cavitation varies and the response is specific for each material. Different morphology and size of the influenced area can evolve during the experiment. The response is dependent on the material properties, chemical composition, structure and treatment of the material of the solid surface. For better understanding of the process of the cavitation erosion, our research will be oriented in close future on the next main directions:

- More complex experimental research of the influence of the geometrical parameters on the erosion

- Research of the influence of the size and geometry of the nozzle

- Detailed research, qualitative and mainly kvantitative description of the damage caused by the cavitation

- Application of the existing non-dimensional criterions, which can help find the relations betwee material properties of the solid materials and the hydraulic parameters of the flow

- If needed, creation of the new non-dimensional criterions, based on the obtained experimental data

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